Final Iowa Greenhouse Gas Inventory and Reference Case Projections 1990-2025

Center for Climate Strategies
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* In November 2008, four tables in Appendix be were revised (Tables B-1, B-3–B-5) to reflect higher load growth estimates.

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Executive Summary

The Center for Climate Strategies (CCS) prepared this report for the Iowa Department of Natural Resources (Iowa DNR) as part of the Iowa Climate Change Advisory Council (ICCAC) process. The report presents an assessment of the State's greenhouse gas (GHG) emissions and anthropogenic sinks (carbon storage) from 1990 to 2025. The preliminary draft report documenting the GHG emissions inventory and reference case projections served as a starting point to assist the State, as well as the ICCAC and its Subcommittees (SCs), with an initial comprehensive understanding of Iowa's current and possible future GHG emissions, and thereby informed them in the identification and analysis of policy options for mitigating GHG emissions.[1] The ICCAC and SCs have reviewed, discussed, and evaluated the draft GHG inventory and reference case projections and the methodologies used in developing them as well as alternative data and approaches for improving the draft GHG inventory and forecast. The inventory and forecast as well as this report have been revised to address the comments provided and approved by the ICCAC.

Emissions and Reference Case Projections (Business-as-Usual)

Iowa's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the period from 1990 to 2025. Historical GHG emission estimates (1990 through 2005)[2] were developed using a set of generally accepted principles and guidelines for State GHG emissions, relying to the extent possible on Iowa-specific data and inputs when it was possible to do so. The reference case projections (2006-2025) are based on a compilation of various projections of electricity generation, fuel use, and other GHG-emitting activities for Iowa, along with a set of simple, transparent assumptions described in the appendices of this report.

The inventory and projections cover the six types of gases included in the US Greenhouse Gas Inventory: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalence (CO_2e), which indicates the relative contribution of each gas, per unit mass, to global average radiative forcing on a global warming potential- (GWP-) weighted basis.[3]

As shown in Table ES-1, activities in Iowa accounted for approximately 120 million metric tons (MMt) of *gross*[4] CO_2e emissions (consumption basis) in 2005, an amount equal to about 1.7% of

[1] "Draft Iowa Greenhouse Gas Inventory and Reference Case Projections, 1990-2025," prepared by the Center for Climate Strategies for the Iowa Department of Natural Resources, April 2008.

[2] The last year of available historical data varies by sector; ranging from 2000 to 2005.

[3] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth–atmosphere system. Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth). See: Boucher, O., et al. "Radiative Forcing of Climate Change." Chapter 6 in *Climate Change 2001: The Scientific Basis*. Contribution of Working Group 1 of the Intergovernmental Panel on Climate Change Cambridge University Press. Cambridge, United Kingdom. Available at: http://www.grida.no/climate/ipcc_tar/wg1/212.htm.

[4] Excluding GHG emissions removed due to forestry and other land uses.

total US gross GHG emissions.[5] Iowa's gross GHG emissions are rising faster than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). Iowa's gross GHG emissions increased by about 23% from 1990 to 2005, while national emissions rose by 16% from 1990 to 2005.

Estimates of carbon sinks within Iowa's forests, including urban forests and land use changes as well as agricultural soils, have also been included in this report. The current estimates indicate that about 27 $MMtCO_2e$ were stored in Iowa soils, forests and agricultural biomass in 2005. This leads to *net* emissions of 92 $MMtCO_2e$ in Iowa in 2005, an amount equal to 1.4% of total US net GHG emissions.

Figure ES-1 illustrates the State's emissions per capita and per unit of economic output.[6] In Iowa, gross CO_2e emissions on a per capita basis were about 35 metric tons (t) of gross CO_2e in 1990, higher than the 1990 national average of 25 tCO_2e. Per capita emissions in Iowa increased to about 40 tCO_2e in 2005. National per capita emissions for the US decreased slightly to 24 tCO_2e from 1990 to 2005. The higher per capita emission rates in Iowa are due in part to emissions in the agricultural industry (agricultural industry emissions are much higher than the national average) and a lower population density (due to a larger rural area) in Iowa relative to the US as a whole.[7] Like the nation as a whole, Iowa's economic growth exceeded emissions growth throughout the 1990-2005 period, leading to declining estimates of GHG emissions per unit of state product. From 1990 to 2005, emissions per unit of gross product dropped by 24% in Iowa and by about 26% nationally.[8]

The principal sources of Iowa's GHG emissions in 2005 are electricity consumption (31% of Iowa's gross GHG emissions); agriculture (23% of Iowa's gross GHG emissions); residential, commercial, and industrial (RCI) fuel use (20% of Iowa's gross GHG emissions); and transportation (17% of Iowa's gross GHG emissions).

As illustrated in Figure ES-2 and shown numerically in Table ES-1, under the reference case projections, Iowa's gross GHG emissions continue to grow, and are projected to climb to about 148 $MMtCO_2e$ by 2025, reaching 52% above 1990 levels. As shown in Figure ES-3, for 2005 through 2025, the electricity consumption sector is projected to be the largest contributor to future emissions growth in Iowa, followed by emissions growth associated with the transportation fuel use, RCI fuel use sectors, and substitutes for ozone depleting substances (ODS).

Some data gaps exist in this analysis, particularly for the reference case projections. Key tasks include review and revision of key emissions drivers that will be major determinants of Iowa's

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[5] The national emissions used for these comparisons are based on 2005 emissions from *Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2006*, April 15, 2008, US EPA # 430-R-08-005, (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

[6] Decennial Population and Population Estimates for Iowa: 1900 – 2007 http://data.iowadatacenter.org/browse/projections.html

[7] Based on information from the US Census Bureau (http://quickfacts.census.gov/qfd/states/19000.html), Iowa has 55,869 square miles, which is 1.6% of the nation's 3,537,438 square miles. In 2005, Iowa had a population density of 53.3 persons per square mile, as compared with 84.7 persons per square mile for the US.

[8] Based on real gross domestic product (millions of chained 2000 dollars) that excludes the affects of inflation, available from the US Bureau of Economic Analysis (http://www.bea.gov/regional/gsp/). The national emissions used for these comparisons are based on 2005 emissions from the 2008 version of EPA's GHG inventory report. (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

future GHG emissions (such as the growth rate assumptions for electricity generation and consumption, transportation fuel use, and RCI fuel use). Appendices A through H provide the detailed methods, data sources, and assumptions for each GHG sector. Also included in Appendices A through H are descriptions of significant uncertainties in emission estimates or methods and suggested next steps for refinement of the inventory and forecast for each sector. Appendix I provides background information on GHGs and climate-forcing aerosols.

GHG Reductions from Recent Actions[9]

The federal Energy Independence and Security Act (EISA) of 2007 was signed into law in December 2007. This federal law contains several requirements that will reduce GHG emissions as they are implemented over the next few years. During the ICCAC process, sufficient information was identified (e.g., implementation schedules) to estimate GHG emission reductions associated with implementing the Corporate Average Fuel Economy (CAFE) requirements and energy efficiency requirements for new appliances and lighting in Iowa.

The ICCAC also identified a number of recent actions that Iowa has undertaken to control GHG emissions while at the same time conserving energy and promoting the development and use of renewable energy sources. Two recent actions (Iowa Executive Orders #6[10] and #41[11] related to reducing energy consumption in state buildings) were identified for which data were available to estimate the emission reductions of the actions relative to the business-as-usual reference case projections.

The GHG emission reductions projected to be achieved by these recent State and Federal actions are summarized in Table ES-2. This table shows a total reduction of about 3.35 MMtCO_2e in 2020 from the business-as-usual reference case emissions, or a 2.8% reduction from the business-as-usual emissions in 2020 for all sectors combined.

[9] Note that actions recently adopted by the state of Iowa have also been referred to as "existing" actions.

[10] State of Iowa, Executive Department. *Executive Order Number Six*. February 2008. Available at: http://publications.iowa.gov/6275/1/06-080221%5B1%5D.pdf

[11] State of Iowa, Executive Department. *Executive Order Number Forty-One*. Available at: http://publications.iowa.gov/2619/1/EO_41.pdf

Table ES-1. Iowa Historical and Reference Case GHG Emissions, by Sector ($MMtCO_2e$)[a]

$MMtCO_2e$	1990	2000	2005	2010	2020	2025	Explanatory Notes for Projections
Energy Use (CO_2, CH_4, N_2O)	**67.0**	**82.1**	**84.6**	**90.5**	**103.3**	**111.0**	
Electricity Use (Consumption)	**27.4**	**35.8**	**37.6**	**38.0**	**43.1**	**47.5**	Totals include emissions for electricity production plus emissions associated with net imported electricity.
Electricity Production (in-state)	26.7	36.7	36.3	41.8	41.8	41.8	*See electric sector assumptions*
Coal	26.5	36.3	34.9	40.4	40.4	40.4	*in appendix A.*
Natural Gas	0.17	0.24	1.15	1.15	1.15	1.15	
Oil	0.05	0.10	0.15	0.15	0.15	0.15	
MSW/Landfill Gas	0.01	0.02	0.06	0.06	0.06	0.06	
Imported Electricity	0.68	-0.87	1.33	-3.74	1.38	5.78	Negative values represtne net exported electricity
Residential/Commercial/ Industrial (RCI) Fuel Use	**21.3**	**25.3**	**24.1**	**27.0**	**29.7**	**30.2**	
Coal	5.53	6.42	6.22	6.45	6.82	6.83	Based on US DOE regional projections
Natural Gas	10.9	11.6	11.0	13.9	15.8	16.3	Based on US DOE regional projections
Petroleum	4.70	7.25	6.78	6.51	6.93	6.86	Based on US DOE regional projections
Wood (CH4 and N2O)	0.13	0.08	0.09	0.17	0.19	0.20	Based on US DOE regional projections
Transportation	**16.9**	**19.1**	**20.7**	**22.8**	**27.2**	**29.4**	
Onroad Gasoline	11.4	12.8	13.0	13.9	16.2	17.2	Based on linear regression of historical VMT and projected national fuel economy
Onroad Diesel	3.96	4.66	5.69	6.76	8.80	9.94	Based on linear regression of historical VMT and projected national fuel economy
Rail	0.31	0.26	0.56	0.56	0.56	0.56	Assumed no growth in activity
Marine Vessels, Natural Gas, LPG, other	0.81	1.07	1.04	1.07	1.22	1.29	Based on USDOE regional projections and historical trends in activity
Jet Fuel and Aviation Gasoline	0.39	0.34	0.45	0.48	0.45	0.42	Based on Iowa DOT operations projections
Fossil Fuel Industry	**1.49**	**1.81**	**2.25**	**2.61**	**3.32**	**3.78**	
Natural Gas Industry	1.48	1.81	2.25	2.61	3.32	3.78	Based on historical trends in activity
Oil Industry	0.00	0.00	0.00	0.00	0.00	0.00	No oil production in Iowa.
Coal Mining	0.01	0.00	0.00	0.00	0.00	0.00	No coal mining in Iowa since 1994
Industrial Processes	**2.74**	**3.82**	**4.59**	**5.35**	**7.04**	**8.14**	
Cement Manufacture (CO_2)	1.18	1.28	1.28	1.35	1.48	1.56	Based on 2004-2014 employment projections for Nonmetallic Mineral Production Manufacturing from Iowa Workforce Information Network
Lime Manufacture (CO_2)	0.06	0.06	0.09	0.11	0.14	0.17	Based on historical annual increase in Iowa state production from 1995-2005
Limestone and Dolomite Use (CO_2)	0.20	0.21	0.18	0.17	0.15	0.15	Based on historical annual decline in Iowa state consumption from 1994-2004
Soda Ash (CO_2)	0.03	0.03	0.03	0.02	0.02	0.02	Based on historical annual decline in Iowa state consumption from 1990-2005
Iron & Steel (CO_2)	0.03	0.10	0.12	0.16	0.27	0.36	Based on historical annual increase in Iowa state production from 2000-2005
Ammonia and Urea (CO_2)	0.64	0.56	0.49	0.47	0.44	0.43	Based on historical annual decline in Iowa state production from 2000-2005
Nitric Acid Production (N_2O)	0.30	0.57	1.01	1.05	1.14	1.19	Based on US EPA projections for this industry.
ODS Substitutes (HFC, PFC)	0.00	0.83	1.23	1.87	3.25	4.15	Based on national projections (US EPA)
Electric Power T&D (SF_6)	0.29	0.17	0.15	0.14	0.13	0.13	Based on national projections (US EPA)
Waste Management	**2.18**	**2.27**	**2.40**	**2.57**	**2.95**	**3.16**	
Waste Combustion	0.07	0.07	0.06	0.06	0.05	0.05	Based on one half growth rate calculated for 1990-2005 emissions growth
Landfills	1.65	1.68	1.82	1.97	2.30	2.48	Based on growth rate calculated for 1995-2005 emissions growth

$MMtCO_2e$	1990	2000	2005	2010	2020	2025	Explanatory Notes for Projections
Wastewater Management	0.46	0.53	0.52	0.54	0.60	0.62	Based on growth rate calculated for 1990-2005 emissions growth
Agriculture	**25.4**	**26.0**	**27.9**	**26.0**	**25.8**	**25.6**	
Enteric Fermentation	5.04	4.39	4.26	3.81	3.27	2.98	Based on projected livestock population
Manure Management	4.49	6.02	6.64	6.55	6.86	7.01	Based on projected livestock population
Agricultural Soils	15.7	15.5	16.8	15.5	15.4	15.3	Used growth rate calculated for 1990-2005 emissions growth
Agricultural Burning	0.13	0.16	0.19	0.20	0.24	0.26	Used growth rate calculated for 1990-2005 emissions growth
Gross Emissions (Consumption Basis, Excludes Sinks)	**97.3**	**114.2**	**119.5**	**124.4**	**139.1**	**147.9**	
increase relative to 1990		*17%*	*23%*	*28%*	*43%*	*52%*	
Emissions Sinks	**-21.8**	**-19.9**	**-27.3**	**-27.3**	**-27.3**	**-27.3**	
Forested Landscape	-7.88	-7.88	-15.3	-15.3	-15.3	-15.3	
Urban Forestry and Land Use	-2.59	-0.65	-0.63	-0.63	-0.63	-0.63	Assumed no change after 2005
Forest Wildfires	0.00	0.00	0.00	0.00	0.00	0.00	
Agricultural Soils (cultivation practices)	-11.4	-11.4	-11.4	-11.4	-11.4	-11.4	Based on 2000 NRCS data
Net Emissions (Includes Sinks)	**75.4**	**94.3**	**92.2**	**97.1**	**111.8**	**120.6**	
increase relative to 1990		*25%*	*22%*	*29%*	*48%*	*60%*	

[a] Totals may not equal exact sum of subtotals shown in this table due to independent rounding.

Figure ES-1. Historical Iowa and US Gross GHG Emissions, Per Capita and Per Unit Gross Product

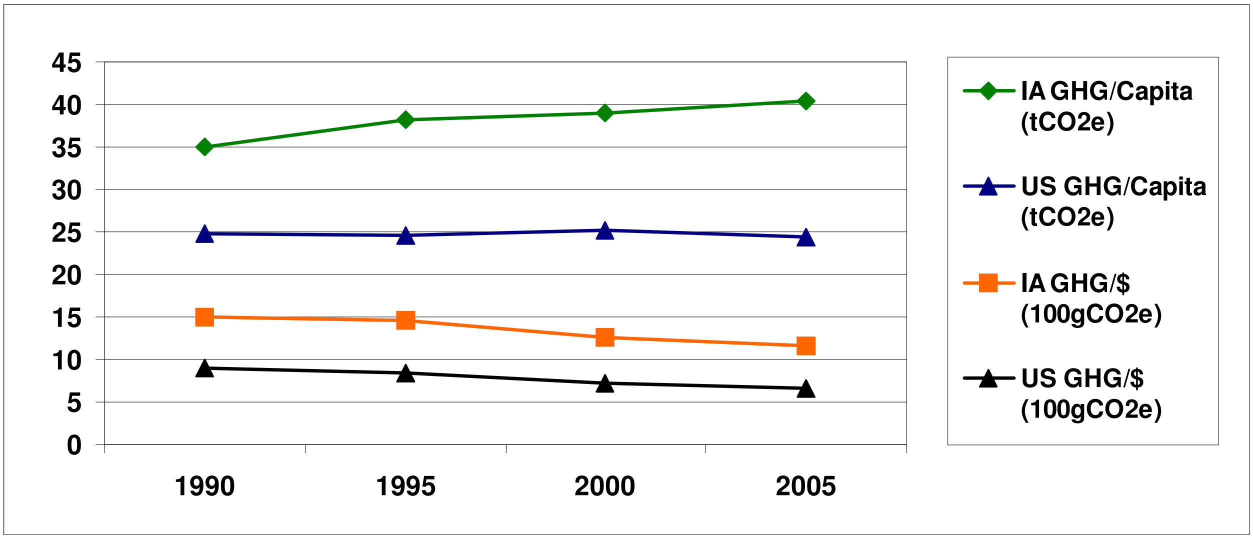
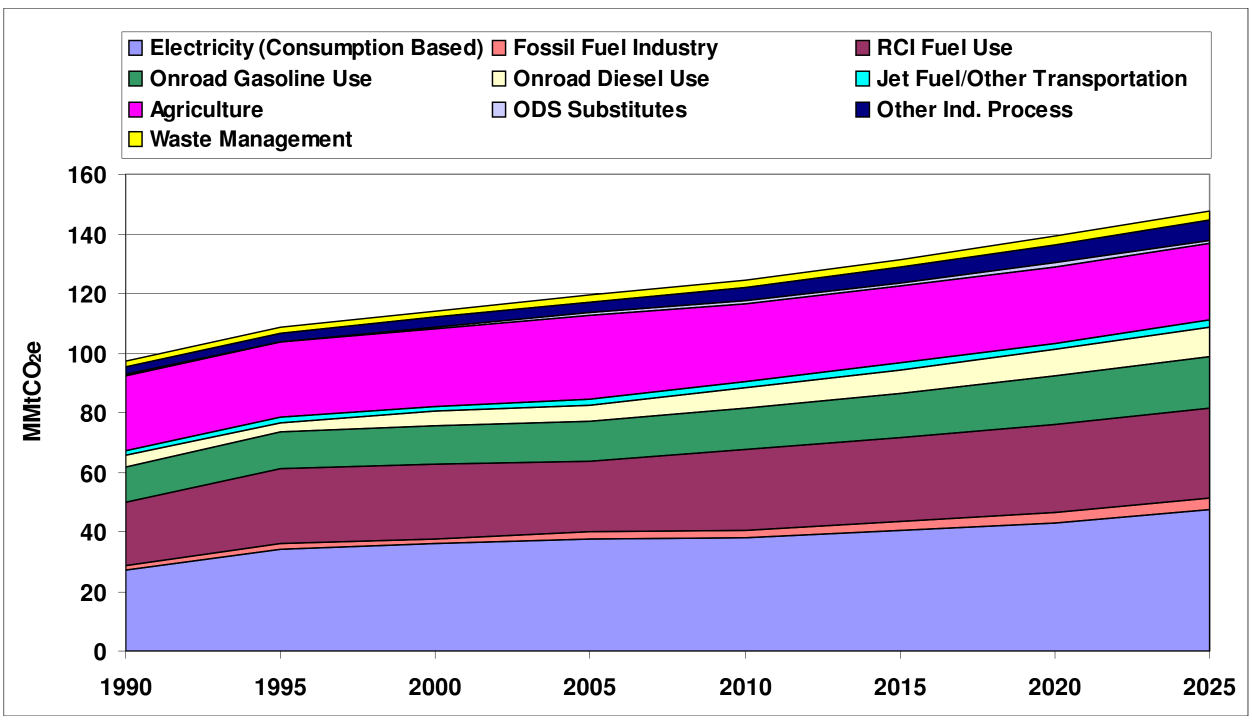
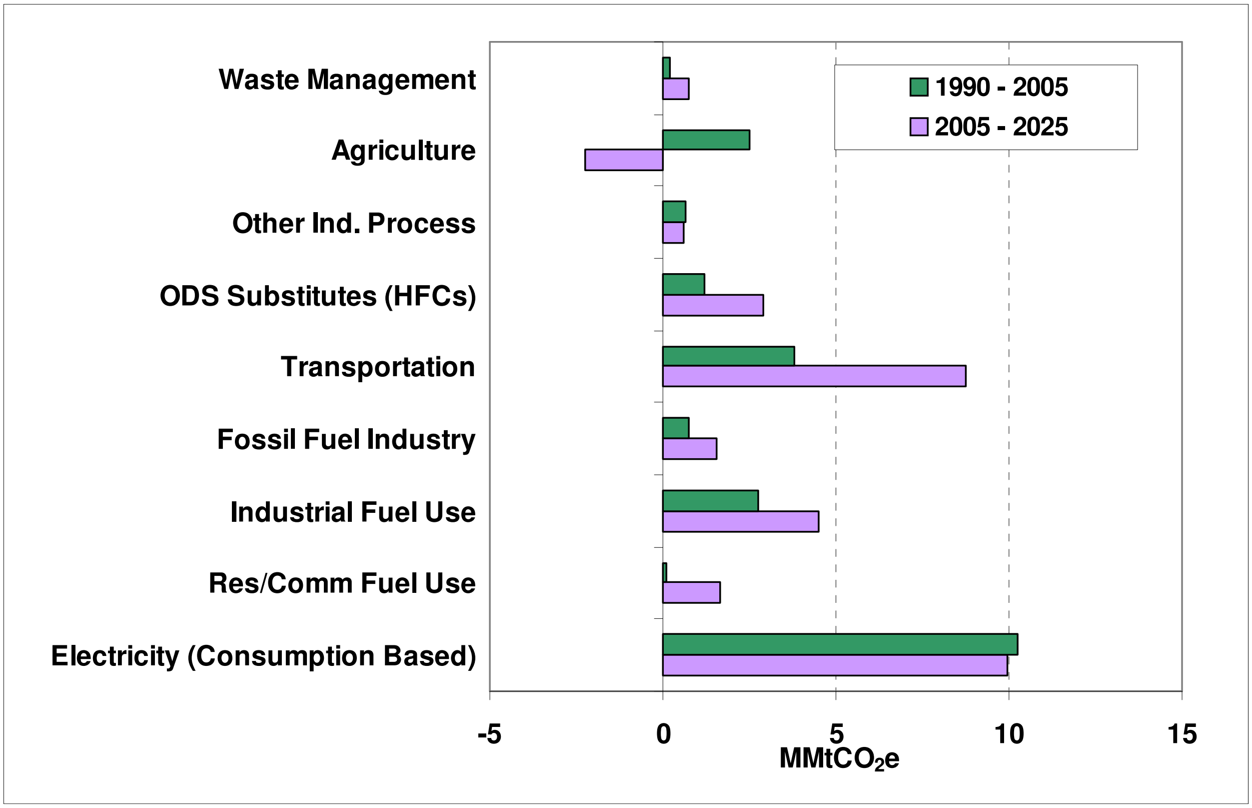


Figure ES-2. Iowa Gross GHG Emissions by Sector, 1990-2025: Historical and Projected



RCI – direct fuel use in residential, commercial, and industrial sectors. ODS – ozone depleting substance.

Figure ES-3. Sector Contributions to Gross Emissions Growth in Iowa, 1990-2025: Reference Case Projections ($MMtCO_2e$ Basis)



Res/Comm – Direct fuel use in residential and commercial sectors. ODS – Ozone depleting substance. HFCs – Hydrofluorocarbons. Emissions associated with other industrial processes include all of the industries identified in Appendix D except emissions associated with ODS substitutes which are shown separately in this graph because of high expected growth in emissions for ODS substitutes.

Table ES-2. Emission Reduction Estimates Associated with the Effect of Recent Actions in Iowa (consumption-basis, gross emissions)

	GHG Reductions ($MMtCO_2e$)		GHG Emissions ($MMtCO_2e$)	
			Business as Usual	With Recent Actions
Sector / Recent Action	**2012**	**2020**	**2020**	**2020**
Residential, Commercial and Industrial (RCI)				
Executive Orders #6 and #41 and Federal Improved Standards for Appliances and Lighting Requirements	0.44	1.42	29.7	28.3
Transportation and Land Use (TLU)				
Federal Corporate Average Fuel Economy (CAFE) Requirements	0.26	1.93	27.2	25.3
Total (RCI + TLU Sectors)	**0.70**	**3.35**	**56.9**	**53.6**
Total (All Sectors)			**119.5**	**116.2**

Table of Contents

Acronyms and Key Terms

AEO2007 – EIA's Annual Energy Outlook 2007

BOD – Biochemical Oxygen Demand

Btu – British Thermal Unit

C – Carbon*

$CaCO_3$ – Calcium Carbonate

CAFE – Corporate Average Fuel Economy

CCS – Center for Climate Strategies

CCT – Carbon Calculation Tool

CFCs – Chlorofluorocarbons*

CH_4 – Methane*

CO – Carbon Monoxide*

CO_2 – Carbon Dioxide*

CO_2e – Carbon Dioxide equivalent*

CRP – Federal Conservation Reserve Program

DNR – Iowa Department of Natural Resources

DOT – Department of Transportation

EAF – Electric Arc Furnace

EIA – US DOE Energy Information Administration

EIIP – Emission Inventory Improvement Program

FAA – Federal Aviation Administration

FAPRI – Food and Agricultural Policy Research Institute

FERC – Federal Energy Regulatory Commission

FHWA – Federal Highway Administration

FIA – Forest Inventory and Analysis

Gg – Gigagrams

GHG – Greenhouse Gas*

GW – Gigawatt

GWh – Gigawatt-hour

GWP – Global Warming Potential*

H_2CO_3 – Carbonic Acid*

H_2O – Water Vapor*

HBFCs – Hydrobromofluorocarbons*

HCFCs – Hydrochlorofluorocarbons*

HFCs – Hydrofluorocarbons*

HNO_3 – Nitric Acid*

HWP – Harvested Wood Products

ICCAC – Iowa Climate Change Advisory Council

IPCC – Intergovernmental Panel on Climate Change*

IRFA – Iowa Renewable Fuels Association

kg – Kilogram

km – Kilometers

kWh – Kilowatt-hour

lb – Pound

LF – Landfill

LG – Landfill Gas

LFGTE – Landfill Gas Collection System and Landfill-Gas-to-Energy

LPG – Liquefied Petroleum Gas

MAPP – Mid-Continent Area Power Pool

Mg – Megagrams

MMBtu – Million British thermal units

MMt – Million Metric tons

MMtc – Million Metric Tons of Carbon

$MMtCO_2e$ – Million Metric tons of Carbon Dioxide equivalent

MSW – Municipal Solid Waste

MW – Megawatt

MWh – Megawatt-Hour

N_2O – Nitrous Oxide*

NASS – National Agriculture Statistical Service

NEI – National Emissions Inventory

NEMS – National Energy Modeling System

NF – National Forest

NH_2 – Urea

NH_3 – Ammonia

NMVOCs – Nonmethane Volatile Organic Compound*

NO_2 – Nitrogen Dioxide*

NO_x – Nitrogen Oxides*

O_3 – Ozone*

ODS – Ozone-Depleting Substance*

OH – Hydroxyl radical*

OPS – Office of Pipeline Safety

PFCs – Perfluorocarbons*

ppb – parts per billion

ppm – parts per million

ppt – parts per trillion

ppmv – parts per million by volume

RCI – Residential, Commercial, and Industrial

SAR – Second Assessment Report*

SED – State Energy Data

SF_6 – Sulfur Hexafluoride*

SIT – State Greenhouse Gas Inventory Tool

SO_2 – Sulfur Dioxide*

t – Metric ton (equivalent to 1.102 short tons)

T&D – Transmission and Distribution

TAR – Third Assessment Report*

TWh – Terawatt-Hour

UNFCCC – United Nations Framework Convention on Climate Change

US DOE – United States Department of Energy

US EPA – United States Environmental Protection Agency

USDA – United States Department of Agriculture

USFS – United States Forest Service

USGS – United States Geological Survey

VMT – Vehicle Mile Traveled

VOCs – Volatile Organic Compound*

WW – Wastewater

yr – Year

* – See Appendix I for more information.

Acknowledgements

We appreciate all of the time and assistance provided by numerous contacts throughout Iowa, as well as in neighboring States, and at federal agencies. Thanks go to in particular the staff at Iowa DNR and other Iowa agencies for their inputs, and in particular to Marnie Stein and Jason Marcel of the Iowa DNR who provided key guidance for and review of this analytical effort.

The authors would also like to express their appreciation to Bill Dougherty, Steve Roe, Katie Pasko, and Jim Wilson of the Center for Climate Strategies (CCS) who provided valuable review comments during development of this report.

Summary of Findings

Introduction

The Center for Climate Strategies (CCS) prepared this report for the Iowa Department of Natural Resources (Iowa DNR) as part of the Iowa Climate Change Advisory Council (ICCAC) process. The report presents an assessment of the State's greenhouse gas (GHG) emissions and anthropogenic sinks (carbon storage) from 1990 to 2025. The preliminary draft report documenting the GHG emissions inventory and reference case projections served as a starting point to assist the State, as well as served as a starting point to assist the State, as well as the ICCAC and its Subcommittees (SCs), with an initial comprehensive understanding of Iowa's current and possible future GHG emissions, and informed them in the identification and analysis of policy options for mitigating GHG emissions.[12] The ICCAC and TWGs have reviewed, discussed, and evaluated the draft GHG inventory and reference case projections and the methodologies used in developing them as well as alternative data and approaches for improving the draft GHG inventory and forecast. The inventory and forecast as well as this report have been revised to address the comments provided and approved by the ICCAC.

Emissions and Reference Case Projections (Business-as-Usual)

Historical GHG emission estimates (1990 through 2005)[13] were developed using a set of generally accepted principles and guidelines for State GHG emissions inventories, as described in the "Approach" section below, relying to the extent possible on Iowa-specific data and inputs. The initial reference case projections (2006-2025) are based on a compilation of various projections of electricity generation, fuel use, and other GHG-emitting activities for Iowa, along with a set of simple, transparent assumptions described in the appendices of this report.

This report covers the six gases included in the US Greenhouse Gas Inventory: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalence (CO_2e), which indicates the relative contribution of each gas, per unit mass, to global average radiative forcing on a global warming potential- (GWP-) weighted basis.[14]

It is important to note that the emissions estimates reflect the *GHG emissions associated with the electricity sources used to meet Iowa's demands,* corresponding to a consumption-based approach to emissions accounting (see "Approach" section below). Another way to look at electricity emissions is to consider the *GHG emissions produced by electricity generation*

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facilities in the State. This report covers both methods of accounting for emissions, but for consistency, all total results are reported as *consumption-based.*

Iowa Greenhouse Gas Emissions: Sources and Trends

Table 1 provides a summary of GHG emissions estimated for Iowa by sector for the years 1990, 2000, 2005, 2010, 2020, and 2025. Details on the methods and data sources used to construct these estimates are provided in the appendices to this report. In the sections below, we discuss GHG emission sources (positive, or *gross*, emissions) and sinks (negative emissions) separately in order to identify trends, projections, and uncertainties clearly for each.

This next section of the report provides a summary of the historical emissions (1990 through 2005) followed by a summary of the reference-case projection-year emissions (2006 through 2025) and key uncertainties. We also provide an overview of the general methodology, principles, and guidelines followed for preparing the inventories. Appendices A through H provide the detailed methods, data sources, and assumptions for each GHG sector. Appendix I provides background information on GHGs and climate-forcing aerosols.

Table 1. Iowa Historical and Reference Case GHG Emissions, by Sector ($MMtCO_2e$)[a]

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Coal	5.53	6.42	6.22	6.45	6.82	6.83	Based on US DOE regional projections
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Petroleum	4.70	7.25	6.78	6.51	6.93	6.86	Based on US DOE regional projections
Wood (CH4 and N2O)	0.13	0.08	0.09	0.17	0.19	0.20	Based on US DOE regional projections
Transportation	**16.9**	**19.1**	**20.7**	**22.8**	**27.2**	**29.4**	
Onroad Gasoline	11.4	12.8	13.0	13.9	16.2	17.2	Based on linear regression of historical VMT and projected national fuel economy
Onroad Diesel	3.96	4.66	5.69	6.76	8.80	9.94	Based on linear regression of historical VMT and projected national fuel economy
Rail	0.31	0.26	0.56	0.56	0.56	0.56	Assumed no growth in activity
Marine Vessels, Natural Gas, LPG, other	0.81	1.07	1.04	1.07	1.22	1.29	Based on USDOE regional projections and historical trends in activity
Jet Fuel and Aviation Gasoline	0.39	0.34	0.45	0.48	0.45	0.42	Based on Iowa DOT operations projections
Fossil Fuel Industry	**1.49**	**1.81**	**2.25**	**2.61**	**3.32**	**3.78**	
Natural Gas Industry	1.48	1.81	2.25	2.61	3.32	3.78	Based on historical trends in activity
Oil Industry	0.00	0.00	0.00	0.00	0.00	0.00	No oil production in Iowa.
Coal Mining	0.01	0.00	0.00	0.00	0.00	0.00	No coal mining in Iowa since 1994
Industrial Processes	**2.74**	**3.82**	**4.59**	**5.35**	**7.04**	**8.14**	
Cement Manufacture (CO_2)	1.18	1.28	1.28	1.35	1.48	1.56	Based on 2004-2014 employment projections for Nonmetallic Mineral Production Manufacturing from Iowa Workforce Information Network
Lime Manufacture (CO_2)	0.06	0.06	0.09	0.11	0.14	0.17	Based on historical annual increase in Iowa state production from 1995-2005
Limestone and Dolomite Use (CO_2)	0.20	0.21	0.18	0.17	0.15	0.15	Based on historical annual decline in Iowa state consumption from 1994-2004
Soda Ash (CO_2)	0.03	0.03	0.03	0.02	0.02	0.02	Based on historical annual decline in Iowa state consumption from 1990-2005
Iron & Steel (CO_2)	0.03	0.10	0.12	0.16	0.27	0.36	Based on historical annual increase in Iowa state production from 2000-2005
Ammonia and Urea (CO_2)	0.64	0.56	0.49	0.47	0.44	0.43	Based on historical annual decline in Iowa state production from 2000-2005
Nitric Acid Production (N_2O)	0.30	0.57	1.01	1.05	1.14	1.19	Based on US EPA projections for this industry.
ODS Substitutes (HFC, PFC)	0.00	0.83	1.23	1.87	3.25	4.15	Based on national projections (US EPA)
Electric Power T&D (SF_6)	0.29	0.17	0.15	0.14	0.13	0.13	Based on national projections (US EPA)
Waste Management	**2.18**	**2.27**	**2.40**	**2.57**	**2.95**	**3.16**	
Waste Combustion	0.07	0.07	0.06	0.06	0.05	0.05	Based on one half growth rate calculated for 1990-2005 emissions growth
Landfills	1.65	1.68	1.82	1.97	2.30	2.48	Based on growth rate calculated for 1995-2005 emissions growth

MMtCO₂e	1990	2000	2005	2010	2020	2025	Explanatory Notes for Projections
Wastewater Management	0.46	0.53	0.52	0.54	0.60	0.62	Based on growth rate calculated for 1990-2005 emissions growth
Agriculture	**25.4**	**26.0**	**27.9**	**26.0**	**25.8**	**25.6**	
Enteric Fermentation	5.04	4.39	4.26	3.81	3.27	2.98	Based on projected livestock population
Manure Management	4.49	6.02	6.64	6.55	6.86	7.01	Based on projected livestock population
Agricultural Soils	15.7	15.5	16.8	15.5	15.4	15.3	Used growth rate calculated for 1990-2005 emissions growth
Agricultural Burning	0.13	0.16	0.19	0.20	0.24	0.26	Used growth rate calculated for 1990-2005 emissions growth
Gross Emissions (Consumption Basis, Excludes Sinks)	**97.3**	**114.2**	**119.5**	**124.4**	**139.1**	**147.9**	
increase relative to 1990		*17%*	*23%*	*28%*	*43%*	*52%*	
Emissions Sinks	**-21.8**	**-19.9**	**-27.3**	**-27.3**	**-27.3**	**-27.3**	
Forested Landscape	-7.88	-7.88	-15.3	-15.3	-15.3	-15.3	
Urban Forestry and Land Use	-2.59	-0.65	-0.63	-0.63	-0.63	-0.63	Assumed no change after 2005
Forest Wildfires	0.00	0.00	0.00	0.00	0.00	0.00	
Agricultural Soils (cultivation practices)	-11.4	-11.4	-11.4	-11.4	-11.4	-11.4	Based on 2000 NRCS data
Net Emissions (Includes Sinks)	**75.4**	**94.3**	**92.2**	**97.1**	**111.8**	**120.6**	
increase relative to 1990		*25%*	*22%*	*29%*	*48%*	*60%*	

[a] Totals may not equal exact sum of subtotals shown in this table due to independent rounding.

Historical Emissions

Overview

In 2005, activities in Iowa accounted for approximately 120 million metric tons (MMt) of CO_2e emissions, an amount equal to about 1.7% of total US GHG emissions.[15] Iowa's gross GHG emissions are rising faster than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). Iowa's gross GHG emissions increased by about 23% from 1990 to 2005, while national emissions rose by 16% from 1990 to 2005.

Figure 1 illustrates the State's emissions per capita and per unit of economic output.[16] In Iowa, gross CO_2e emissions on a per capita basis were about 35 metric tons (t) of gross CO_2e in 1990, higher than the 1990 national average of 25 tCO_2e. Per capita emissions in Iowa increased to 40 tCO_2e in 2005. National per capita emissions for the US decreased slightly to 24 tCO_2e in 2005. The higher per capita emission rates in Iowa are driven by emissions in the agricultural industry (agricultural industry emissions are much higher than the national average) and a lower population density (due to a larger rural area) in Iowa relative to the US as a whole.[17] Like the nation as a whole, Iowa's economic growth exceeded emissions growth throughout the 1990-2005 period leading to declining estimates of GHG emissions per unit of state product. From 1990 to 2005, emissions per unit of gross product dropped by 24% in Iowa and by about 26% nationally.[18]

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[15] United States emissions estimates are drawn from US EPA 2008, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2005* (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

[16] Decennial Population and Population Estimates for Iowa: 1900 – 2007 http://data.iowadatacenter.org/browse/projections.html

[17] Based on information from the US Census Bureau (http://quickfacts.census.gov/qfd/states/19000.html), Iowa has 55,869 square miles, which is 1.6% of the nation's 3,537,438 square miles. In 2005, Iowa had a population density of 53.3 persons per square mile, as compared with 84.7 persons per square mile for the US.

[18] Based on real gross domestic product (millions of chained 2000 dollars) that excludes the effects of inflation, available from the US Bureau of Economic Analysis (http://www.bea.gov/regional/gsp/). The national emissions used for these comparisons are based on 2005 emissions. (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

Figure 1. Historical Iowa and US Gross GHG Emissions, Per Capita and Per Unit Gross Product

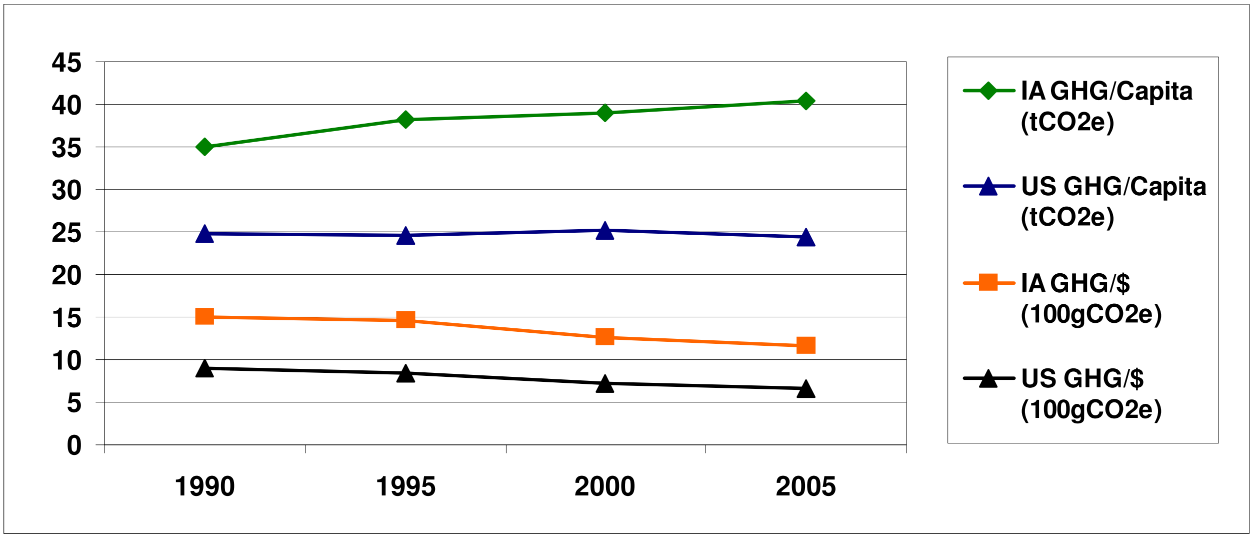


Figure 2 compares gross GHG emissions estimated for Iowa to emissions for the U.S. for 2005.

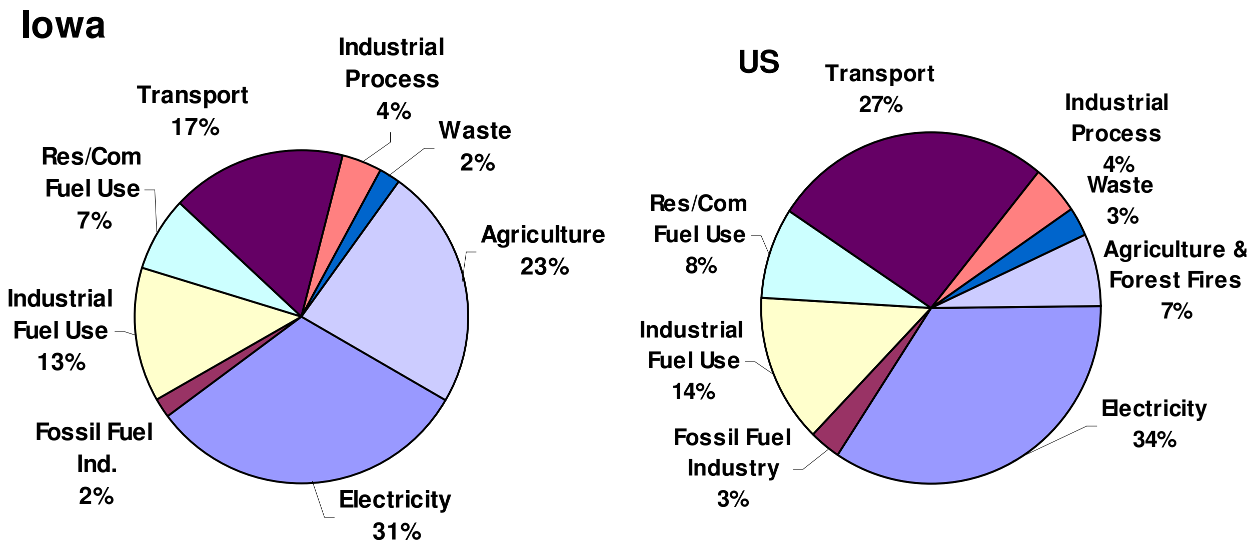
The principal sources of Iowa's GHG emissions in 2005 are electricity consumption (31% of Iowa's gross GHG emissions); agriculture (23% of Iowa's gross GHG emissions); residential, commercial, and industrial (RCI) fuel use (20% of Iowa's gross GHG emissions); and transportation (17% of Iowa's gross GHG emissions).

While the industrial processes sector accounted for 4% of gross GHG emissions in 2005, emissions in this sector are increasing rapidly. Industrial process emissions are rising due to the increasing use of HFCs as substitutes for ozone-depleting chlorofluorocarbons (CFCs).[19] Other industrial process emissions result from CO_2 released during production of ammonia, cement, lime, and iron and steel, and soda ash, limestone, and dolomite use. In addition, nitric acid production releases N_20 and SF_6 is released in the use of electric power transmission and distribution (T&D) equipment.

Methane emissions associated with natural gas transmission and distribution (included under the fossil fuel industry category) accounted for 2% of Iowa's gross GHG emissions in 2005. Waste management also accounted for about 2% of the State's gross GHG emissions in 2005.

[19] CFCs are also potent GHGs; they are not, however, included in GHG estimates because of concerns related to implementation of the Montreal Protocol (See Appendix I for additional information). HFCs are used as refrigerants in the RCI and transport sectors as well as in the industrial sector; they are included here, however, within the industrial processes emissions.

Figure 2. Gross GHG Emissions by Sector, Iowa and US – 2005 Data



Notes: Res/Com = Residential and commercial fuel use sectors. Emissions for the residential, commercial, and industrial fuel use sectors are associated with the direct use of fuels (natural gas, petroleum, coal, and wood) to provide space heating, water heating, process heating, cooking, and other energy end-uses. The commercial sector accounts for emissions associated with the direct use of fuels by, for example, hospitals, schools, government buildings (local, county, and state) and other commercial establishments. The industrial processes sector accounts for emissions associated with manufacturing and excludes emissions included in the industrial fuel use sector. The transportation sector accounts for emissions associated with fuel consumption by all on-road and non-highway vehicles. Non-highway vehicles include jet aircraft, gasoline-fueled piston aircraft, railway locomotives, boats, and ships. Emissions from non-highway agricultural and construction equipment are included in the industrial sector. Emissions associated with forest wildfires and rangeland were not calculated for Iowa due to a lack of data on acreage burned.
Electricity = Electricity generation sector emissions on a consumption basis, including emissions associated with electricity imported from outside of Iowa and excluding emissions associated with electricity exported from Iowa to other states.

A Closer Look at the Four Major Sources: Electricity Consumption; Agriculture; Residential, Commercial, Industrial (RCI) Fuel Consumption; Transportation

Electricity Consumption Sector

As shown in Figure 2, electricity consumption accounted for about 31% of Iowa's gross GHG emissions in 2005 (about 38 $MMtCO_2e$), which was very similar to the national average share of emissions from electricity consumption (34%).[20] Electricity generated by plants located in Iowa comes primarily from coal (71% in 2005), while virtually all of the rest comes from nuclear (17% in 2005), wind and hydroelectric (6% in 2005), and natural gas (5% in 2005). In 2005, Iowa imported 4% of all electricity consumed from out-of-state generators. The GHG emissions associated with Iowa's electricity consumption sector increased by 10.2 $MMtCO_2e$ between 1990 and 2005, 46% of the total growth in GHG emissions over this period.

[20] For the US as a whole, there is relatively little difference between the emissions from electricity use and emissions from electricity production, as the US imports only about 1% of its electricity, and exports far less.

In 2005, emissions associated with Iowa's electricity consumption (38 $MMtCO_2e$) were about 1.3 $MMtCO_2e$ higher than those associated with electricity production (36.3 $MMtCO_2e$, see Table 1). The higher level for consumption-based emissions reflects GHG emissions associated with net imports of electricity from other states to meet Iowa's electricity demand.[21] In some historical and forecast years, Iowa is an electricity import state. In other years, Iowa is an electricity export state, when its total gross generation by the in-state power plants exceeds the annual demand for electricity in the state. The reference case projection assumes that production-based emissions (associated with electricity generated in-state) will increase by about 5 $MMtCO_2e$ between 2005 and 2025, and consumption-based emissions (associated with electricity consumed in-state) will increase by about 10 $MMtCO_2e$.

The consumption-based approach can better reflect the emissions (and emissions reductions) associated with activities occurring in Iowa, particularly with respect to electricity use (and efficiency improvements), and is particularly useful for policy-making.

Agricultural Sector

The agricultural sector accounts for 23% of the gross GHG emissions in Iowa in 2005. This is significantly higher than the national average for agricultural emissions in that year (7%). However, this is not at all surprising considering the importance of the agricultural sector to the economy in Iowa.

These emissions primarily come from agricultural soils, manure management, and enteric fermentation. Agricultural soils can produce GHG emissions from nitrogen fertilizers and manure as well as from decomposition of crop residues. Manure management can result in CH_4 emissions as a result of manure breaking down. Enteric fermentation is the result of normal digestive processes of livestock, and this results in CH_4 emissions. All of these processes can result in emissions of N_2O. Emissions from the agricultural sector are projected to decrease by 8% between 2005 and 2025. This decrease is expected to come primarily from the agricultural soils-livestock and enteric fermentation categories.

Residential, Commercial, and Industrial Fuel Use Sectors

In 2005, combustion of oil, natural gas, coal, and wood in the RCI sectors contributed about 20% (about 24 $MMtCO_2e$) of Iowa's gross GHG emissions, slightly lower than the RCI sector contribution for the nation (22%). Activities in the RCI[22] sectors produce GHG emissions when fuels are combusted to provide space heating, process heating, and energy for other applications.

The residential sector's share of total RCI emissions from direct fuel use was 20% (4.8 $MMtCO_2e$) in 2005, the commercial sector accounted for 15% (3.6 $MMtCO_2e$), and the industrial sector's share of total RCI emissions from direct fuel use was 65% (15.7 $MMtCO_2e$). Overall, emissions for the RCI sectors (excluding those associated with electricity consumption) are expected to increase by 25% between 2005 and 2025. Emissions from the commercial sector are projected to increase by 48% from 2005 to 2025. The industrial sector is predicted to have a 29% increase. In contrast, emissions from the residential sector are expected to decrease slightly (1%) between 2005 and 2025.

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[21] Estimating the emissions associated with electricity use requires an understanding of the electricity sources (both in-state and out-of-state) used by utilities to meet consumer demand. The current estimate reflects some very simple assumptions, as described in Appendix A.

[22] The industrial sector also includes emissions associated with agricultural energy use.

Transportation Sector

As shown in Figure 2, the transportation sector accounted for about 17% of Iowa's gross GHG emissions in 2005 (about 21 $MMtCO_2e$), which was lower than the national average share of emissions from transportation fuel consumption (27%). The GHG emissions associated with Iowa's transportation sector increased by 3.8 $MMtCO_2e$ between 1990 and 2005.

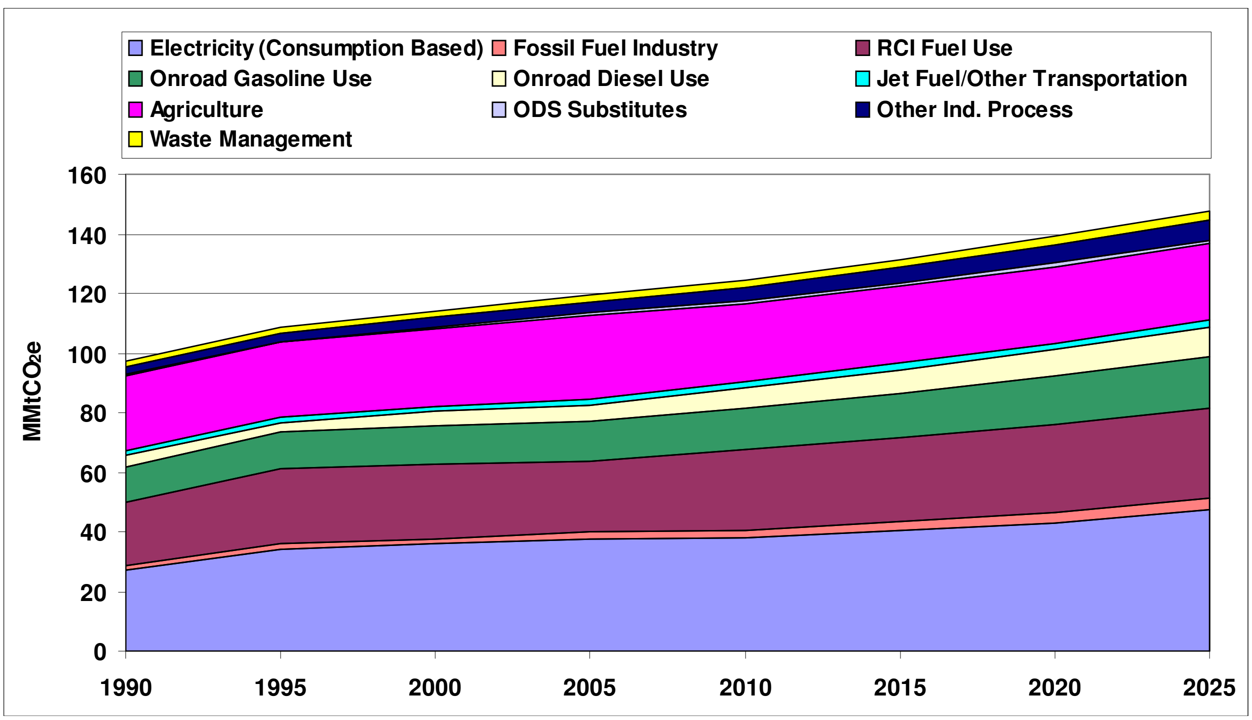
From 1990 through 2005, Iowa's GHG emissions from transportation fuel use have risen steadily at an average rate of about 1.4% annually. In 2005, onroad gasoline vehicles accounted for about 63% of transportation GHG emissions. Onroad diesel vehicles accounted for another 28% of emissions. Air and marine travel, rail, and other sources (natural gas- and liquefied petroleum gas- (LPG-) fueled-vehicles used in transport applications) accounted for the remaining 9% of transportation emissions. GHG emissions from onroad gasoline use increased 14% between 1990 and 2005. Meanwhile, GHG emissions from onroad diesel use rose 44% during that period, suggesting rapid growth in freight movement within or across the State.

Reference Case Projections (Business as Usual)

Relying on a variety of sources for projections, as noted below and in the appendices, we developed a simple reference case projection of GHG emissions through 2025. As illustrated in Figure 3 and shown numerically in Table 1, under the reference case projections, Iowa gross GHG emissions continue to grow steadily, climbing to about 148 MMtCO_2e by 2025, 52% above 1990 levels. This equates to a 1.1% annual rate of growth from 2005 to 2025. Relative to 2005, the share of emissions associated with electricity consumption and the transportation sector both increase slightly to 32% and 20%, respectively, in 2025. The share of emissions from the industrial processes and fossil fuel industry sectors is projected to increase to 6% and 3%, respectively, by 2025. The share of emissions from the RCI fuel use sector and the waste management sector is projected to remain the same at about 20% and 2%, respectively, of Iowa's gross GHG emissions in 2025, while the agriculture sector is projected to decrease to 17%.

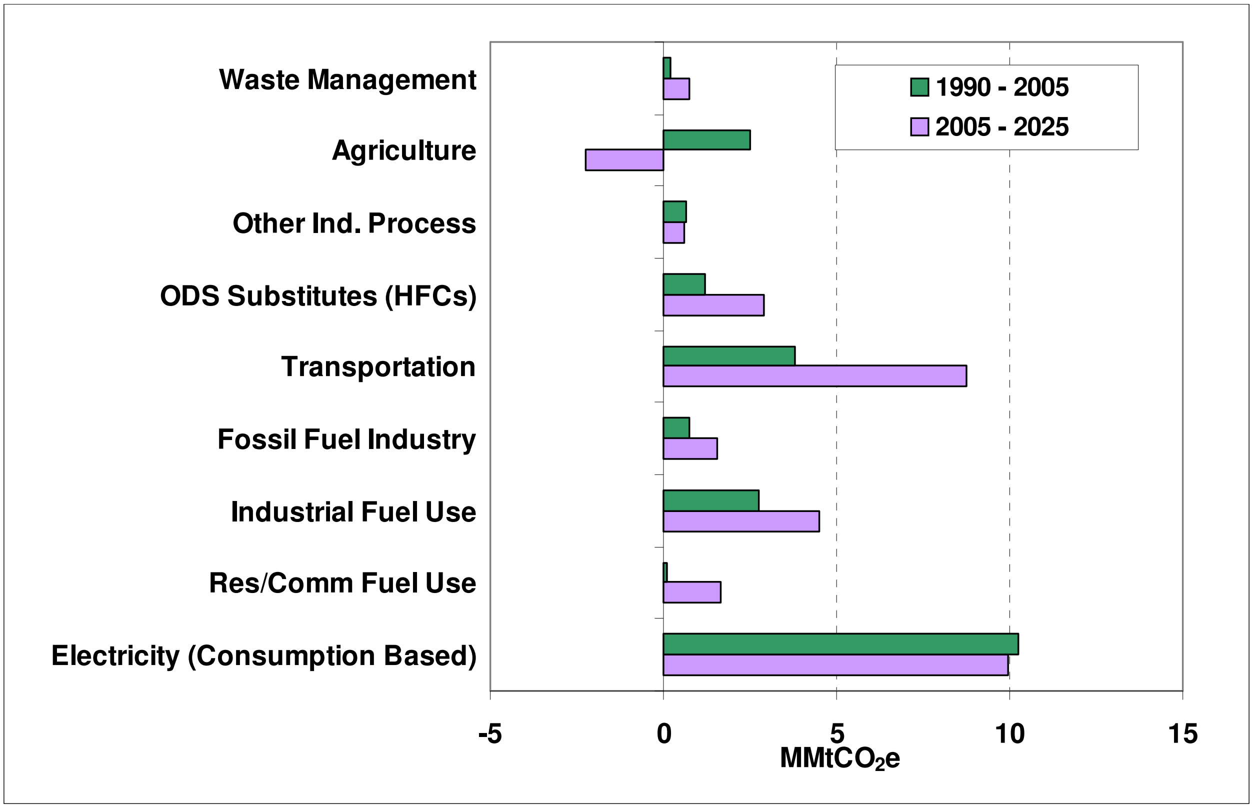
The electricity consumption sector is projected to be the largest contributor to future emissions growth, followed by emissions associated with the transportation sector, as shown in Figure 4. Table 2 summarizes the growth rates that drive the growth in the Iowa reference case projections, as well as the sources of these data.

Figure 3. Iowa Gross GHG Emissions by Sector, 1990-2025: Historical and Projected



RCI – direct fuel use in residential, commercial, and industrial sectors. ODS – ozone depleting substance.

Figure 4. Sector Contributions to Gross Emissions Growth in Iowa, 1990-2025: Historical and Reference Case Projections ($MMtCO_2e$ Basis)



Res/Comm – Direct fuel use in residential and commercial sectors. ODS – Ozone depleting substance. HFCs – Hydrofluorocarbons. Emissions associated with other industrial processes include all of the industries identified in Appendix D except emissions associated with ODS substitutes which are shown separately in this graph because of high expected growth in emissions for ODS substitutes.

Table 2. Key Annual Growth Rates for Iowa, Historical and Projected

	1990-2005	2005-2025	Sources
Population	0.42%	0.06%	Decennial Population and Population Estimates for Iowa: 1900 – 2007 - http://data.iowadatacenter.org/datatables/State/stpopest19002007.xls "Iowa Census Data Tables: Projections," State Data Center of Iowa, http://data.iowadatacenter.org/browse/projections.html
Electricity Sales **Total Sales**[a] **IA Sales**[b]	 2.5% 2.4%	 1.9% 1.5%[c] 1.9%[d] 2.1%[e]	For 1990-2005, annual growth rate in total electricity sales for all sectors combined in Iowa calculated from EIA State Electricity Profiles (Table 8) http://www.eia.doe.gov/cneaf/electricity/st_profiles/iowa.html and sales by Iowa generators calculated by subtracting T&D losses from net generations collected from EIA Annual Electric Utility Data - 906/920 database. For 2005-2025, annual growth rates are based on data that Iowa utilities provided for Iowa load growth forecast for 2007 through 2025.
Vehicle Miles Traveled	2.1%	1.8%	Iowa historical VMT data (1994-2006) provided by Donald Howe, Iowa Department of Transportation. Future data were estimated based on historical trends.

[a] Represents annual growth in total sales of electricity by generators inside or outside of Iowa to RCI sectors located within Iowa.
[b] Represents annual growth in total sales of electricity by generators in Iowa to RCI sectors located within Iowa.
[c] Reference Case
[d] Sensitivity Analysis Case 1
[e] Sensitivity Analysis Case 2

ICCAC Revisions

The following identifies the revisions that the ICCAC made to the inventory and reference case projections, thus explaining the differences between this report and the initial assessment completed during April 2008:[23]

***Energy Supply*:**

Changes to the 2005 Inventory

- The inventory now includes MidAmerican Energy Company's 25% ownership of the 1,700 megawatt (MW) Quad Cities Station nuclear plant in Illinois. This equates to about 3,350 gigawatt-hours (GWh) at 90% capacity. In both the inventory and reference case projections, this generation has been treated as an in-state resource because of its ownership status.

Changes to the Forecast (2006 and Later)

- A revised load growth forecast for Iowa provided by the Iowa utilities has been used.
- The AEO 2007 growth forecast data in the draft I&F was updated with data from AEO 2008.
- In the initial analysis, Energy Information Administration (EIA) forecast data of the Mid-Continent Area Power Pool (MAPP) region was used to project the electricity generation growth by fuel type in Iowa. In this report, added/retired electricity generation capacities provided by the Iowa utilities was used to project the electricity generation by fuel type in Iowa for the forecast years.

[23] In addition, a minor change was made to the transportation sector reference case projection emissions. This was done to correct the growth rate for marine gasoline fuel consumption to reflect the historical marine gas consumption trend, leading to a decrease of 0.03 MMtCO2e in the marine emissions.

Changes to the Reference Case

- Added the 790 MW Walter Scott Jr supercritical coal plant that came online in 2007;
- Added the 1284.3 MW new wind capacities of MidAmerican between 2005-2009;
- Included the power uprate for the Duane Arnold Energy Center that is scheduled to be completed in 2009;
- Added the 200 MW Alliant Franklin County (Whispering Willow) wind farm (will be on the line by 2010);
- Added the 2010 Corn Belt 71 MW wind capacity; and
- Included 100 MW of new wind capacity each year from 2014 to 2020, in response to the Clean and Renewable Energy (CRE) SC's request to extrapolate the 2008-2013 wind installation (average of 100 MW per year) to the future.

Additions to the Sensitivity Analysis Case 1 (in addition to the new capacities added in the Reference Case)

- The 649 MW Marshalltown coal plant;
- The 10% biomass co-firing requirement;
- The retirement of the Lansing units;
- Fuel switching in the Dubuque Generating Station Units from coal to natural gas; and
- Alliant 200 MW new wind capacity by 2013.

Additions to the Sensitivity Analysis Case 2 adds (in addition to the new capacities added in the Reference Case and the Sensitivity Analysis Case 1)

- The 750 MW Elk Run plant.

Agriculture:

- Soil carbon flux due to cultivation practices has been revised using a year 2000 estimate of the soil carbon sequestration in Iowa. This comes from a publication by William Stigliani, which references a 2001 study of soil carbon in Iowa. This replaced the United States Department of Agriculture (USDA) 1997 soil carbon estimates used for the initial analysis.

Reference Case Projections with Recent Federal and State Actions[24]

The federal Energy Independence and Security Act (EISA) of 2007 was signed into law in December 2007. This federal law contains several requirements that will reduce GHG emissions as they are implemented over the next few years. During the ICCAC process, sufficient information was identified (e.g., implementation schedules) to estimate GHG emission reductions associated with implementing the Corporate Average Fuel Economy (CAFE) requirements and energy efficiency requirements for new appliances and lighting in Iowa.

The ICCAC also identified a number of recent actions that Iowa has undertaken to control GHG emissions while at the same time conserving energy and promoting the development and use of renewable energy sources. Two of these recent actions were identified for which data were available to estimate the emission reductions of the actions relative to the business-as-usual reference case projections.

[24] Note that actions recently adopted by the state of Iowa have also been referred to as "existing" actions.

The GHG emission reductions projected to be achieved by these recent State and Federal actions are summarized in Table 3. This table shows a total reduction of about 3.35 $MMtCO_2e$ in 2020 from the business-as-usual reference case emissions, or a 2.8% reduction from the business-as-usual emissions in 2020 for all sectors combined.

Brief Summary of the Three EISA Components Analyzed as Recent Federal Actions

Federal Improved Standards for Appliance Energy Efficiency: Subtitle A of Title III of EISA contains new or updated standards for external power supplies (the small black boxes attached to the power cords of many electronic products), residential boilers, clothes washers, dishwashers, dehumidifiers, walk-in coolers and freezers, and electric motors. Additionally, the US Department of Energy (DOE) must issue a new standard by 2014 for the electricity usage of furnace fans. Starting July 1, 2010, DOE must incorporate energy use from standby mode and off mode into future standards for covered appliances. Finally, the subtitle allows regional standards to be set for heating and cooling equipment. With the exception of furnace fans, effective dates range from July 2008 (external power supplies) to October 2012 (dehumidifiers).

Federal Improved Standards for Lighting Energy Efficiency: Subtitle B of Title III of EISA contains new or updated standards for incandescent reflector lamps, metal halide lamp fixtures (commonly used in high-ceiling commercial and industrial applications), and general service lamps (light bulbs). Among these standards, the biggest energy saver is for common light bulbs, requiring them to use about 25%–30% less energy than today's most common incandescent bulbs by 2012–2014 (phasing in over several years) and at least 60% less energy by 2020.

Federal Corporate Average Fuel Economy Requirements: Subtitle A of Title I of EISA imposes new CAFE standards beginning with the 2011 model year vehicles. The average combined fuel economy of automobiles will be at least 35 mpg by 2020, with separate standards applying to passenger and non-passenger automobiles. The standard will be phased in, starting with the 2011 model year, so that the CAFE increases each year until the average fuel economy of 35 mpg is reached by 2020.

Brief Summary of Iowa Recent Actions.

Energy Efficiency for State Buildings: Section I of Executive Order 41 calls for all State agencies to identify and implement energy efficiency measures. Specifically, it calls for the reduction of energy consumption in facilities owned by the State by 15% by 2010, relative to 2000 levels. Section II.B.1 of Executive Order 6 established an Energy Excellent Buildings Task Force, which will focus on achieving 30% energy consumption reduction at state office buildings by 2015, relative to 2000 baseline.

Table 3. Emission Reduction Estimates Associated with the Effect of Recent Federal and State Actions in Iowa (consumption-basis, gross emissions)

Sector / Recent Action	GHG Reductions ($MMtCO_2e$)		GHG Emissions ($MMtCO_2e$)	
			Business as Usual	With Recent Actions
	2012	2020	2020	2020
Residential, Commercial and Industrial (RCI)				
Executive Orders #6 and #41 and Federal Improved Standards for Appliances and Lighting Requirements	0.44	1.42	29.7	28.3
Transportation and Land Use (TLU)				
Federal Corporate Average Fuel Economy (CAFE) Requirements	0.26	1.93	27.2	25.3
Total (RCI + TLU Sectors)	**0.70**	**3.35**	**56.9**	**53.6**
Total (All Sectors)			**119.5**	**116.2**

Key Uncertainties and Next Steps

Some data gaps exist in this inventory, and particularly in the reference case projections. Key tasks for future refinement of this inventory and forecast include review and revision of key drivers, such as the electricity demand, RCI fuel use, and transportation growth rates that will be major determinants of Iowa's future GHG emissions (See Table 2 and Figure 4). These growth rates are driven by uncertain economic, demographic and land use trends (including growth patterns and transportation system impacts), all of which deserve closer review and discussion.

Approach

The principal goal of compiling the inventories and reference case projections presented in this document is to provide the State of Iowa with an understanding of Iowa's historical, current, and projected (expected) GHG emissions. The following sections explain the general methodology and the general principles and guidelines followed during development of these GHG inventories for Iowa.

General Methodology

We prepared this analysis in close consultation with Iowa agencies, in particular, with the staff at Iowa DNR. The overall goal of this effort is to provide simple and straightforward estimates, with an emphasis on robustness, consistency, and transparency. As a result, we rely on reference forecasts from best available State and regional sources where possible. Where reliable existing forecasts are lacking, we use straightforward spreadsheet analysis and constant growth-rate extrapolations of historical trends rather than complex modeling.

In most cases, we follow the same approach to emissions accounting for historical inventories used by the US EPA in its national GHG emissions inventory[25] and its guidelines for States.[26] These inventory guidelines were developed based on the guidelines from the Intergovernmental

[25] US EPA, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2006*, April 15, 2008, US EPA # 430-R-08-005, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.
[26] http://yosemite.epa.gov/oar/globalwarming.nsf/content/EmissionsStateInventoryGuidance.html.

Panel on Climate Change (IPCC), the international organization responsible for developing coordinated methods for national GHG inventories.[27] The inventory methods provide flexibility to account for local conditions. The key sources of activity and projection data used are shown in Table 4. Table 4 also provides the descriptions of the data provided by each source and the uses of each data set in this analysis.

General Principles and Guidelines

A key part of this effort involves the establishment and use of a set of generally accepted accounting principles for evaluation of historical and projected GHG emissions, as follows:

- **Transparency:** We report data sources, methods, and key assumptions to allow open review and opportunities for additional revisions later based on input from others. In addition, we report key uncertainties where they exist.
- **Consistency:** To the extent possible, the inventory and projections were designed to be externally consistent with current or likely future systems for State and national GHG emission reporting. We have used the EPA tools for State inventories and projections as a starting point. These initial estimates were then augmented and/or revised as needed to conform with State-based inventory and base-case projection needs. For consistency in making reference case projections, we define reference case actions for the purposes of projections as those *currently in place or reasonably expected over the time period of analysis*.
- **Priority of Existing State and Local Data Sources:** In gathering data and in cases where data sources conflicted, we placed highest priority on local and State data and analyses, followed by regional sources, with national data or simplified assumptions such as constant linear extrapolation of trends used as defaults where necessary.
- **Priority of Significant Emissions Sources:** In general, activities with relatively small emissions levels may not be reported with the same level of detail as other activities.
- **Comprehensive Coverage of Gases, Sectors, State Activities, and Time Periods:** This analysis aims to comprehensively cover GHG emissions associated with activities in Iowa. It covers all six GHGs covered by US and other national inventories: CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs. The inventory estimates are for the year 1990, with subsequent years included up to most recently available data (typically 2002 to 2005), with projections to 2025.
- **Use of Consumption-Based Emissions Estimates:** To the extent possible, we estimated emissions that are caused by activities that occur in Iowa. For example, we reported emissions associated with the electricity consumed in Iowa. The rationale for this method of reporting is that it can more accurately reflect the impact of State-based policy strategies such as energy efficiency on overall GHG emissions, and it resolves double-counting and exclusion problems with multi-emissions issues. This approach can differ from how inventories are compiled, for example, on an in-state production basis, in particular for electricity.

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[27] http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

Table 4. Key Sources for Iowa Data, Inventory Methods, and Growth Rates

Source	Information provided	Use of Information in this Analysis
US EPA State Greenhouse Gas Inventory Tool (SIT)	US EPA SIT is a collection of linked spreadsheets designed to help users develop State GHG inventories for 1990-2005. US EPA SIT contains default data for each State for most of the information required for an inventory. The SIT methods are based on the methods provided in the Volume VIII document series published by the Emissions Inventory Improvement Program (http://www.epa.gov/ttn/chief/eiip/techreport/volume08/index.html).	Where not indicated otherwise, SIT is used to calculate emissions for 1990-2005 from RCI fuel combustion, transportation, industrial processes, agriculture and forestry, and waste. We use SIT emission factors (CO_2, CH_4, and N_2O per British thermal unit (Btu) consumed) to calculate energy use emissions.
US DOE Energy Information Administration (EIA) State Energy Data (SED)	EIA SED provides energy use data in each State, annually to 2005 for all RCI sectors and fuels and pipeline natural gas consumption for fossil fuel production sector	EIA SED is the source for most energy use data. Emission factors from US EPA SIT are used to calculate energy-related emissions.
EIA State Annual Electric Utility Data — EIA 906/920 Database	EIA provides information on the electric power industry generation by primary energy source for 1990 – 2005.	EIA 906/920 Database was used to determine the mix of in-state electricity generation by fuel. Electricity sales were projected off of 2005 sales provided in this reference.
EIA AEO2007	EIA AEO2007 projects energy supply and demand for the US from 2005 to 2030. Energy consumption is estimated on a regional basis.	EIA AEO2007 is used to project changes in fuel use by the RCI sectors.
EIA AEO2008	EIA AEO2008 projects energy supply and demand for the US at the regional level from 2005 to 2030. Regional outputs for the Mid-Continent Area Power Pool (MAPP) region, in which Iowa is located, are used.	The MAPP region projections of on-site usage, transmission and distribution (T&D) losses are used in the ES sector GHG emission forecast.
Iowa Utilities	Load growth forecast for the period of 2007 to 2025 is provided by the utilities in Iowa, including Interstate P & L, MidAmerican, the Rural Electric Cooperatives, and the Municipal Utilities.	The Iowa weighted average load growth rate for each year is computed based on utility sales. The weighted average load growth rate is then used to estimate Iowa's electricity demand over the forecasting period of 2006-2025.
Iowa Utilities	Added/retired electricity generation capacities in Iowa in forecast years	The added/retired generation capacity information is used to project the in-state electricity supply of Iowa in both the reference case and the two sensitivity analysis cases.
US Department of Transportation (DOT), Office of Pipeline Safety (OPS)	Natural gas transmission pipeline mileage (2001-2005), and distribution pipeline mileage/number of services (2004–2005). [Values for earlier years were estimated using trends in related surrogate variables – see Appendix E for details.]	OPS data entered into SIT to calculate historical emissions. Transmission pipeline emissions projected using smallest annualized increase in state transmission emissions (3.87%) from each of 3 periods analyzed (1990-2005; 1995-2005; and 2000-2005); distribution pipeline emissions projected using AEO2007 West North Central region natural gas consumption forecast.
US Forest Service	Data on forest carbon stocks for multiple years.	Data are used to calculate CO_2 flux over time (terrestrial CO_2 sequestration in forested areas).

Source	Information provided	Use of Information in this Analysis
USDS National Agricultural Statistics Service (NASS)	USDA NASS provides data on crops and livestock.	Crop production data used in SIT to estimate agricultural residue and agricultural soils emissions; livestock population data used in SIT to estimate manure and enteric fermentation emissions.

For electricity, we estimate, in addition to the emissions due to fuels combusted at electricity plants in the State, the emissions related to electricity *consumed* in Iowa. This entails accounting for the electricity sources used by non-Iowa utilities to meet Iowa consumer demands. As this analysis is refined in the future, one could also attempt to estimate other sectoral emissions on a consumption basis, such as accounting for emissions from transportation fuel used in Iowa, but purchased out-of-state. In some cases, this can require venturing into the relatively complex terrain of life-cycle analysis. In general, we recommend considering a consumption-based approach where it will significantly improve the estimation of the emissions impact of potential mitigation strategies. For example re-use, recycling, and source reduction can lead to emission reductions resulting from lower energy requirements for material production (such as paper, cardboard, and aluminum), even though production of those materials, and emissions associated with materials production, may not occur within the State.

Details on the methods and data sources used to construct the inventories and forecasts for each source sector are provided in the following appendices:

- Appendix A. Electricity Supply and Use
- Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion
- Appendix C. Transportation Energy Use
- Appendix D. Industrial Processes
- Appendix E. Fossil Fuel Production Industry
- Appendix F. Agriculture
- Appendix G. Waste Management
- Appendix H. Forestry & Land Use

Appendix I provides additional background information from the US EPA on GHGs and global warming potential values.

Appendix A. Electricity Supply and Use

Overview

This appendix describes the data sources, key assumptions, and the methodology used to develop an inventory of greenhouse gas (GHG) emissions over the 1990-2005 period associated with the generation of electricity to meet electricity demand in Iowa. It also describes the data sources, key assumptions, and methodology used to develop a forecast of GHG emissions over the 2006-2025 period associated with meeting electricity demand in the state. Specifically, the following topics are covered in this Appendix:

- *Data sources:* This section provides an overview of the data sources that were used to develop the inventory and forecast, including publicly accessible websites where this information can be obtained and verified.
- *Greenhouse Gas Inventory methodology:* This section provides an overview of the methodological approach used to develop the Iowa GHG inventory for the electric supply sector.
- *Greenhouse Gas Forecast Methodology – Reference Case:* This section provides an overview of methodological approach used to develop the Iowa GHG Reference Case forecast for the electric supply sector.
- *Greenhouse Gas Forecast Methodology – Sensitivity Analysis Cases:* This section provides an overview of methodological approach used to develop two Iowa GHG Sensitivity Analysis Cases forecast for the electric supply sector. The first Sensitivity Analysis Case evaluates the impact of the Marshalltown coal plant and its associated coal-fired generation retirement, biomass co-firing, new wind generation addition, etc. The second Sensitivity Analysis Case evaluates the impact of Elk Run coal plant running along with the Marshalltown plant.
- *Greenhouse Gas Inventory Results:* This section provides an overview of key results of the Iowa GHG inventory for the electric supply sector.
- *Greenhouse Gas Forecast Results:* This section provides an overview of key results of the Iowa GHG forecast for the electric supply sector. The results of both the Reference Case and the two Sensitivity Analysis Cases are presented.

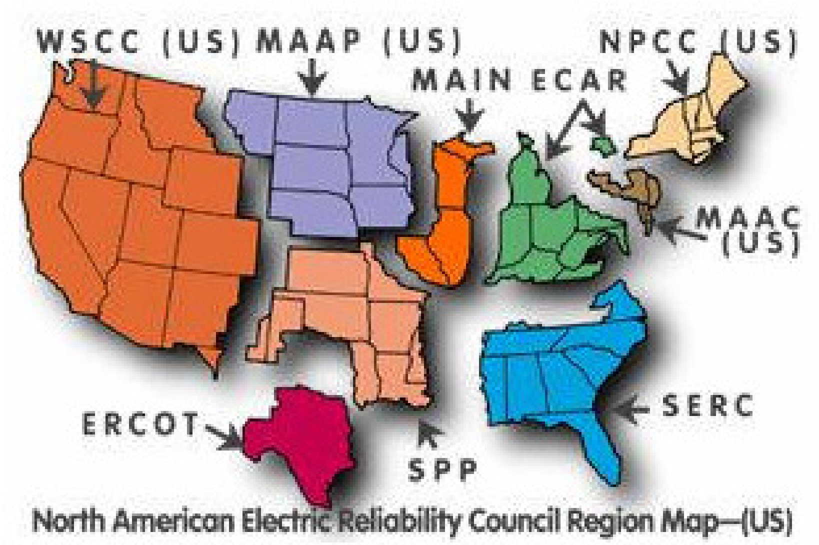
Data Sources

We considered several sources of information in the development of the inventory and forecast of carbon dioxide equivalent (CO_2e) emissions from Iowa power plants. These are briefly summarized below:

- *Iowa Load Growth Forecast Data.* Load growth forecast for the period of 2007 to 2025 is provided by the utilities in Iowa, including Interstate P & L, MidAmerican, the Rural Electric Cooperatives, and the Municipal Utilities. The Iowa weighted average load growth rate for each year is computed based on utility sales. The weighted average load growth rate is then used to estimate Iowa's electricity demand over the forecasting period of 2006-2025.
- *EIA-906/920 Monthly Time Series data.* This is a database file available from the Energy Information Administration (EIA) of the US Department of Energy. The information in the database is based on information collected from utilities in Forms EIA-906/920 and EIA-860. Historical data for years 1990-2005 were extracted for Iowa. Year 2005 (forecast base year) data

of neighboring states MN, ND, NE, SD, and MT were also collected. Data from these forms provide, among other things, fuel consumption and net generation in power stations located in these states by plant type. This information can be accessed from http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html.

- *Annual Energy Outlook 2008.* This is an output of an EIA analysis using the National Energy Modeling System (NEMS), a model that forecasts electric expansion/electricity demand in the USA. In particular, regional outputs for the Mid-Continent Area Power Pool (MAPP) region was used. The MAPP region is the one in which Iowa is located (see map at right). The MAPP results include forecasts of gross generation, net generation, combustion efficiency, total sales, on-site usage, transmission and distribution (T&D) losses, and exports/imports through the year 2025. This information is available in supplemental tables that can be accessed directly from http://www.eia.doe.gov/oiaf/aeo/supplement/index.html. The source of the above map is http://www.bydesign.com/fossilfuels/crisis/html/NERC_regions_map.html.



- *Annual Energy Outlook 1996*-2007 Editions. Historical data on gross generation, net generation, total sales, on-site usage, T&D losses, and emission intensities for the MAPP region were extracted for years 1994-2004. The information is available in supplemental tables that can be accessed directly from http://www.eia.doe.gov/oiaf/archive.html#aeo.

- *Monthly Cost and Quality of Fuels for Electric Plants.* This information is available from the Federal Energy Regulatory Commission (FERC). The database relies on information collected from utilities in the FERC-423 form. It was used to determine the share of coal type (i.e., whether bituminous, sub-bituminous, anthracite, or lignite) used in Iowa power plants over the period 1990-2005. It can be accessed directly from http://www.eia.doe.gov/cneaf/electricity/page/ferc423.html.

- *Electric Power Annual 2006.* This information is available from the EIA. The database compiles capacity, net generation, and total retail electricity sales by state. It was used to determine total sales of electricity across all sectors for years 1990 through 2005. It can be accessed directly from http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html.

- *Energy conversion factors.* This is based on Table A-238 of Annex 6 in the USEPA's 2006 GHG Inventory for the US. The table is entitled "Conversion Factors to Energy Units (Heat Equivalents)". This information can be accessed directly from the following website: http://www.epa.gov/climatechange/emissions/downloads06/07Annex6.pdf.

- *Fuel combustion oxidation factors.* This is based on Table A-27 in Annex 2 of the USEPA's 2006 US GHG inventory for the US. This information can be accessed directly from: http://www.epa.gov/climatechange/emissions/downloads06/06_Annex_Chapter2.pdf.
- *Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emission factors.* For all fuels except Municipal Solid Waste (MSW), these emission factors are based on Annex 2 and Annex 3 of the USEPA's 2006 GHG inventory for the US. This information can be accessed directly from: http://www.epa.gov/climatechange/emissions/downloads06/06_Annex_Chapter2.pdf and http://www.epa.gov/climatechange/emissions/downloads06/07Annex3.pdf. For MSW, emission factors are based on the EIA's Office of Integrated Analysis and Forecasting, Voluntary Reporting of Greenhouse Gases Program, Table of Fuel and Energy Source: Codes and Emission Coefficients. This information can be accessed directly from http://www.eia.doe.gov/oiaf/1605/coefficients.html.
- *Global warming potentials.* These are based on values proposed by the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report. This information can be accessed directly from http://www.ipcc.ch/ipccreports/assessments-reports.htm.

Greenhouse Gas Inventory Methodology

The methodology used to the develop the Iowa inventory of GHG emissions associated with electricity production and consumption is based on methods developed by the IPCC and used by the USEPA in the development of the US GHG inventory. There are four fundamental premises of the GHG inventory developed for Iowa, as briefly described below:

- The GHG inventory should be estimated based on both the production and consumption of electricity. Developing the production estimate involves tallying up the GHG emissions associated with the operation of power plants physically located in Iowa, regardless of ownership.[28] Developing the consumption estimate involves tallying up the GHG emissions associated with consumption of electricity in Iowa, regardless of where the electricity is produced. Note the difference between the WRI methodology which is production based for the electricity sector.
- The GHG inventory should be estimated based on emissions at the point of electric generation only. That is, GHG emissions associated with upstream fuel cycle process such as primary fuel extraction, transport to refinery/processing stations, refining, beneficiation, and transport to the power station are not included.
- As an approximation, in those years that Iowa is an importer of power, it was assumed that all power generated in Iowa was consumed in Iowa and the gap between the demand and in-state generation is met by imports from the MAPP region. In fact, some of the power generated in Iowa is exported. However, given the similarity in the average carbon intensity of Iowa power stations and that of power stations in the surrounding MAPP region, the potential error associated with this simplifying assumption is small, on the order of 2%, plus or minus.
- Several key assumptions were used for making projections of CO_2, CH_4, and N_2O emissions for the electric sector out to 2025. These are summarized in Table A1.

[28] MidAmerican has 25% ownership of the 1700 MW Quad Cities Station nuclear plant in IL. The Clean and Renewable Energy subcommittee suggested, and ICCAC approved counting this electricity as generated in Iowa for 1990-2030.

Table A1. Key Assumptions used in the Iowa GHG Forecast

Key Assumptions	2005	Reference Case		Sensitivity Analysis Case 1		Sensitivity Analysis Case 2	
		2025	Average Annual Change (%)	2025	Average Annual Change (%)	2025	Average Annual Change (%)
Iowa electricity demand (GWh)	42,757	62,159	1.89%	62,159	1.89%	62,159	1.89%
Iowa gross generation (GWh)	46,269	59,498	1.27%	64,805	1.70%	70,587	2.13%
Iowa utility sales to meet Iowa demand[a] (GWh)	41,246	55,387	1.48%	60,328	1.92%	65,710	2.36%
Import sales from MAPP region (GWh)	1,511	6,772	7.79%	1,831	0.97%	-3,551	-16.75%
Gross generation from MAPP imports[b] (GWh)	1,695	7,275	7.56%	1,967	0.75%	-3,815	-16.25%
Power plant heat rate (BTU/kWh)							
Coal	11,034	10,705	-0.12%	10,536	-0.18%	10,285	-0.28%
Nuclear	10,378	10,378	0.00%	10,378	0.00%	10,378	0.00%
Natural Gas	8,581	8,581	0.00%	8,681	0.05%	8,681	0.05%
Oil	15,518	15,518	0.00%	15,518	0.00%	15,518	0.00%
Municipal Solid Waste (MSW)	11,280	11,280	0.00%	11,280	0.00%	11,280	0.00%
Biomass	NA	NA	NA	11,878	NA	11,878	NA
Landfill Gas (LFG)	12,489	12,489	0.00%	12,489	0.00%	12,489	0.00%
Wind	9,939	9,939	0.00%	9,939	0.00%	9,939	0.00%
Hydroelectric	9,939	9,939	0.00%	9,939	0.00%	9,939	0.00%
Losses (%)							
From on-site usage	0.60%	0.28%	-5.04%	0.28%	-5.04%	0.28%	-5.04%
From T&D and on-site usage	10.86%	6.91%	-2.97%	6.91%	-2.97%	6.91%	-2.97%

[a] Iowa utility sales to meet the Iowa demand is computed by multiplying the Iowa gross in-state generation by one minus the loss rate associated with on-site usage and T&D.
[b] Gross generation associated with the MAPP imports is computed by dividing the import sales from MAPP by one minus the loss rate associated with on-site usage and T&D.

There were several steps in the methodology for the development of the electric sector GHG inventory for the period 1990-2005. These are briefly outlined below:

- Determine the coal quality used in Iowa power stations (i.e., share of anthracite, bituminous, lignite, sub-bituminous, and coal wastes used).
- Determine gross annual primary energy consumption by Iowa power stations by plant and fuel type.
- Determine gross annual generation associated with net power imports to satisfy Iowa electricity demand or net power exports that exceed the Iowa electricity demand.

- Multiply gross annual primary energy consumption by Iowa power stations by CO_2e emission factors. This provides an estimate of the Iowa GHG inventory on a production basis.
- Multiply annual gross generation associated with net power imports (or exports) by the carbon emission intensity (in units of metric tons CO2e per megawatt-hour [tCO2e/MWh]) of the MAPP region. This provides an estimate of the additional GHG emissions associated with meeting Iowa electricity demand in excess of generation from local power plants (in import years) or the GHG emissions associated with the exported electricity to outside Iowa (in the export years). Add (or subtract) the emissions associated with net power imports (or exports) to (or from) the production-based emissions. This provides an estimate of the GHG inventory on a consumption basis.

Greenhouse Gas Forecast Methodology – Reference Case

We consider that the most useful methodology for constructing a GHG forecast is one that attempts to build information from the bottom-up. That is, the GHG forecast was developed using detailed State-specific data regarding projected sales, gross in-state generation, supply-side efficiency improvements, planned capacity additions and retirements by plant type/vintage, and changes over time regarding losses associated with on-site use and T&D.

For the Reference Case, we simulate the new generation capacities in Iowa in the forecasting years as presented in Table A2.

Coal quality. An overview of the methodology applied to forecast quality of coal used in Iowa power stations is briefly summarized below:

- For the Base Year of 2005, determine the coal quality used in Iowa power stations (i.e., share of anthracite, bituminous, lignite, sub-bituminous, and coal wastes used).
- For the period 2006 through and including 2025, assume that the coal quality is the same as the Base year.

Table A2. New Electricity Generation Capacities Simulated in the Reference Case

Addition Name	Fuel	MW	Capacity Factor	Heat Rate	Date
Century	Wind	150 MW	37%		2006
Intrepid Addition	Wind	15 MW	37%		2006
Century Addition	Wind	35 MW	37%		2006
Walter Scott	Coal	790 MW	92%	9,000 Btu/kwh	2007
Victory	Wind	99 MW	37%		2007
Iowa State Fair	Wind	0.5	37%		2008
Pomeroy I	Wind	123	37%		2008
Century Expansion	Wind	15	37%		2008
Pomeroy II	Wind	75	37%		2008
GE Charles City	Wind	75	37%		2009
Adair	Wind	175.80	37%		2009
Pomeroy III	Wind	58.50	37%		2009
Carroll	Wind	150	37%		2009
Walnut	Wind	100.50	37%		2009
Walnut II	Wind	52.50	37%		2009
Duane Arnold Uprate	Nuclear	10 MW	90%	10,444 Btu/kwh	2009
Alliant Franklin County (Whispering Willow)	Wind	200 MW	41%		2010
Corn Belt	Wind	71 MW	36%		2010
Additional Wind Capacity	Wind	100 MW	36%		Each year from 2014 to 2020

Total Sales. An overview of the methodology applied to forecast annual sales of electricity to Iowa consumers is briefly summarized below:

- For the Base Year of 2005, total retail sales in Iowa were 42,757 gigawatt-hour (GWh) based on EIA data.
- For the year 2006, the EIA retail sales data indicates a 1.36% increase from the 2005 sales level. Therefore, the total retail sales in Iowa in 2006 were 43,336 GWh.
- For the period 2007 through and including 2025, compute the weighted average annual growth rate of Iowa load growth based on the data provided by four Iowa utilities – Interstate P & L, MidAmerican, Rural Electric Cooperatives, and Municipal Utilities.
- For the period 2007 through and including 2025, apply the weighted average annual growth rate to the base year sales to get the forecast annual sales.[29]
    - The Iowa Utilities Board has directed the investor-owned utilities to include analyses of the effects of goals equivalent to saving 1.5% of retail electric sales in Iowa, up

[29] Electricity sales for the residential, commercial, and industrial (RCI) sectors are used in Appendix B to allocate emissions associated with electricity generation to each sector for comparison to emissions associated with the direct use of natural gas, petroleum, coal, and wood by each sector. Electricity sales for each sector were calculated using the following three steps: (1) calculate the sectoral growth rate in MAPP region from 2006 to 2025; (2) apply the MAPP sectoral growth rate to Iowa Base Year (2005) electricity sales for each sector; and (3) benchmark total sector sales to the control totals that are computed based on Iowa state-specific utility load growth forecasts.

from .8% in 2008. Should the energy efficiency plans filed by the utilities be approved, the effects of these additional investments are not included in the load growth forecasts.

Gross Generation. An overview of the methodology applied to forecast annual gross electricity generation by Iowa power stations is briefly summarized below:

- For the Base Year of 2005, estimate losses associated with on-site usage of electricity by plant type for Iowa power plants. On-site usage losses were assumed to be equal to the MAPP regional average of 0.6% of gross generation.
- For the Base Year of 2005, combine actual net electric generation data (i.e., from the inventory) and assumed average on-site losses (i.e., from the MAPP region) to estimate gross generation by plant type.
- For the period 2006 through and including 2025, compute the annual additional gross generation associated with the new generation capacities listed in Table A2.
- For the period 2006 through and including 2025, compute the Reference Case gross generation of the IA utilities by adding the annual additional gross generation to the 2005 base year gross generation.

Energy use. An overview of the methodology applied to forecast annual primary energy use at Iowa power stations is briefly summarized below:

- For the Base Year of 2005, establish the actual primary energy consumption for Iowa power plants as reported by the databases used to develop the inventory.
- For the period 2006 through and including 2025, compute the annual additional energy use associated with the new generation capacities using the heat rate parameters shown in Table A2.
- For the period 2006 through and including 2025, compute the Reference Case energy use of the IA utilities by adding the annual additional energy use to the 2005 base year energy use.

Combustion efficiency. An overview of the methodology applied to forecast annual heat rates at Iowa power stations is briefly summarized below:

- For the Base Year of 2005 through and including 2025, estimate gross heat rate of Iowa power stations by dividing the plant type-specific gross generation estimate by the plant type-specific gross primary energy consumption estimate.

Electricity imports. An overview of the methodology applied to forecast annual net electricity imports to meet Iowa demand is briefly summarized below:

- For the Base Year of 2005 through and including 2025, estimate Iowa utility sales to meet Iowa electricity demand by multiplying the Iowa projected gross generation by one minus the percent losses from on-site usage and T&D (MAPP regional on-site usage rate and T&D loss rate are utilized here).
- For the Base Year of 2005 through and including 2025, estimate the difference between total sales in Iowa and the total sales by Iowa power stations. If the former is higher than the latter,

Iowa needs to import electricity. If the former is lower than the latter, Iowa has excess electricity to export to other states.

- For the Base Year of 2005 through and including 2025, estimate the gross generation associated with imports (or exports) by dividing sales from imports (or exports) by one minus the percent losses from on-site usage and T&D in the MAPP region.

Carbon dioxide-equivalent emissions from Iowa power stations. An overview of the methodology applied to forecast annual CO_2e emissions is briefly summarized below:

- For the Base Year of 2005 through and including 2025, estimate total CO_2 emissions from Iowa power stations by multiplying total primary energy use by the CO_2 emission factor and the global warming potential.
- For the Base Year of 2005 through and including 2025, estimate total CH_4 emissions from Iowa power stations by multiplying total primary energy use by the CH_4 emission factor and the global warming potential.
- For the Base Year of 2005 through and including 2025, estimate total N_2O emissions from Iowa power stations by multiplying total primary energy use by the N_2O emission factor and the global warming potential.
- For the Base Year of 2005 through and including 2020, estimate total CO_2e emissions from Iowa power stations by adding the CO_2e of CO_2, CH_4, and N_2O.

Carbon dioxide-equivalent emissions from imported (or exported) electricity. An overview of the methodology applied to forecast annual CO_2e emissions associated with electricity imports (or exports) is briefly summarized below:

- For the Base Year of 2005 through and including 2025, estimate the average annual GHG emission intensity (i.e., metric tons (t) of CO_2, CH_4, and N_2O per MWh of gross generation). For imports, the average GHG emission intensity of the MAPP region is estimated. For exports, the average GHG emission intensity of the state generation mix is estimated.
- For the Base Year of 2005 through and including 2025, estimate total CO_2 emissions associated with imported (or exported) electricity by multiplying the gross generation associated with these imports (or exports) by the CO_2 emission intensity and the global warming potential.
- For the Base Year of 2005 through and including 2025, estimate total CH_4 emissions associated with imported (or exported) electricity by multiplying the gross generation associated with these imports (or exports) by the CH_4 emission intensity and the global warming potential.
- For the Base Year of 2005 through and including 2025, estimate total N_2O emissions associated with imported (or exported) electricity by multiplying the gross generation associated with these imports (or exports) by the N_2O emission intensity and the global warming potential.
- For the Base Year of 2005 through and including 2025, estimate total CO_2e emissions associated with imported (or exported) electricity by adding the CO_2e of CO_2, CH_4, and N_2O.

Greenhouse Gas Forecast Methodology – Sensitivity Analysis Cases

In the first Sensitivity Analysis Case, we evaluate the impact of the Marshalltown coal plant and its associated coal-fired generation retirement, biomass co-firing, new wind generation addition, etc. to the GHG emissions in Iowa in the forecast years. We made the decision to keep the Marshalltown plant out of the baseline forecast because DNR is still reviewing the permit application and CCS's inventory and forecast methodology requires new plants to have received all necessary permits in order to allow it in the reference case. The Marshalltown plant will be included in a sensitivity analysis of the baseline forecast including the following assumptions:

- The Sutherland Unit 4 plant is listed as having a biomass co-firing requirement. The 10% biomass co-firing requirement is assumed to be added at 5% a year for 2 years starting from 2013 and then keep at the level of 10% afterwards.
- The retirement of the Lansing units using historical capacity utilization of the retired plants.
- Alliant will permanently switch the fuel source of its Dubuque Generating Station Units from coal to natural gas.
    - The historical capacity factor for Dubuque will be used to calculate CO_2 emissions reductions from fuel switching.
    - The characteristics of the new gas plant in terms of heat rate and capacity factor are assumed to be 15741Btu/kwh and a 5% capacity factor (Dubuque will then operate essentially as a peaking resource).
- Alliant will also build 200 MW of new wind by 2013.

In the second Sensitivity Analysis Case, we evaluate the impact of Elk Run coal plant running along with the Marshalltown plant.

Table A3 presents the parameters for the added/retired capacities in the Sensitivity Analysis Cases:

Table A3. Parameters for the Added/retired Capacities in the Sensitivity Analysis Cases

Addition Name	MW	Capacity Factor	Heat Rate	Technology and Fuel	Date
Sutherland Unit 4 (Marshalltown)	649 MW	88%	9400 Btu/kwh	Supercritical Coal	2013
Elk Run Plant (Independent Power Producer)	750 MW	88%	8389 Btu/kwh[30]	Supercritical Coal	~2014
New Wind Capacity of Alliant	200 MW	41%		Wind	2013
Retirement Name (if applicable)	**MW**			**Technology and Fuel**	**Date**
Lansing Units 2 & 3	45 MW	33.73%[31]	11730.22 Btu/kwh[32]	Pulverized Coal	2013
Fuel Switching Name (if applicable)	**MW**			**Technology and Fuel**	**Date**
Dubuque (coal)	80	45.07%[33]	14300.17 Btu/kwh[34]	Pulverized Coal	2013
Dubuque (gas)	80	5%	15741 Btu/kwh	Simple Cycle Gas	2013

The methodologies used to compute the in-state gross generation, energy use, electricity imports (or exports), and GHG emissions in the Sensitivity Analysis Cases are the same as those used in the Reference Case.

Greenhouse Gas Forecast Results

Table A4 and Figure A1 summarize the characteristics of the electric generation system in Iowa, together with a breakdown in generation and emissions for Iowa power stations for 2005. The following subsections provide an overview of the results of the GHG emissions inventory and reference case and sensitivity cases projections estimated using the methodological approach described above.

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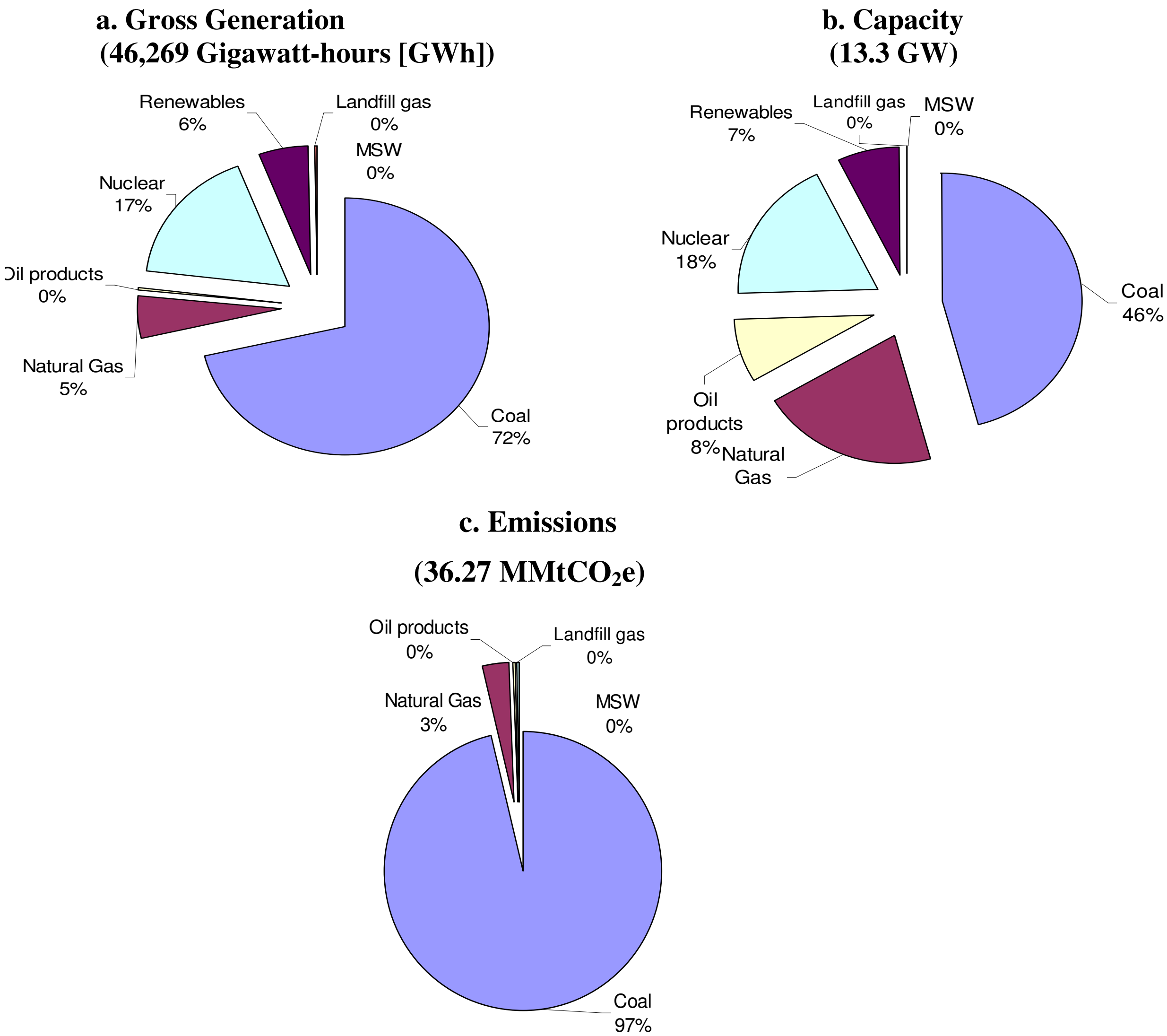
[30] This is the 2015 heat rate (reference case) for advanced coal presented in Table 47 of the EIA *Assumptions to the Annual Energy Outlook 2008 (Electricity Market Module)*. http://www.eia.doe.gov/oiaf/aeo/assumption/index.html.
[31] 2004 weighted average capacity factor of Lansing Unit 2 & 3. Source: EPA eGRID2006 Version 2.1. http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html
[32] Source: EPA eGRID2006 Version 2.1.
[33] 2004 weighted average capacity factor of Dubuque ST2, 3, & 4. Source: EPA eGRID2006 Version 2.1.
[34] Source: EPA eGRID2006 Version 2.1.

Table A4. Summary of Iowa Electric Generator Characteristics for the 2005 Base Year

Type	Fuel	Gross Generation (GWh)	Capacity (MW)	Fuel use (Billion Btu)	Heat rate (Btu/KWh)	Emissions (MMtCO$_2$e)
Steam plants	Non-lignite coal	33,005	6,060	364,184	11,034	34.91
	Lignite coal	0	0	0	NA	0.00
	Natural Gas	107	19	1,711	15,931	0.09
	Residual oil	0	0	0	NA	0.00
	Diesel oil	23	0	261	11,574	0.02
	Petroleum coke	0	0	0	NA	0.00
	LFG	14	0	156	11,305	0.01
	Refuse derived fuel/MSW	26	0	298	11,280	0.01
	Biomass	0	0	0	NA	0.00
	Nuclear	7,915	2,421	82,142	10,378	0.00
	Subtotal:	*41,090*	*8,500*	*448,752*		*35.04*
Turbines	Natural Gas	93	1,371	1,638	17,637	0.09
	Diesel	102	472	1,564	15,348	0.11
	Landfill Gas	0	0	0	NA	0.00
	Waste oils/solvents	0	24	5	20,380	0.00
	Subtotal:	*195*	*1,867*	*3,207*		*0.20*
Combined Cycle	Natural Gas	2,284	1,245	17,893	7,833	0.96
	Diesel	5	0	44	9,156	0.00
	Landfill Gas	0	0	0	NA	0.00
	Subtotal:	*2,289*	*1,245*	*17,937*		*0.97*
Engines	Natural Gas	4	93	114	28,118	0.01
	Diesel	14	620	198	14,085	0.01
	Landfill Gas	54	6	690	12,792	0.04
	LPG	0	0	0	NA	0.00
	subtotal:	*72*	*720*	*1,001*		*0.06*
Renewable	Wind	1,657	820	16,470	9,939	0.00
	Solar PV	0	0	0	NA	0.00
	Hydroelectric	965	131	9,594	9,939	0.00
	Subtotal:	*2,622*	*952*	*26,064*		*0.00*
All	***Total***	**46,269**	**13,284**	**496,961**		**36.27**

Figure A1. Breakdown of Iowa Generation, Capacity and Emissions – 2005 Base Year

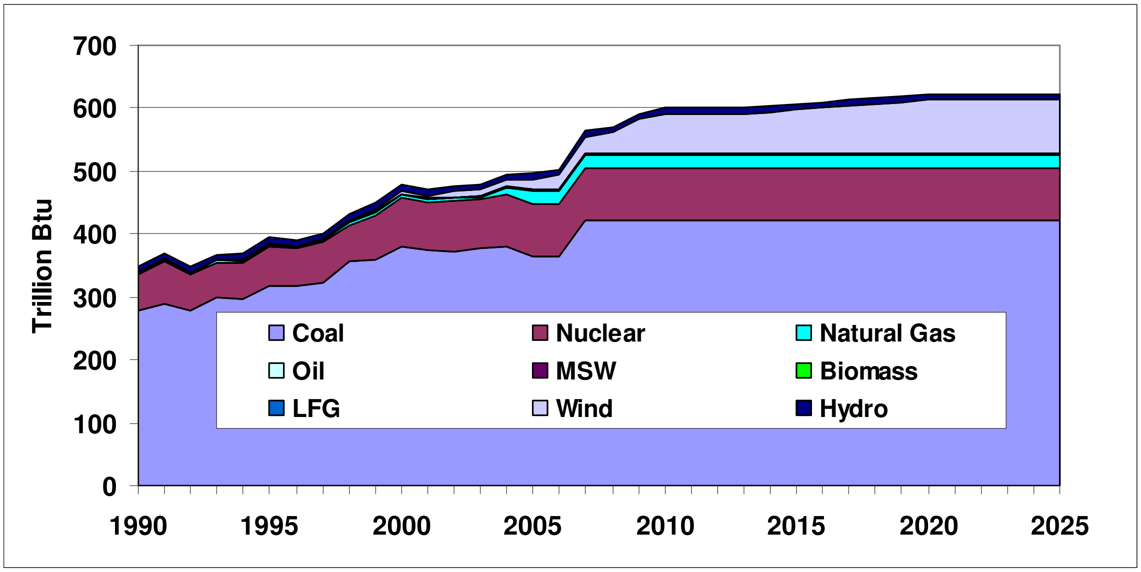


Primary Energy Consumption

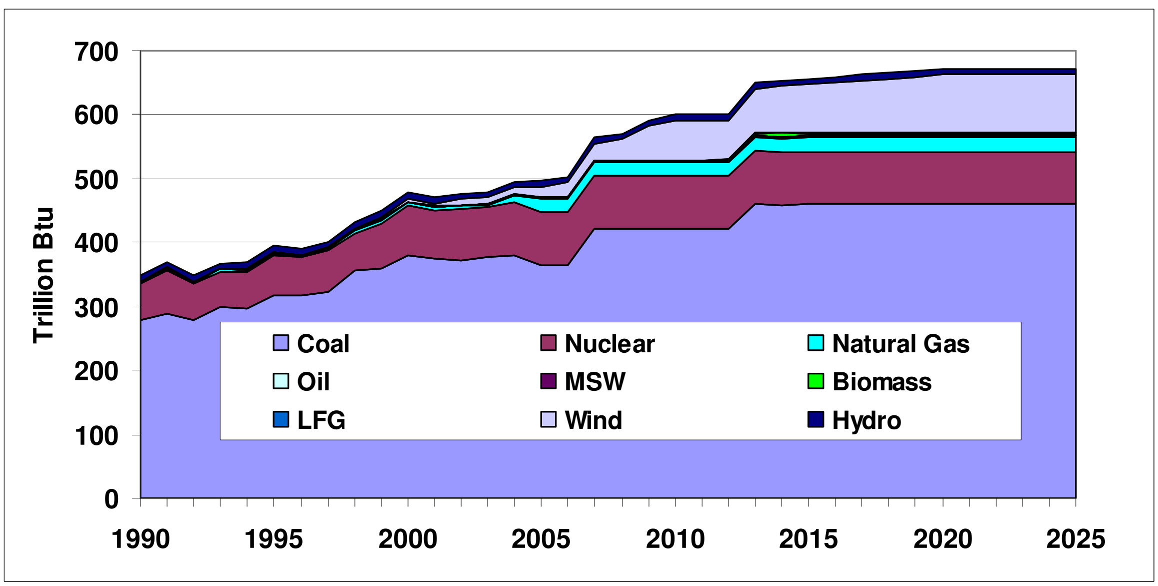
Total primary energy consumption associated with electricity generation in Iowa is summarized in Figure A2. Primary energy consumption in Iowa is dominated by coal resources.

Figure A2. Gross Primary Energy Use at Iowa Power Stations

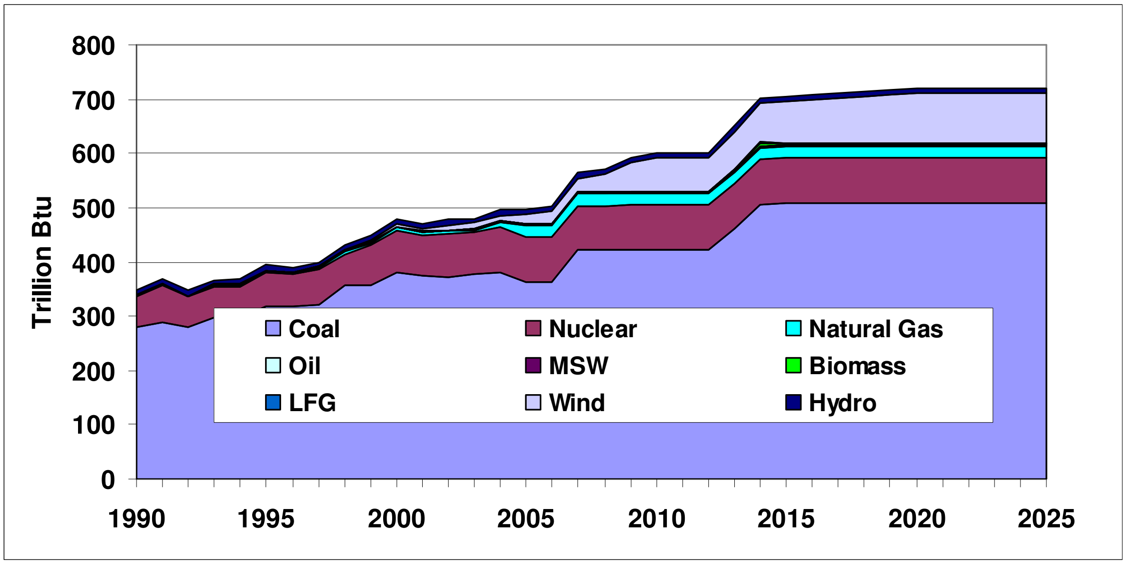
(1) Reference Case:



(2) Sensitivity Analysis Case 1:



(3) Sensitivity Analysis Case 2:



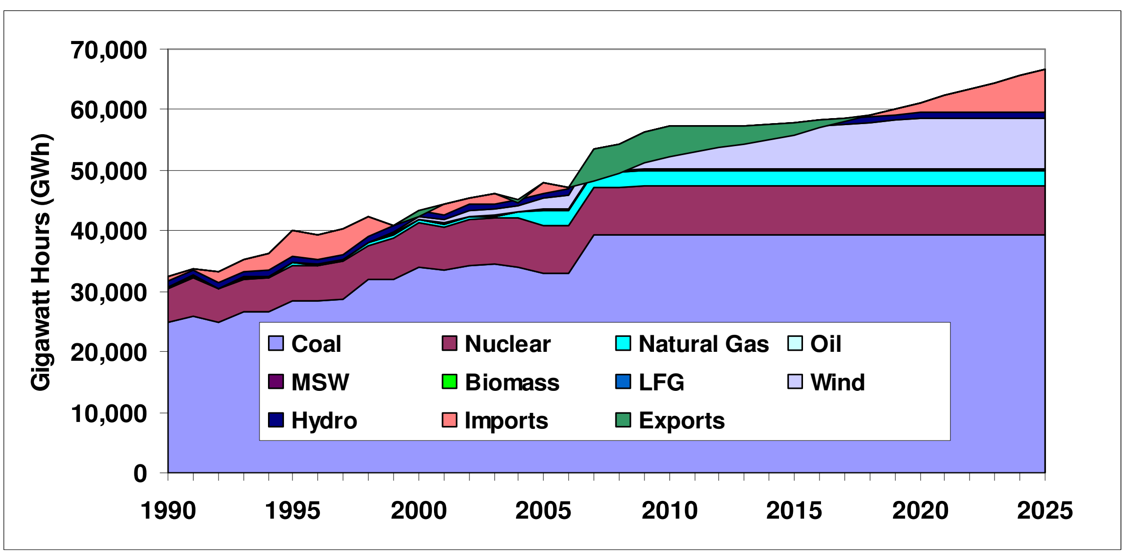
Source: Results shown in this figure are based on the approach described in the text.

Gross Generation

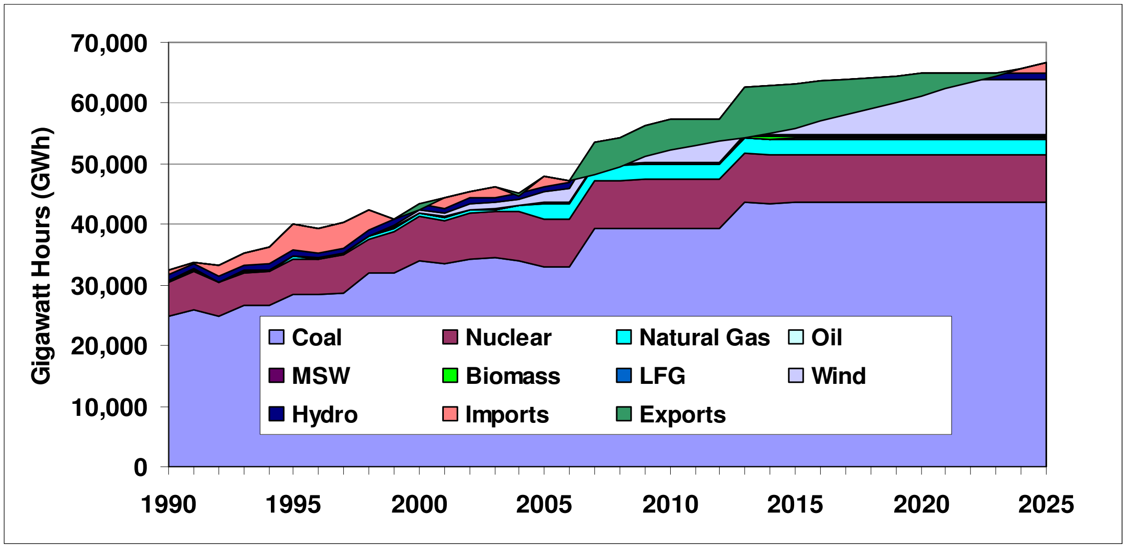
Total gross generation by Iowa power plants is summarized in Figure A3. Gross generation in Iowa is dominated by steam units, which are primarily based on coal fuel.

Figure A3. Gross Generation at Iowa Power Stations

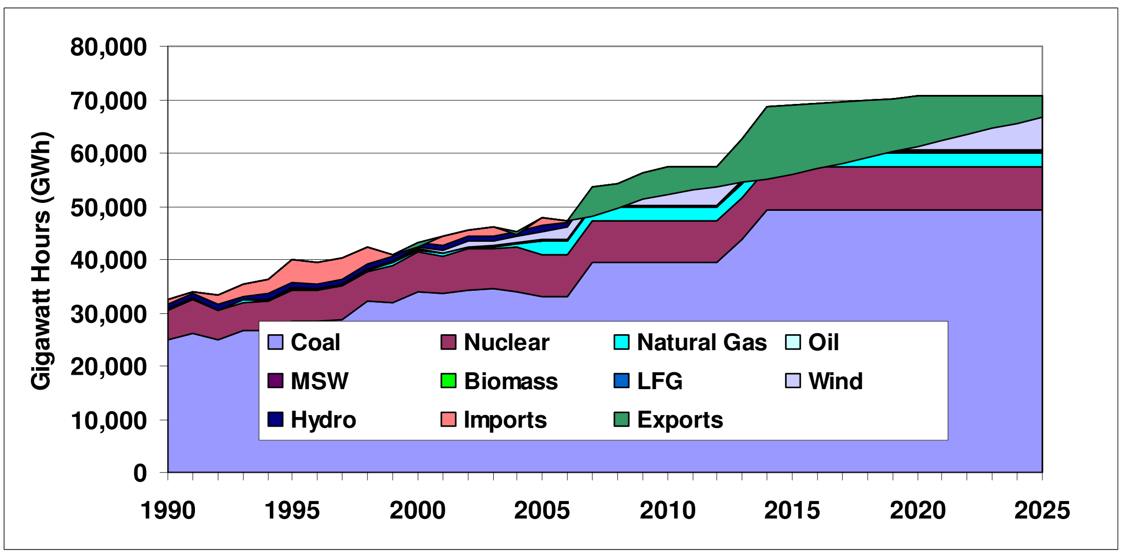
(1) Reference Case:



(2) Sensitivity Analysis Case 1:



(3) Sensitivity Analysis Case 2:



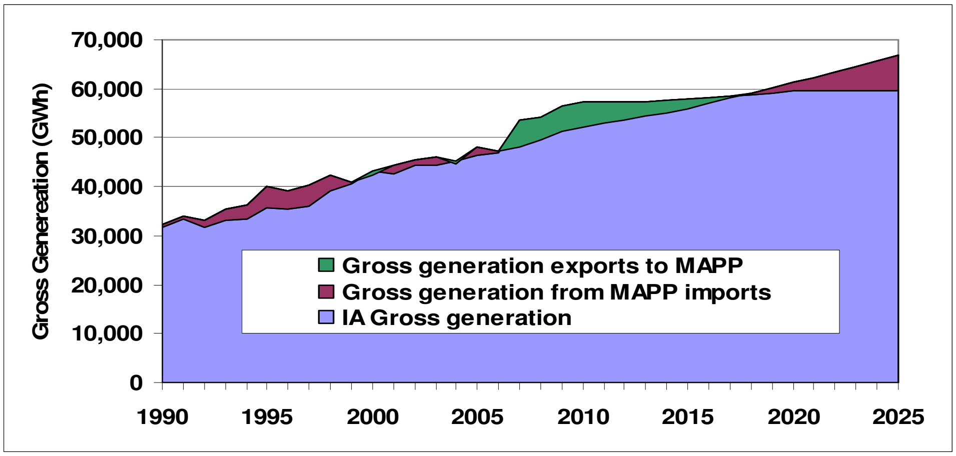
Source: Results shown in this figure are based on the approach described in the text.

Imported (or Exported) Electricity

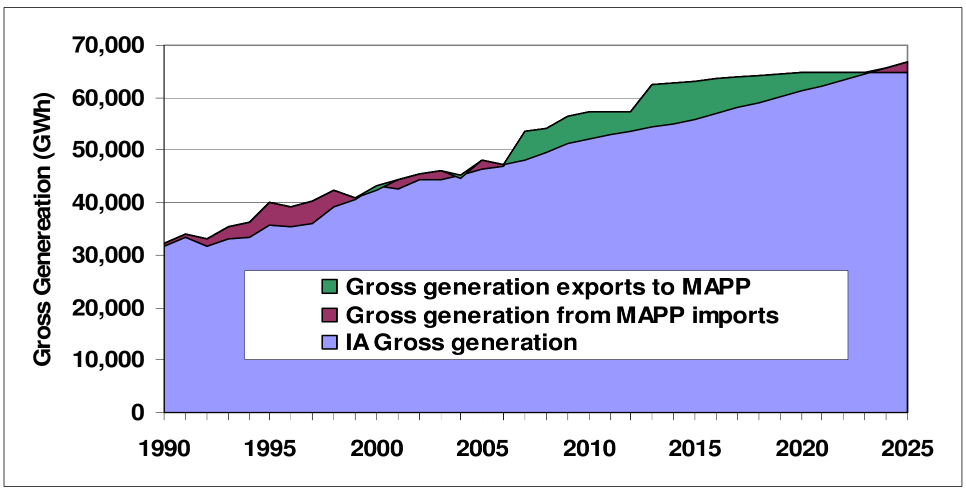
In some historical and forecast years, Iowa is an electricity import state. In those years, to meet annual demand for electricity in Iowa, total gross generation by Iowa power plants needs to be augmented by electricity imports. As indicated earlier, it was assumed that this power is imported from the MAPP region. In other years, Iowa is an electricity export state, when its total gross generation by the in-state power plants exceeds the annual demand for electricity in the state. Figure A4 summarizes the gross generation and the state imports from MAPP region or exports to the MAPP region.

Figure A4. Composition of Gross Generation to Meet Iowa's Electricity Demand

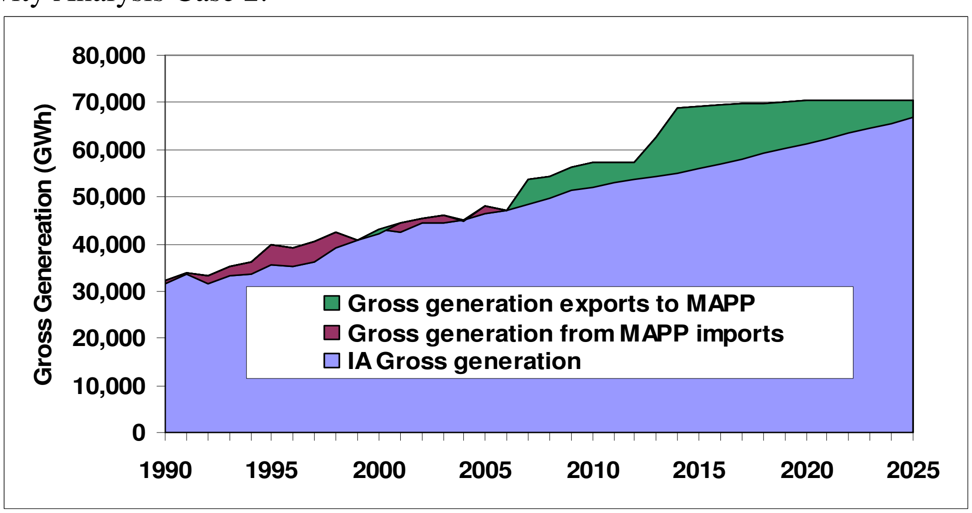
(1) Reference Case:



(2) Sensitivity Analysis Case 1:



(3) Sensitivity Analysis Case 2:



Source: Results shown in this figure are based on the approach described in the text.

Total Gross GHG Emissions

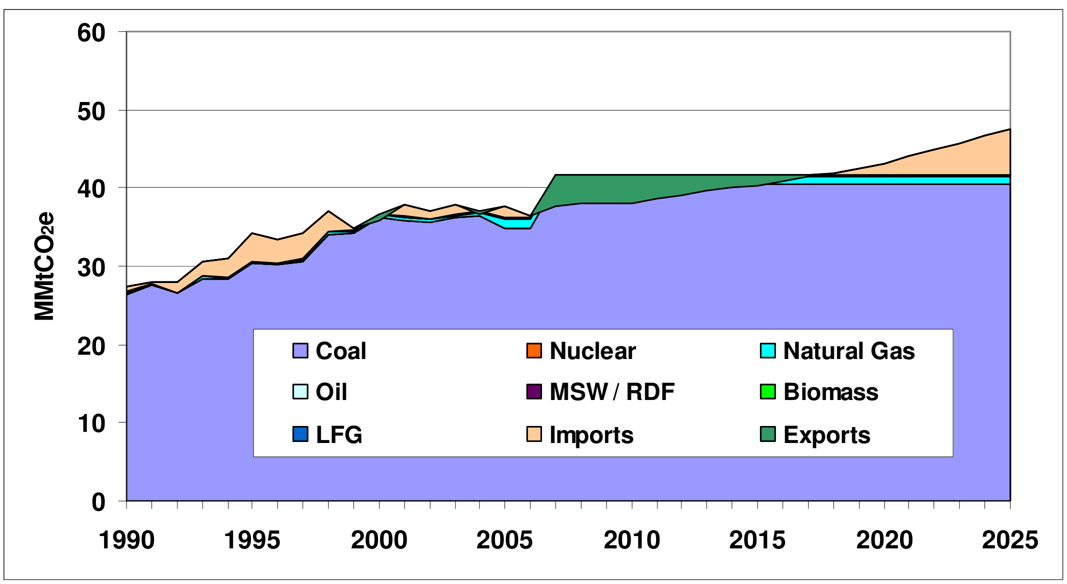
Total emissions associated with generation by Iowa power plants as well as those associated with electricity imports or exports of Iowa are summarized in Figure A5 by fuel type. Figure A6 compares emissions on a production (in-state generation) and consumption (in-state generation plus (or minus) imports (or exports)) basis. Figures A5 and A6 were developed from the emissions data in Tables A5.

On a consumption basis, emissions were about 37.61 $MMtCO_2e$ in 2005 and the projections in 2025 are very similar across the three cases. The 2025 consumption-based emissions are projected to be 47.54 $MMtCO_2e$, 47.00 $MMtCO_2e$, and 47.41 $MMtCO_2e$ for the Reference Case, Sensitivity Analysis Case 1, and Sensitivity Analysis Case 2, respectively. These correspond to an overall increase of about 25% during this 20-year period.

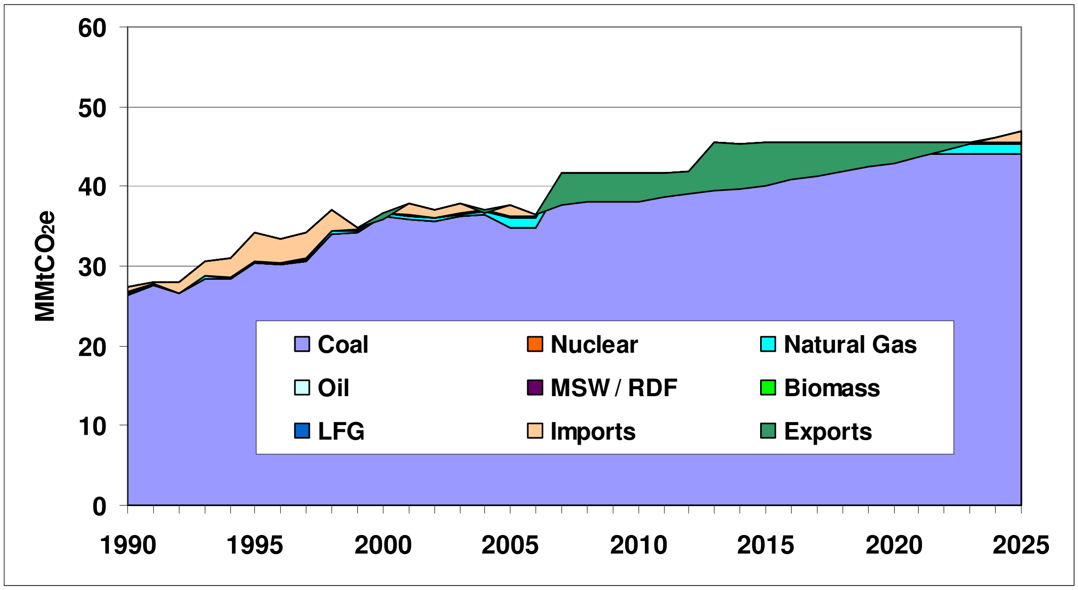
On a production basis, emissions were about 36.27 $MMtCO_2e$ in 2005 and the projections in 2025 vary across the three cases because of the difference in the new in-state generation capacities included in the forecast. The 2025 production-based emissions are projected to be 41.76 MMtCO2e, 45.44 $MMtCO_2e$, and 50.09 $MMtCO_2e$ for the Reference Case, Sensitivity Analysis Case 1, and Sensitivity Analysis Case 2, respectively. These correspond to an overall increase of about 15%, 25%, and 38% during this 20-year period.

Figure A5. Total Gross GHG Emissions Associated with Iowa Electric Demand by Fuel Type ($MMtCO_2e$)

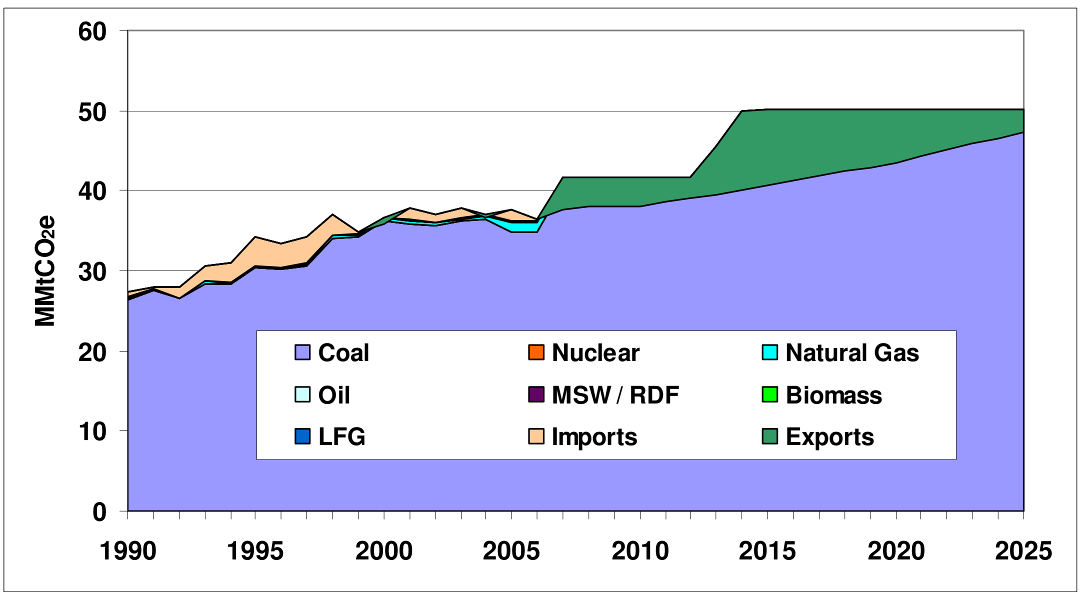
(1) Reference Case:



(2) Sensitivity Analysis Case 1:



(3) Sensitivity Analysis Case 2:



Source: Results shown in this figure are based on the approach described in the text.
LFG = landfill gas, MSW = municipal solid waste, RDF = refuse-derived fuel.

Table A5. Total Gross GHG Emissions Associated with Iowa Electric Demand by Fuel Type ($MMtCO_2e$)

(1) Reference Case:

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Electricity - Consumption Based	**27.4**	**34.3**	**35.8**	**37.6**	**38.0**	**40.3**	**43.1**	**47.5**
Net Imported Electricity	0.68	3.67	-0.87	1.33	-3.74	-1.45	1.38	5.78
Electricity - Production Based	**26.7**	**30.6**	**36.7**	**36.3**	**41.8**	**41.8**	**41.8**	**41.8**
Coal	26.5	30.4	36.3	34.9	40.4	40.4	40.4	40.4
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.17	0.21	0.24	1.15	1.15	1.15	1.15	1.15
Oil	0.05	0.06	0.10	0.15	0.15	0.15	0.15	0.15
MSW	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LFG	0.00	0.00	0.01	0.05	0.05	0.05	0.05	0.05
Wind	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(2) Sensitivity Analysis Case 1:

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Electricity - Consumption Based	**27.4**	**34.3**	**35.8**	**37.6**	**38.0**	**40.2**	**42.9**	**47.0**
Net Imported Electricity	0.68	3.67	-0.87	1.33	-3.74	-5.27	-2.50	1.56
Electricity - Production Based	**26.7**	**30.6**	**36.7**	**36.3**	**41.8**	**45.4**	**45.4**	**45.4**
Coal	26.5	30.4	36.3	34.9	40.4	44.0	44.0	44.0
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.17	0.21	0.24	1.15	1.15	1.18	1.18	1.18
Oil	0.05	0.06	0.10	0.15	0.15	0.15	0.15	0.15
MSW	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Biomass	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
LFG	0.00	0.00	0.01	0.05	0.05	0.05	0.05	0.05
Wind	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(3) Sensitivity Analysis Case 2:

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Electricity - Consumption Based	**27.4**	**34.3**	**35.8**	**37.6**	**38.0**	**40.6**	**43.5**	**47.4**
Net Imported Electricity	0.68	3.67	-0.87	1.33	-3.74	-9.44	-6.56	-2.68
Electricity - Production Based	**26.7**	**30.6**	**36.7**	**36.3**	**41.8**	**50.1**	**50.1**	**50.1**
Coal	26.5	30.4	36.3	34.9	40.4	48.7	48.7	48.7
Nuclear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.17	0.21	0.24	1.15	1.15	1.18	1.18	1.18
Oil	0.05	0.06	0.10	0.15	0.15	0.15	0.15	0.15
MSW	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Biomass	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
LFG	0.00	0.00	0.01	0.05	0.05	0.05	0.05	0.05
Wind	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Results in this table based on the approach described in the text.

Table A4. Total Gross GHG Emissions Associated with Iowa Electric Demand by Plant Type ($MMtCO_2e$)

(1) Reference Case:

Plant Type	1990	1995	2000	2005	2010	2015	2020	2025
Electricity - Consumption Based	**27.4**	**34.3**	**35.8**	**37.6**	**38.0**	**40.3**	**43.1**	**47.5**
Net Imported Electricity	0.68	3.67	-0.87	1.33	-3.74	-1.45	1.38	5.78
Electricity - Production Based	**26.7**	**30.6**	**36.7**	**36.3**	**41.8**	**41.8**	**41.8**	**41.8**
Steam plants	26.6	30.6	36.5	35.0	40.5	40.5	40.5	40.5
Turbines	0.05	0.07	0.11	0.20	0.20	0.20	0.20	0.20
Combined Cycle	0.00	0.00	0.01	0.97	0.97	0.97	0.97	0.97
Engines	0.01	0.01	0.03	0.06	0.06	0.06	0.06	0.06
Renewable	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(2) Sensitivity Analysis Case 1:

Plant Type	1990	1995	2000	2005	2010	2015	2020	2025
Electricity - Consumption Based	**27.4**	**34.3**	**35.8**	**37.6**	**38.0**	**40.2**	**42.9**	**47.0**
Net Imported Electricity	0.68	3.67	-0.87	1.33	-3.74	-5.27	-2.50	1.56
Electricity - Production Based	**26.7**	**30.6**	**36.7**	**36.3**	**41.8**	**45.4**	**45.4**	**45.4**
Steam plants	26.6	30.6	36.5	35.0	40.5	44.2	44.2	44.2
Turbines	0.05	0.07	0.11	0.20	0.20	0.23	0.23	0.23
Combined Cycle	0.00	0.00	0.01	0.97	0.97	0.97	0.97	0.97
Engines	0.01	0.01	0.03	0.06	0.06	0.06	0.06	0.06
Renewable	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(3) Sensitivity Analysis Case 2:

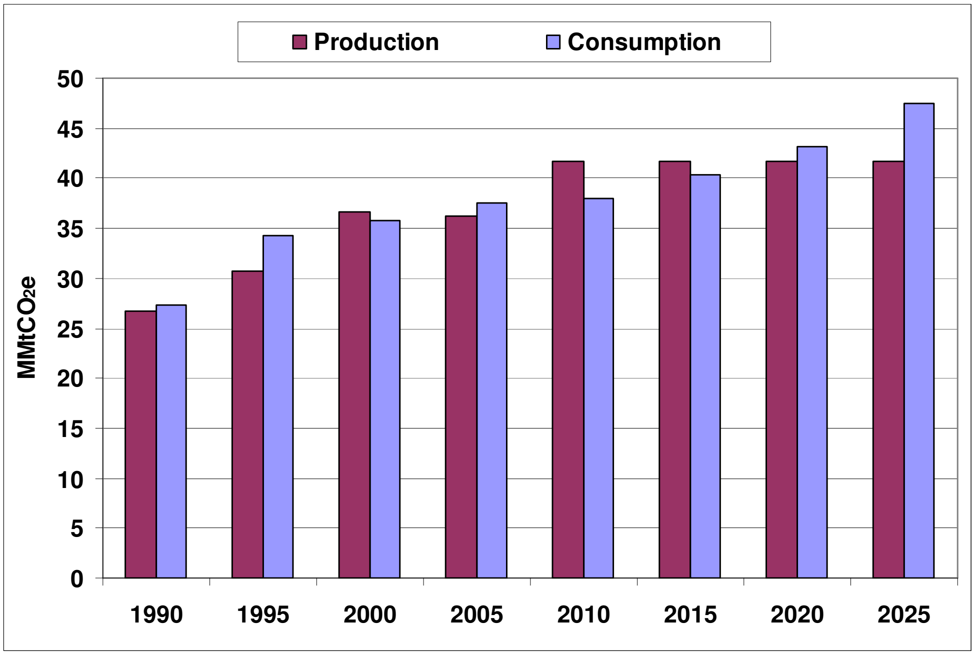
Plant Type	1990	1995	2000	2005	2010	2015	2020	2025
Electricity - Consumption Based	**27.4**	**34.3**	**35.8**	**37.6**	**38.0**	**40.6**	**43.5**	**47.4**
Net Imported Electricity	0.68	3.67	-0.87	1.33	-3.74	-9.44	-6.56	-2.68
Electricity - Production Based	**26.7**	**30.6**	**36.7**	**36.3**	**41.8**	**50.1**	**50.1**	**50.1**
Steam plants	26.6	30.6	36.5	35.0	40.5	48.8	48.8	48.8
Turbines	0.05	0.07	0.11	0.20	0.20	0.23	0.23	0.23
Combined Cycle	0.00	0.00	0.01	0.97	0.97	0.97	0.97	0.97
Engines	0.01	0.01	0.03	0.06	0.06	0.06	0.06	0.06
Renewable	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Results in this table based on the approach described in the text.

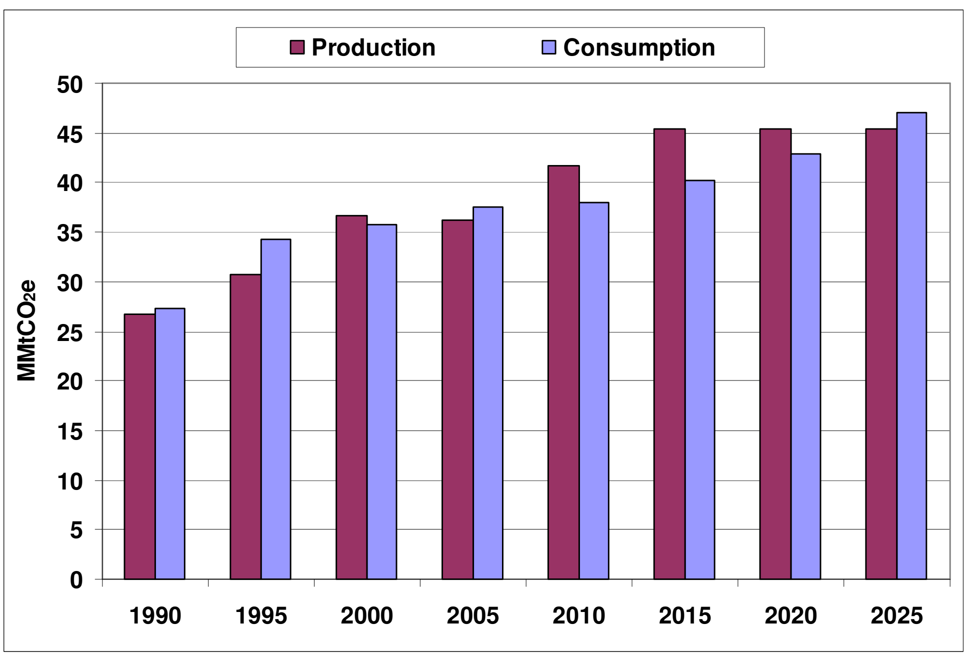
[1] Fuels combusted by steam plants in Iowa include coal, natural gas, distillate (diesel), petroleum coke, landfill gas, municipal solid waste, and nuclear.
[2] Fuels combusted by turbines in Iowa include natural gas, diesel, and waste oils/solvents.
[3] Fuels combusted by combined-cycle plants include natural gas and diesel.
[4] Fuels combusted by internal combustion engines include natural gas, diesel, and landfill gas.
[5] Renewable fuels include wind and hydroelectric.

Figure A6. Electricity Generation Gross GHG Emissions – Production and Consumption Basis (1990-2025)

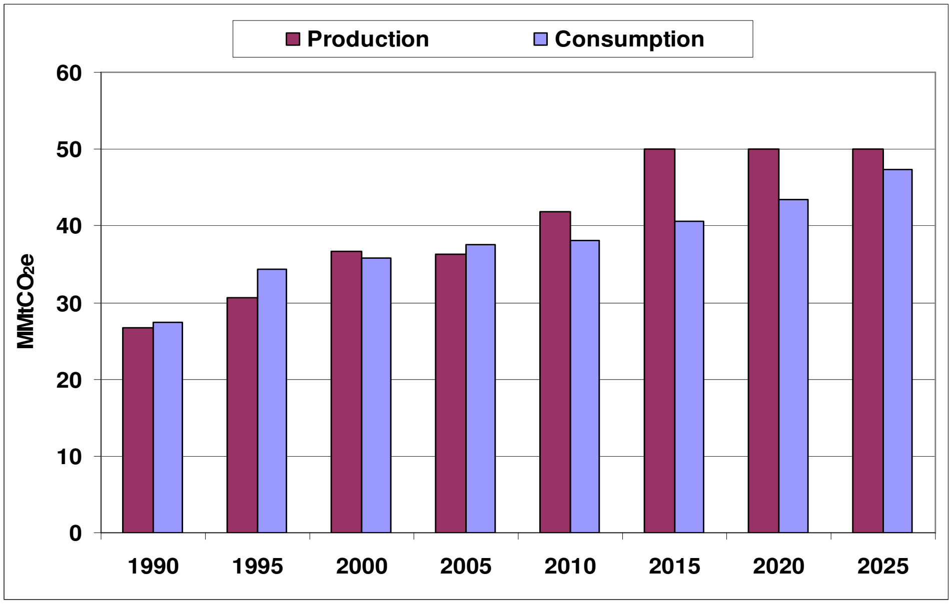
(1) Reference Case:



(2) Sensitivity Analysis Case 1:



(3) Sensitivity Analysis Case 2:



Source: Results shown in this figure are based on the approach described in the text.

Key Uncertainties

Key sources of uncertainty underlying the estimates above are as follows:

- Electricity on-site usage and T&D loss estimates were used to convert gross generation in the forecast to sales to meet the state's demand. In years that the estimated Iowa utility sales to the customers were less than estimates of electricity demand, Iowa will need to import electricity to fulfill electricity demand that cannot be met by in-state generators. In years that the estimated Iowa utility sales were more than estimates of electricity demand, Iowa would export electricity. The on-site usage and T&D loss estimates are taken from the EIA AEO2008 for the MAPP region. Improvements to these estimates (based on input from the state's utilities) could help to get more accurate emissions associated with imported (or exported) electricity.
- For combined heat and power facilities that generate and sell electricity to the power grid, emissions associated with the fuel they burn are included in the commercial and industrial fuel use sector (see Appendix B). The fuel use associated with these facilities is aggregated by fuel and sector and, therefore, cannot be broken out easily so that they can be reported under the electricity supply and use sector. Future work could include an assessment to determine how best to isolate emissions associated with combined heat and power facilities.
- Fuel price changes influence consumption levels and, to the extent that price trends for competing fuels differ, may encourage switching among fuels, and thereby affect emissions estimates. In particular, unanticipated events that affect fuel prices could affect both the supply and demand of the electricity forecast for Iowa, and thus the estimated emissions associated with them.

Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion

Overview

Activities in the RCI[35] sectors produce carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions when fuels are combusted to provide space heating, water heating, process heating, cooking, and other energy end-uses. Carbon dioxide accounts for over 99% of these emissions on a million metric tons (MMt) of CO_2 equivalent (CO_2e) basis in Iowa. In addition, since these sectors consume electricity, one can also attribute emissions associated with electricity generation to these sectors in proportion to their electricity use.[36] Direct use of oil, natural gas, coal, and wood in the RCI sectors accounted for an estimated 24.1 MMtCO_2e of gross greenhouse gas (GHG) emissions in 2005.[37]

Emissions and Reference Case Projections

Emissions from direct fuel use were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for RCI fossil and wood fuel combustion.[38] The default data used in SIT for Iowa are from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data* (SED). The SIT files were updated to include 2004 and 2005 SED information for Iowa for natural gas, petroleum, wood, and coal for each of the RCI sectors.[39]

Note that the EIIP methods for the industrial sector exclude from CO_2 emission estimates the amount of carbon that is stored in products produced from fossil fuels for non-energy uses. For example, the methods account for carbon stored in petrochemical feedstocks, and in liquefied petroleum gases (LPG) and natural gas used as feedstocks by chemical manufacturing plants (i.e., not used as fuel), as well as carbon stored in asphalt and road oil produced from petroleum. The carbon storage assumptions for these products are explained in detail in the EIIP guidance

[35] The industrial sector includes emissions associated with agricultural energy use and natural gas consumed as lease and plant fuel. Emissions associated with pipeline fuel use are included in Appendix E

[36] Emissions associated with the electricity supply sector (presented in Appendix A) have been allocated to each of the RCI sectors for comparison of those emissions to the fuel-consumption-based emissions presented in Appendix B. Note that this comparison is provided for information purposes and that emissions estimated for the electricity supply sector are not double-counted in the total emissions for the state. One could similarly allocate GHG emissions from natural gas T&D, other fuels production, and transport-related GHG sources to the RCI sectors based on their direct use of gas and other fuels, but we have not done so here due to the difficulty of ascribing these emissions to particular end-users. Estimates of emissions associated with the transportation sector are provided in Appendix C, and estimates of emissions associated with natural gas T&D are provided in Appendix E.

[37] Emissions estimates from wood combustion include only N_2O and CH_4. Carbon dioxide emissions from biomass combustion are assumed to be "net zero", consistent with US EPA and Intergovernmental Panel on Climate Change (IPCC) methodologies, and any net loss of carbon stocks due to biomass fuel use should be accounted for in the land use and forestry analysis.

[38] GHG emissions were calculated using SIT, with reference to *EIIP, Volume VIII*: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004, and Chapter 2 "Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion", August 2004.

[39] EIA *State Energy Consumption, Price, and Expenditure Estimates (SEDS),* (http://www.eia.doe.gov/emeu/states/_seds_updates.html).

document.[40] The fossil fuel types for which the EIIP methods are applied in the SIT software to account for carbon storage include the following categories: asphalt and road oil, coking coal, distillate fuel, feedstocks (naphtha with a boiling range of less than 401 degrees Fahrenheit), feedstocks (other oils with boiling ranges greater than 401 degrees Fahrenheit), LPG, lubricants, miscellaneous petroleum products, natural gas, pentanes plus,[41] petroleum coke, residual fuel, still gas, and waxes. Data on annual consumption of the fuels in these categories as chemical industry feedstocks were obtained from the EIA SED.

Table B1 shows historical and projected growth rates for electricity sales by sector. The 1990-2005 electricity sales by RCI sector date were obtained from EIA.[42] For 2005 to 2025, the total annual growth rate in the electricity sales was estimated from utility forecasts as described in Appendix A. The growth rates for each sector were estimated assuming that the proportion of electricity consumed by each sector in each year is the same as the regional proportions for the Mid-Continent Area Power Pool as reported by EIA's *Annual Energy Outlook 2008* (AEO2008).[43] The proportion of each RCI sector's sales to total sales was used to allocate emissions associated with the electricity supply sector to each of the RCI sectors.

Table B2 shows historical and projected growth rates for energy use by sector and fuel type. Reference case emissions from direct fuel combustion were estimated based on fuel consumption forecasts from EIA's *Annual Energy Outlook 2007* (AEO2007).[44] For the RCI sectors, annual growth rates for natural gas, oil, wood, and coal were calculated from the AEO2007 regional forecast that EIA prepared for the West North Central modeling region. For the residential sector, the AEO2007 annual growth rate in fuel consumption from 2005 through 2025 was normalized using the AEO2007 population forecast and then weighted using Iowa's population forecast over this period. Iowa's rate of population growth is expected to average about 0.06% annually between 2005 and 2025.[45] Growth rates for the commercial and industrial sectors were based on the AEO2007 West North Central regional estimates of growth which reflect expected responses of the economy — as simulated by the EIA's National Energy Modeling System — to changing fuel and electricity prices and changing technologies, as well as to structural changes within each sector (such as shifts in subsectoral shares and in energy use patterns).

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[40] EIIP, Volume VIII: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004.

[41] A mixture of hydrocarbons, mostly pentanes and heavier fractions, extracted from natural gas.

[42] Iowa Electricity Profile, Energy Information Administration, http://www.eia.doe.gov/cneaf/electricity/st_profiles/iowa.html.

[43] EIA AEO2008 with Projections to 2030 (http://www.eia.doe.gov/oiaf/aeo/).

[44] EIA AEO2007 with Projections to 2030 (http://www.eia.doe.gov/oiaf/archive.html#aeo).

[45] Decennial Population and Population Estimates for Iowa: 1990 – 2007 (http://data.iowadatacenter.org/datatables/State/stpopest19002007.xls) and Interim Projections: Total Population and Numeric and Percent Change for the U.S. and States: 2000 to 2030, US Census Bureau, (http://data.iowadatacenter.org/browse/projections.html).

Table B1. Electricity Sales Annual Growth Rates, Historical and Projected

Sector	1990-2005*	2005-2025**
Residential	1.7%	1.7%
Commercial	2.7%	2.7%
Industrial	3.1%	1.5%
Total	**2.5%**	**1.9%**

* 1990-2005 compound annual growth rates calculated from Iowa electricity sales by year from EIA state electricity profiles (Table 8), http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html.
** Total growth rate estimated from forecasts for utility companies in Iowa (MidAmerican, Rural Electric, Municipal Utilities, and Interstate) provided by the individual utilities. Sector growth rates estimated by applying yearly sector to total proportions from AEO2008 projections for Mid-Continent Area Power Pool.

Table B2. Historical and Projected Average Annual Growth in Energy Use in Iowa, by Sector and Fuel, 1990-2025

	1990-2005[a]	2005-2010[b]	2010-2015[b]	2015-2020[b]	2020-2025[b]
Residential					
natural gas	-0.4%	0.7%	0.2%	-0.2%	-0.5%
petroleum	0.6%	0.4%	-0.5%	-0.7%	-0.9%
wood	-1.8%	1.2%	-0.8%	-0.3%	-0.6%
coal	-4.6%	-3.5%	-0.9%	-1.0%	-1.1%
Commercial					
natural gas	0.2%	2.6%	3.2%	2.4%	0.8%
petroleum	2.1%	2.0%	2.5%	1.7%	0.4%
wood	0.3%	1.4%	1.4%	1.4%	0.0%
coal	1.5%	1.2%	1.4%	1.4%	0.0%
Industrial					
natural gas	0.3%	8.4%	1.2%	1.3%	1.1%
petroleum	2.4%	-1.4%	0.7%	0.7%	-0.2%
wood	-3.5%	24%	2.1%	1.9%	1.4%
coal	0.7%	0.7%	0.4%	0.6%	0.0%

[a] Compound annual growth rates calculated from EIA SED historical consumption by sector and fuel type for Iowa. Petroleum includes distillate fuel, kerosene, and liquefied petroleum gases for all sectors plus residual oil for the commercial and industrial sectors.
[b] Figures for growth periods starting after 2005 are calculated from AEO2007 projections for EIA's West North Central region. Regional growth rates for the residential sector are adjusted for Iowa's projected population.

Results

Figures B1, B2, and B3 show historical and projected emissions for the RCI sectors in Iowa from 1990 through 2025. These figures show the emissions associated with the direct consumption of fossil fuels and, for comparison purposes, show the share of emissions associated with the generation of electricity consumed by each sector. The residential sector's share of total RCI emissions from direct fuel use and electricity was 30% in 1990, decreased to 27% in 2005, and is projected to decline to 25% in 2025. The commercial sector's share of total RCI emissions from direct fuel use and electricity use was 21% in 1990, increased slightly to 22% in 2005, and is projected to increase to 26% by 2025. The industrial sector's share of total RCI emissions from direct fuel use and electricity use was 49% in 1990, increased to 51% in 2005, and is projected to decrease slightly to 50% in 2025. Emissions associated with the generation of electricity to meet RCI demand accounts for about 70% of the emissions for the residential sector, 72% of the emissions for the commercial sector, and 47% of the emissions for the industrial sector, on average, over the 1990 to 2025 time period. From 1990 to 2025, natural gas consumption is the next highest source of emissions for the residential and commercial sectors, accounting, on average, for about 22% and 20% of total emissions, respectively. For the industrial sector, emissions associated with the combustion of natural gas, coal, and petroleum account for about 20%, 18%, and 15% respectively, on average, from 1990 to 2025.

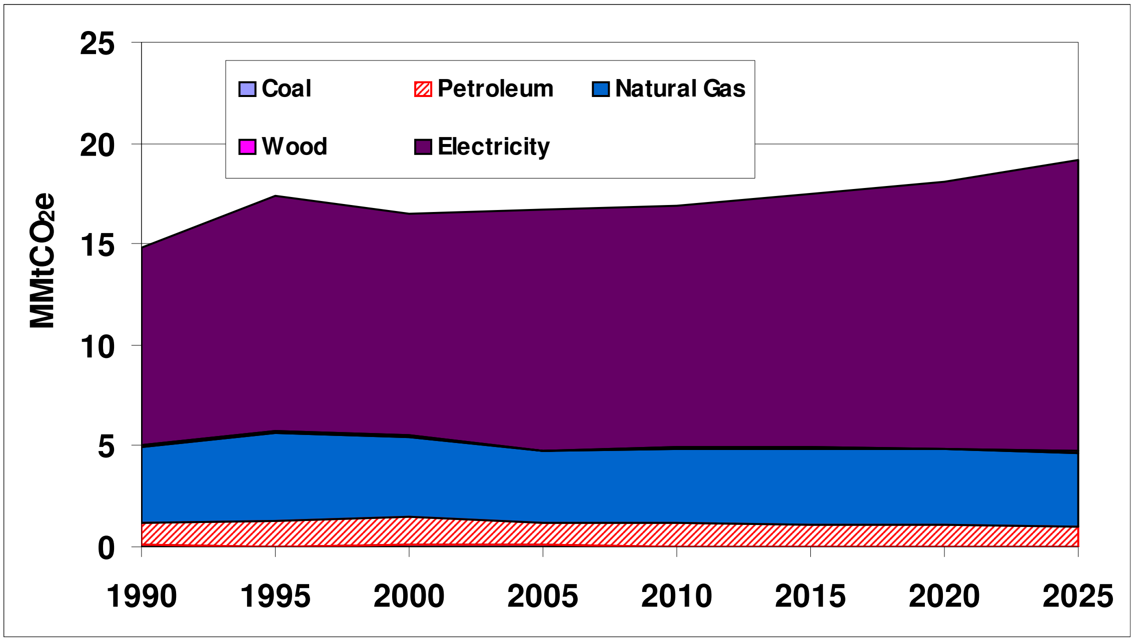
Residential Sector

Figure B1 presents the emission inventory and reference case projections for the residential sector. Figure B1 was developed from the emissions data in Table B3a. Table B3b shows the relative contributions of emissions associated with each fuel type to total residential sector emissions.

For the residential sector, emissions from electricity and direct fossil fuel use in 1990 were 14.8 $MMtCO_2e$, and are estimated to increase to 19.2 $MMtCO_2e$ by 2025. Emissions associated with the generation of electricity to meet residential energy consumption demand accounted for about 66% of total residential emissions in 1990, and are estimated to increase to 75% of total residential emissions by 2025. In 1990, natural gas consumption accounted for about 26% of total residential emissions, and is estimated to account for about 19% of total residential emissions by 2025. Residential sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 1.2 $MMtCO_2e$ combined, and accounted for about 8% of total residential emissions. By 2025, emissions associated with the consumption of these three fuels are estimated to decrease slightly to 1.1 $MMtCO_2e$, accounting for 6% of total residential sector emissions by that year.

For the 20-year period from 2005 to 2025, residential-sector GHG emissions associated with the use of electricity and natural gas are expected to increase at average annual rates of about 1.0% and 0.1% respectively. Emissions associated with the use of coal, petroleum, and wood are expected to decline annually by about -1.6%, -0.4%, and –0.1%, respectively. Total GHG emissions for this sector increase by an average of about 0.7% annually over the 20-year period.

Figure B1. Residential Sector GHG Emissions from Fuel Consumption



Source: Calculations based on approach described in text.
Note: Emissions associated with coal and wood combustion are too small to be seen on this graph.

Table B3a. Residential Sector Emissions Inventory and Reference Case Projections (MMtCO_2e)

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	0.12	0.03	0.07	0.06	0.05	0.05	0.04	0.04
Petroleum	1.04	1.26	1.43	1.08	1.10	1.08	1.04	0.99
Natural Gas	3.82	4.39	3.94	3.60	3.72	3.76	3.73	3.64
Wood	0.05	0.04	0.03	0.04	0.04	0.04	0.04	0.04
Electricity Consumption	9.77	11.64	11.02	11.93	11.95	12.54	13.28	14.47
Total	14.80	17.36	16.51	16.71	16.87	17.46	18.13	19.18

Source: Calculations based on approach described in text.

Table B3b. Residential Sector Proportions of Total Emissions by Fuel Type

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	0.8%	0.2%	0.5%	0.3%	0.3%	0.3%	0.2%	0.2%
Petroleum	7.0%	7.2%	8.7%	6.5%	6.5%	6.2%	5.7%	5.2%
Natural Gas	25.8%	25.3%	23.9%	21.5%	22.1%	21.5%	20.6%	19.0%
Wood	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Electricity Consumption	66.1%	67.1%	66.8%	71.4%	70.9%	71.8%	73.3%	75.4%

Source: Calculations based on approach described in text.
Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B3a.

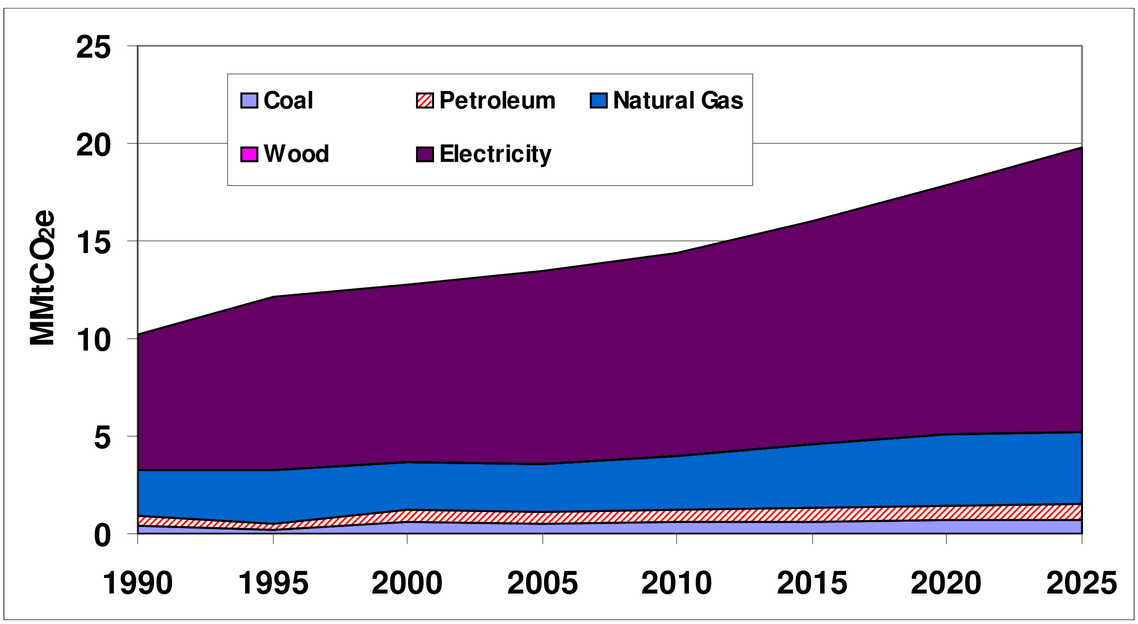
Commercial Sector

Figure B2 presents the emission inventory and reference case projections for the commercial sector. Figure B2 was developed from the emissions data in Table B4a. Table B4b show the relative contributions of emissions associated with each fuel type to total commercial sector emissions.

For the commercial sector, emissions from electricity and direct fossil fuel use in 1990 were about 10.2 $MMtCO_2e$, and are estimated to increase to about 19.8 $MMtCO_2e$ by 2025. Emissions associated with the generation of electricity to meet commercial energy consumption demand accounted for about 68% of total commercial emissions in 1990, and are estimated to increase to 74% of total commercial emissions by 2025. In 1990, natural gas consumption accounted for about 23% of total commercial emissions and is estimated to account for about 19% of total commercial emissions by 2025. Commercial-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 0.9 $MMtCO_2e$ combined, and accounted for about 9% of total commercial emissions. By 2025, emissions associated with the consumption of these three fuels are estimated to be 1.5 $MMtCO_2e$ and to account for 8% of total commercial sector emissions.

For the 20-year period 2005 to 2025, commercial-sector GHG emissions associated with the use of electricity, natural gas, and petroleum are expected to increase at average annual rates of about 1.9%, 2.2%, and 1.6%, respectively. Emissions associated with the use of both coal and wood are expected to increase at average annual rates of about 1.0%. Total GHG emissions for this sector increase by an average of about 2.0% annually over the 20-year period.

Figure B2. Commercial Sector GHG Emissions from Fuel Consumption



Source: Calculations based on approach described in text.
Note: Emissions associated with coal and wood combustion are too small to be seen on this graph.

Table B4a. Commercial Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	0.44	0.18	0.57	0.55	0.58	0.62	0.67	0.67
Petroleum	0.44	0.35	0.62	0.59	0.65	0.74	0.80	0.82
Natural Gas	2.35	2.69	2.44	2.41	2.74	3.20	3.60	3.76
Wood	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Electricity Consumption	7.00	8.89	9.10	9.91	10.42	11.48	12.75	14.58
Total	10.24	12.12	12.73	13.47	14.40	16.05	17.83	19.83

Source: Calculations based on approach described in text.

Table B4b. Commercial Sector Proportions of Total Emissions by Fuel Type

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	4.3%	1.5%	4.4%	4.1%	4.0%	3.9%	3.8%	3.4%
Petroleum	4.3%	2.9%	4.9%	4.4%	4.5%	4.6%	4.5%	4.1%
Natural Gas	23.0%	22.2%	19.1%	17.9%	19.0%	20.0%	20.2%	19.0%
Wood	0.1%	0.05%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%
Electricity Consumption	68.4%	73.4%	71.5%	73.6%	72.4%	71.5%	71.5%	73.5%

Source: Calculations based on approach described in text.
Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B4a.

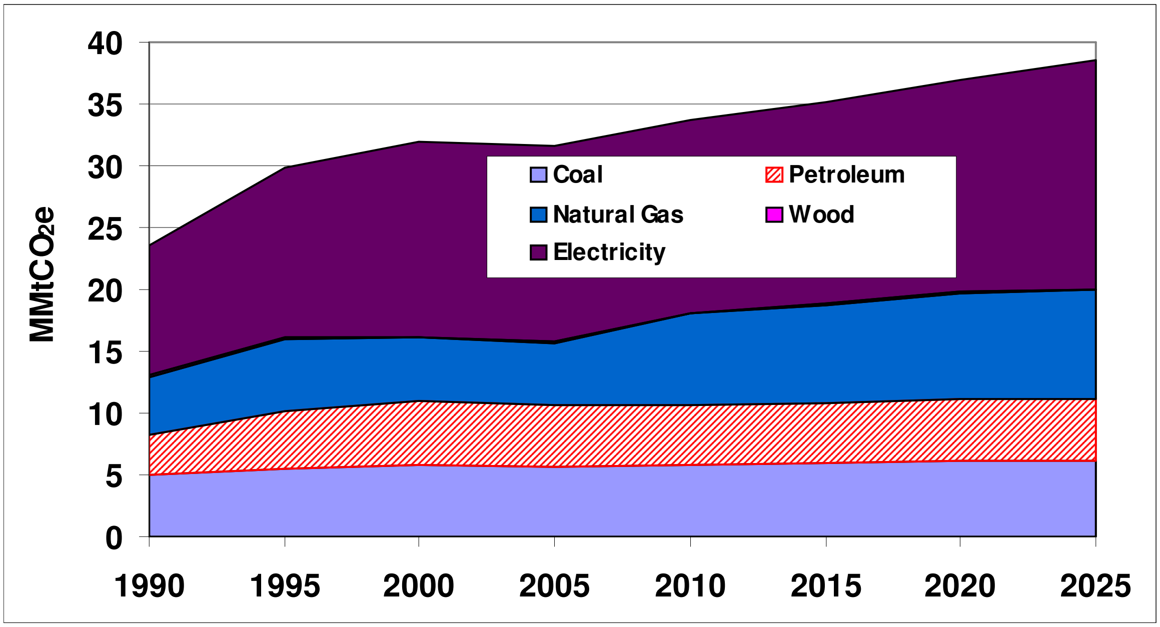
Industrial Sector

Figure B3 presents the emission inventory and reference case projections for the industrial sector. Figure B3 was developed from the emissions data in Table B5a. Table B5b show the relative contributions of emissions associated with each fuel type to total industrial sector emissions.

For the industrial sector, emissions from electricity and direct fuel use in 1990 were 23.6 $MMtCO_2e$ and are estimated to increase to about 38.7 $MMtCO_2e$ by 2025. Emissions associated with the generation of electricity to meet industrial energy consumption demand accounted for about 45% of total industrial emissions in 1990, and are estimated to be about 48% of total industrial emissions by 2025. In 1990, natural gas consumption accounted for about 20% of total industrial emissions, and is estimated to account for about 23% of total industrial emissions by 2025. Coal consumption accounted for about 21% of total industrial emissions in 1990, and is estimated to decline to about 16% of total industrial emissions by 2025. In 1990, petroleum consumption accounted for about 14% of total industrial emissions, and is estimated to decrease slightly to 13% of total industrial emissions in 2025. Emissions associated with wood consumption by the industrial sector are about 0.3% of total emissions in 1990 and are expected to increase slightly to 0.4% by 2025.

For the 20-year period 2005 to 2025, industrial-sector GHG emissions associated with the use of electricity, natural gas, wood, and coal are expected to increase at average annual rates of about 0.8%, 3.0%, 6.9%, and 0.4% respectively. Emissions associated with the use of petroleum are expected to decrease annually by about -0.1%. Total GHG emissions for the industrial sector increase by an average of about 1.0% annually over the 20-year period.

Figure B3. Industrial Sector GHG Emissions from Fuel Consumption



Source: Calculations based on approach described in text.
Note: Emissions associated with wood combustion are too small to be seen on this graph.

Table B5a. Industrial Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	4.98	5.50	5.78	5.61	5.82	5.93	6.11	6.12
Petroleum	3.22	4.64	5.20	5.11	4.75	4.93	5.09	5.05
Natural Gas	4.73	5.90	5.19	4.97	7.44	7.90	8.43	8.91
Wood	0.07	0.06	0.04	0.04	0.12	0.13	0.15	0.16
Electricity Consumption	10.59	13.78	15.69	15.75	15.65	16.29	17.11	18.49
Total	23.59	29.87	31.90	31.49	33.77	35.19	36.89	38.73

Source: Calculations based on approach described in text.

Table B5b. Industrial Sector Proportions of Total Emissions by Fuel Type

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	21.1%	18.4%	18.1%	17.8%	17.2%	16.8%	16.6%	15.8%
Petroleum	13.7%	15.5%	16.3%	16.2%	14.1%	14.0%	13.8%	13.0%
Natural Gas	20.0%	19.8%	16.3%	15.8%	22.0%	22.5%	22.9%	23.0%
Wood	0.3%	0.2%	0.1%	0.1%	0.4%	0.4%	0.4%	0.4%
Electricity Consumption	44.9%	46.1%	49.2%	50.0%	46.3%	46.3%	46.4%	47.8%

Source: Calculations based on approach described in text.
Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B5a.

Key Uncertainties

Key sources of uncertainty underlying the estimates above are as follows:

- Population and economic growth are the principal drivers for electricity and fuel use. The reference case projections are based on regional fuel consumption projections for EIA's West North Central modeling region. Consequently, there are significant uncertainties associated with the projections. Future work should attempt to base projections of GHG emissions on fuel consumption estimates specific to Iowa to the extent that such data become available.
- The AEO2007 projections assume no large long-term changes in relative fuel and electricity prices, relative to current price levels and to US DOE projections for fuel prices. Price changes would influence consumption levels and, to the extent that price trends for competing fuels differ, may encourage switching among fuels, and thereby affect emissions estimates.

Appendix C. Transportation Energy Use

Overview

Transportation is one of the largest greenhouse gas (GHG) source sectors in Iowa. The transportation sector includes light- and heavy-duty (onroad) vehicles, aircraft, rail engines, and marine engines. Carbon dioxide (CO_2) accounts for about 97% of the transportation sector's GHG emissions in 1990 and is projected to increase to about 98% of transportation GHG emissions by 2025. Most of the remaining GHG emissions from the transportation sector are due to nitrous oxide (N_2O) emissions from gasoline engines.

Historical Emissions and Reference Case Projections

Historical GHG emissions were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[46,47] For onroad vehicles, the CO_2 emission factors are in units of pounds (lb) per million British thermal unit (MMBtu) and the methane (CH_4) and N_2O emission factors are both in units of grams per vehicle mile traveled (VMT). Key assumptions in this analysis are listed in Table C1. The default fuel consumption data within SIT were used to estimate emissions, with the most recently available fuel consumption data (2004 and 2005) from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data* (SED) added.[48] The default VMT data in SIT were replaced with annual VMT from the Iowa Department of Transportation (DOT).[49] Default data from the Federal Highway Administration (FHWA)[50] were used to allocate the state-level VMT to vehicle types.

Onroad Vehicles

Iowa DOT provided statewide VMT data for the years from 1990 through 2006.[51] These data were used to replace the default SIT VMT data for 1990 through 2005 for calculating CH_4 and N_2O emissions. These VMT data were distributed by vehicle type in the same proportion as the default VMT data in the SIT. The default EIA SED data were used to calculate the CO_2 emissions from onroad vehicles for the historical years. Gasoline consumption estimates for 1990-2005 were adjusted by subtracting ethanol consumption, per the methodology used in SIT. The historical EIA ethanol consumption data show that use of ethanol in Iowa increased from 2.0% of the gasoline consumption on a Btu basis in 1990 to 5.6% in 2005. For the reference case projections, ethanol consumption was assumed to remain at the 2005 level.

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[46] CO_2 emissions were calculated using SIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter. 1. "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004.
[47] CH_4 and N_2O emissions were calculated using SIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter. 3. "Methods for Estimating Methane and Nitrous Oxide Emissions from Mobile Combustion", August 2004.
[48] Energy Information Administration, State Energy Consumption, Price, and Expenditure Estimates (SED), http://www.eia.doe.gov/emeu/states/_seds.html
[49] Iowa historical VMT data provided by Donald Howe, Iowa Department of Transportation.
[50] Highway Statistics, Federal Highway Administration, http://www.fhwa.dot.gov/policy/ohpi/hss/index.htm.
[51] Iowa historical VMT data provided by Donald Howe, Iowa Department of Transportation.

Table C1. Key Assumptions and Methods for the Transportation Inventory and Projections

Vehicle Type and Pollutants	Methods
Onroad gasoline, diesel, natural gas, and liquefied petroleum gas (LPG) vehicles – CO_2	**Inventory (1990-2005)** US EPA SIT and fuel consumption from EIA SED **Reference Case Projections (2005-2025)** Gasoline and diesel fuel use projected with VMT projections based on 1990-2005 historical trends adjusted by fuel efficiency improvement projections from EPA. Other onroad fuels projected using West North Central Region fuel consumption projections from EIA AEO2007 adjusted using state-to-regional ratio of population growth.
Onroad gasoline and diesel vehicles – CH_4 and N_2O	**Inventory (1990-2005)** State total VMT replaced with VMT provided by Iowa DNR, VMT allocated by vehicle type using default VMT by vehicle type data in SIT. **Reference Case Projections (2006-2020)** State total VMT projections were based on 1990-2005 historical trends and allocated to vehicle types using vehicle specific growth rates from AEO2007.
Non-highway fuel consumption (jet aircraft, gasoline-fueled piston aircraft, boats, locomotives) – CO_2, CH_4 and N_2O	**Inventory (1990-2005)** US EPA SIT and fuel consumption from EIA SED. **Reference Case Projections (2006-2020)** Aircraft projected using aircraft operations projections from provided by Iowa DOT. No growth assumed for rail diesel. Marine gasoline projected based on historical data.

Projections of state VMT to 2025 were not available from Iowa DOT or Iowa Department of Natural Resources (DNR); therefore, total annual VMT was projected based on a linear regression of the 1990 through 2005 historical data. Forecasting the total annual VMT based on the 1990-2005 historical data yields an average annual growth rate of 1.8% for 2005-2025. The resulting total annual VMT data for 2006-2025 were then allocated by vehicle type based on national VMT forecasts by vehicle type reported in EIA's *Annual Energy Outlook 2007* (AEO2007).[52] The AEO2007 data were incorporated because they indicate significantly different VMT growth rates for certain vehicle types (e.g., 27% growth between 2005 and 2025 in light-duty gasoline vehicle VMT versus 61% growth in heavy-duty diesel truck VMT over this period). The AEO2007 vehicle type-based national growth rates were applied to the 2005 Iowa estimates of VMT by vehicle type. These VMT data were then proportionally adjusted to total to the projected statewide VMT totals for each year. The resulting vehicle-type VMT estimates and compound annual average growth rates are displayed in Tables C2 and C3, respectively. These

[52] US Department of Energy, Energy Information Administration, *Annual Energy Outlook 2007 with Projections to 2030,* DOE/EIA-0383(2007), February 2007, available at http://www.eia.doe.gov/oiaf/aeo/index.html.

VMT growth rates were used to forecast the CH_4 and N_2O emissions from onroad gasoline and diesel vehicles. These VMT growth rates were also applied to natural gas vehicles.

For forecasting CO_2 emissions, growth in fuel consumption is needed. Onroad gasoline and diesel fuel consumption were forecasted by developing a set of growth factors that adjusted the VMT projections shown in Table C2 to account for improvements in vehicle fuel efficiency. Projected vehicle fuel efficiency data were obtained from EPA. The resulting onroad fuel consumption growth rates are shown in Table C4. Growth rates for projecting CO_2 emissions from natural gas and LPG vehicles were calculated by allocating the AEO2007 consumption of these fuels in the West North Central region and allocating this to Iowa based on the ratio of the State's projected population to the region's projected population. Growth rates for projecting CO_2 emissions from lubricants consumption were calculated based on total VMT growth.

Table C2. Iowa Projected Vehicle Miles Traveled Estimates (million miles)

Vehicle Type	2005	2010	2015	2020	2025
Heavy-Duty Diesel Vehicle	3,634	4,376	5,028	5,649	6,308
Heavy -Duty Gasoline Vehicle	537	529	545	579	634
Light-Duty Diesel Truck	299	379	489	648	904
Light-Duty Diesel Vehicle	90	114	147	195	272
Light-Duty Gasoline Truck	9,932	10,881	11,840	12,781	13,653
Light-Duty Gasoline Vehicle	16,842	18,452	20,078	21,672	23,152
Motorcycle	235	257	280	302	323
Total	31,569	34,988	38,408	41,827	45,247

Table C3. Iowa Vehicle Miles Traveled Compound Annual Growth Rates

Vehicle Type	2005-2010	2010-2015	2015-2020	2020-2025
Heavy-Duty Diesel Vehicle	3.8%	2.8%	2.4%	2.2%
Heavy-Duty Gasoline Vehicle	-0.3%	0.6%	1.2%	1.8%
Light-Duty Diesel Truck	4.9%	5.2%	5.8%	6.9%
Light-Duty Diesel Vehicle	4.9%	5.2%	5.8%	6.9%
Light-Duty Gasoline Truck	1.8%	1.7%	1.5%	1.3%
Light-Duty Gasoline Vehicle	1.8%	1.7%	1.5%	1.3%
Motorcycle	1.8%	1.7%	1.5%	1.3%

Table C4. Iowa Onroad Fuel Consumption Compound Annual Growth Rates

Fuel Growth Factors	2005-2010	2010-2015	2015-2020	2020-2025
Onroad gasoline	1.5%	1.5%	1.5%	1.3%
Onroad diesel	3.5%	2.9%	2.5%	2.5%
Natural Gas	15.4%	5.9%	2.7%	2.3%
LPG	5.0%	1.8%	1.3%	1.2%

Aviation

For the aircraft sector, emission estimates for 1990 to 2005 are based on SIT methods and fuel consumption from EIA. Emissions were projected from 2006 to 2025 using general aviation and commercial aircraft operations provided by Iowa DOT,[53] military operations projections from the Federal Aviation Administration's (FAA) Terminal Area Forecast System,[54] and national aircraft fuel efficiency forecasts. To estimate changes in jet fuel consumption, aircraft operations from air carrier, air taxi/commuter, and military aircraft were first summed for each year of interest. The post-2005 estimates were adjusted to reflect the projected increase in national aircraft fuel efficiency (indicated by increased number of seat miles per gallon), as reported in AEO2007. Because AEO2007 does not estimate fuel efficiency changes for general aviation aircraft, forecast changes in aviation gasoline consumption were based solely on the projected number of general aviation aircraft operations in Iowa, which was obtained from the Iowa DOT source noted above. The resulting compound annual average growth rates are displayed in Table C5.

Table C5. Iowa Aviation Fuels Compound Annual Growth Rates

Fuel	2005-2010	2010-2015	2015-2020	2020-2025
Aviation Gasoline	2.4%	1.1%	0.6%	0.6%
Jet Fuel	1.2%	-0.4%	-1.4%	-1.5%

Rail and Marine Vehicles

For the rail and recreational marine sectors, 1990-2005 estimates are based on SIT methods and fuel consumption from EIA. Marine gasoline consumption was projected to 2025 based on a linear regression of the 1990 through 2005 historical data. The historical data for rail shows no significant positive or negative trend; therefore, no growth was assumed for this sector.

For the commercial marine sector (marine diesel and residual fuel), 1990-2005 emission estimates are based on SIT emission rates applied to estimates of Iowa marine vessel diesel and residual fuel consumption. Because the SIT default relies on marine vessel fuel consumption estimates that represent the State in which fuel is sold rather than consumed, an alternative method was used to estimate Iowa marine vessel fuel consumption. Iowa fuel consumption estimates were developed by allocating 1990-2005 national diesel and residual oil vessel bunkering fuel consumption estimates obtained from EIA.[55] Marine vessel fuel consumption data were allocated to Iowa using the marine vessel activity allocation methods/data compiled to

[53] Michelle McEnany, Office of Aviation, Iowa Department of Transportation.
[54] Terminal Area Forecast, Federal Aviation Administration, http://www.apo.data.faa.gov/main/taf.asp.
[55] US Department of Energy, Energy Information Administration, "Petroleum Navigator" (diesel data obtained from http://tonto.eia.doe.gov/dnav/pet/hist/kd0vabnus1a.htm; residual data obtained from http://tonto.eia.doe.gov/dnav/pet/hist/kprvatnus1a.htm).

support the development of EPA's National Emissions Inventory (NEI).[56] In keeping with the NEI, 75% of each year's distillate fuel and 25% of each year's residual fuel were assumed to be consumed within the port area (remaining consumption was assumed to occur while ships are underway). National port area fuel consumption was allocated to Iowa based on year-specific freight tonnage data by state as reported in "Waterborne Commerce of the United States, Part 5 – Waterways and Harbors National Summaries."[57]

Nonroad Engines

It should be noted that fuel consumption data from EIA includes nonroad gasoline and diesel fuel consumption in the commercial and industrial sectors. Emissions from these nonroad engines, including nonroad vehicles such as snowmobiles and dirt bikes, are included in the inventory and forecast for the residential, commercial, and industrial (RCI) sectors. Table C6 shows how EIA divides gasoline and diesel fuel consumption between the transportation, commercial, and industrial sectors.

Table C6. EIA Classification of Gasoline and Diesel Consumption

Sector	Gasoline Consumption	Diesel Consumption
Transportation	Highway vehicles, marine	Vessel bunkering, military use, railroad, highway vehicles
Commercial	Public non-highway, miscellaneous use	Commercial use for space heating, water heating, and cooking
Industrial	Agricultural use, construction, industrial and commercial use	Industrial use, agricultural use, oil company use, off-highway vehicles

Results

As shown in Figure C1 and in Table C7, onroad gasoline consumption accounts for the largest share of transportation GHG emissions. Emissions from onroad gasoline vehicles increased by about 14% from 1990 to 2005, accounting for 63% of total transportation emissions in 2005. GHG emissions from onroad diesel fuel consumption increased by 44% from 1990 to 2005, and by 2005 accounted for 28% of GHG emissions from the transportation sector. Emissions from marine vessels grew by 44% from 1990 to 2005, accounting for 4.1% of GHG transportation emissions in Iowa in 2005. Emissions from locomotives varied from a high of 0.69 $MMtCO_2e$ in 1996 to a low of 0.16 $MMtCO_2e$ in 2001 and accounted for 2.7% of transportation emissions in 2005 (0.56 $MMtCO_2e$). Emissions from all other categories combined (aviation, natural gas and liquefied petroleum gas (LPG), and oxidation of lubricants) contributed to about 3% of total transportation emissions in 2005.

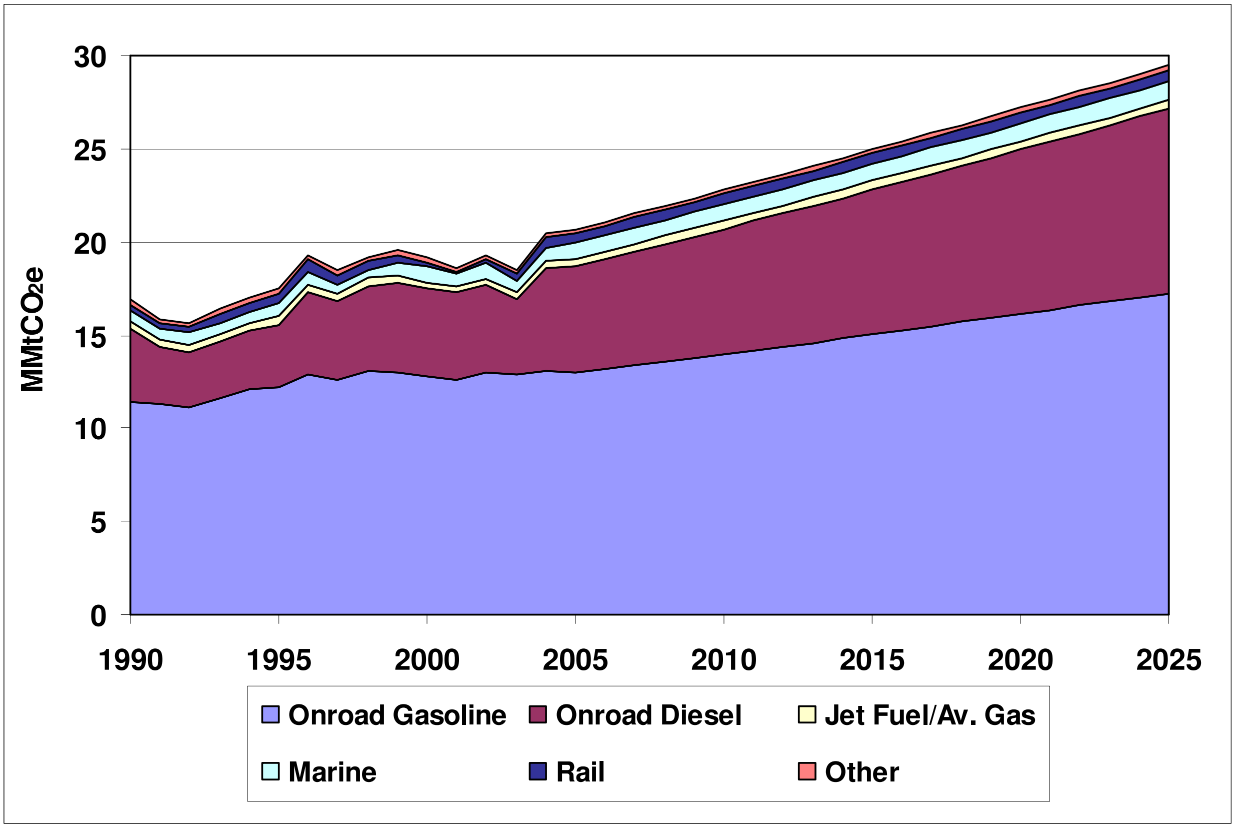
GHG emissions from onroad gasoline consumption are projected to increase by about 33%, and emissions from onroad diesel consumption are expected to increase by 75% between 2005 and 2025. Emissions from aviation are projected to decrease by 6% from 2005 to 2025, while marine emissions are projected to increase by 19% from 2005 to 2025. Overall, the transportation sector

[56] See methods described in ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002nei_mobile_nonroad_methods.pdf

[57] "Waterborne Commerce of the United States" http://www.iwr.usace.army.mil/ndc/wcsc/wcsc.htm. Note that it was necessary to estimate 1990-1996 values by applying the available 1997 Iowa percentage of national waterborne tonnage.

GHG emissions in Iowa are expected to increase to 29 $MMtCO_2e$ by 2025, a 42% increase over 2005 emission levels.

Figure C1. Transportation Gross GHG Emissions by Category, 1990-2025



Source: Calculations based on approach described in text.

Table C7. Gross GHG Emissions from Transportation ($MMtCO_2e$)

Source	1990	1995	2000	2005	2010	2015	2020	2025
Onroad Gasoline	11.40	12.22	12.81	12.96	13.94	15.03	16.16	17.23
Onroad Diesel	3.96	3.35	4.66	5.69	6.76	7.78	8.80	9.94
Jet Fuel/Aviation Gas	0.39	0.45	0.34	0.45	0.48	0.47	0.45	0.42
Marine Vessels	0.58	0.70	0.84	0.84	0.84	0.90	0.95	1.00
Rail	0.31	0.54	0.26	0.56	0.56	0.56	0.56	0.56
Other	0.23	0.22	0.23	0.20	0.23	0.25	0.27	0.29
Total	***16.88***	***17.48***	***19.13***	***20.69***	***22.81***	***24.98***	***27.17***	***29.44***

Source: Calculations based on approach described in text.

Key Uncertainties

Uncertainties in Onroad Fuel Consumption

A major uncertainty in this analysis is the conversion of the projected VMT to fuel consumption. These are based on first allocating Iowa's total VMT by vehicle type using national vehicle type growth projections from AEO2007 modeling, which may not reflect Iowa conditions. The conversion of the VMT data to fuel consumption also includes national assumptions regarding fuel economy by vehicle type.

Energy Independence and Security Act of 2007

The reference case projections documented here do not include the corporate average fuel economy (CAFE) or biofuels provisions (or any other provisions) of the Energy Independence and Security Act of 2007. Increases in vehicle fuel economy resulting from this act would lead to reduced CO2 emissions from onroad vehicles. Reductions attributable to the CAFE provisions of this Act are quantified as a recent action.

Uncertainties in Aviation Fuel Consumption

The jet fuel and aviation gasoline fuel consumption from EIA is actually fuel purchased in the State, and therefore, includes fuel consumed during state-to-state flights and international flights. The fuel consumption associated with international air flights should not be included in the State inventory; however, data were not available to subtract this consumption from total jet fuel estimates. Another uncertainty associated with aviation emissions is the use of general aviation forecasts to project aviation gasoline consumption. General aviation aircraft consume both jet fuel and aviation gasoline, but fuel specific data were not available.

Uncertainties in Marine Fuel Consumption

There are several assumptions that introduce uncertainty into the estimates of commercial marine fuel consumption. These assumptions include:

- 75% of marine diesel and 25% of residual fuel is consumed in port
- The proportion of freight tonnage at ports in Iowa to the total national freight tonnage reflects the proportion of national marine fuel that is consumed in Iowa.

Appendix D. Industrial Processes

Overview

Emissions in the industrial processes category span a wide range of activities, and reflect non-combustion sources of greenhouse gas (GHG) emissions from several industries. The industrial processes that exist in Iowa, and for which emissions are estimated in this inventory, include the following:

- Carbon Dioxide (CO_2) from:
  - Production of cement, lime, iron and steel, and ammonia;[58]
  - Consumption of limestone, dolomite, and soda ash;
- Nitrous oxide (N_2O) from nitric acid production;
- Sulfur hexafluoride (SF_6) from:
  - Transformers used in electric power transmission and distribution (T&D) systems;
- Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) from consumption of substitutes for ozone-depleting substances (ODS) used in cooling and refrigeration equipment.

In addition, at Iowa Department of Natural Resources' (DNR) request, CCS has included CO_2 emission estimates from fermentation of grain sugar that occurs during ethanol production.

These emission estimates are reported separately, at the end of this appendix because it is assumed that the biomass used in ethanol production absorbs CO_2 when it is grown, and adds no net CO_2 to the atmosphere. These emission estimates were obtained from Iowa DNR based on ethanol production data in the State.[59]

Other industrial processes that are sources of GHG emissions but are not found in Iowa include the following:

- N_2O from adipic acid production;
- PFCs from aluminum production;
- HFCs from HCFC-22 production;
- SF_6 from magnesium production and processing;
- HFCs, PFCs, and SF_6 from semiconductor manufacture.

Historical Emissions and Reference Case Projections

Greenhouse gas emissions for 1990 through 2005 were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software, and the methods provided in the Emission Inventory Improvement Program (EIIP)

[58] Note that CO_2 emissions from urea application is estimated as part of the same category as ammonia production.
[59] *2007 Greenhouse Gas Emissions from Selected Iowa Source Categories*, Iowa Department of Natural Resources, Environmental Services Division, August 28, 2008, http://www.iowadnr.gov/air/prof/ghg/files/2007_Greenhouse_Gas_Inventory.pdf.

guidance document for this sector.[60] Table D1 identifies for each emissions source category the information needed for input into SIT to calculate emissions, the data sources used for the analysis described here, and the historical years for which emissions were calculated based on the availability of data.

Table D1. Approach to Estimating Historical Emissions

Source Category	Time Period for which Data Available	Required Data for SIT	Data Source
Cement Manufacture	1992-2005	Metric tons (t) of clinker produced and masonry cement produced each year.	Iowa Department of Natural Resources (DNR) provided clinker production data for 1992-2005; 1990-1991 data were unavailable so 1992 clinker production data was used as a surrogate for 1990 and 1991. No historical masonry cement production was provided from Iowa DNR.
Lime Manufacture	1993-2000, 2003-2005	t of lime produced each year.	Historical production for Iowa from USGS Minerals Yearbook, Lime Statistics and Information. Default production data are not available in SIT for 1990-1992, 2001, and 2002; data for 1993 were used as surrogate for 1990-1992 production; data for 2000 were used for 2001 production; and data for 2003 were used for 2002 production (http://minerals.usgs.gov/minerals/pubs/commodity/lime/index.html#myb).
Limestone and Dolomite Consumption	1994 – 2004	t of limestone and dolomite consumed.	Historical consumption (sales) for Iowa from USGS Minerals Yearbook, Crushed Stone Statistics and Information, (http://minerals.usgs.gov/minerals/pubs/commodity/stone_crushed/). In SIT, the state's total limestone consumption (as reported by USGS) is multiplied by the ratio of national limestone consumption for industrial uses to total national limestone consumption. Additional information on these calculations, including a definition of industrial uses, is available in Chapter 6 of the EIIP guidance document. Default limestone production data are not available in SIT for 1990 – 1993 and for 2005; data for 1994 were used for 1990 – 1993 as a surrogate to fill in production data missing for these years.
Soda Ash Consumption	1990 – 2005	t of soda ash consumed for use in consumer products such as glass, soap and detergents, paper, textiles, and food.	Historical emissions are calculated in SIT based on the state's population and national per capita soda ash consumption from the US EPA national GHG inventory. -- National historical consumption (sales) for US from USGS Minerals Yearbook, Soda Ash Statistics and Information (http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/). -- US (1990-2000 and 2000-2005) and state (2000-2005) population from US Census Bureau (http://www.census.gov/popest/states/NST-ann-est.html). -- State (1990-2000) population from US Census Bureau (http://www.census.gov/popest/archives/2000s/vintage_2001/CO-EST2001-12/CO-EST2001-12-19.html).
Ammonia Production and Urea Application	1990-2005	t of ammonia produced and urea consumed	SIT default activity data for ammonia production and urea application for 1990-2005; activity data is based on national USGS data.

[60] GHG emissions were calculated using SIT, with reference to EIIP, Volume VIII: Chapter. 6. "Methods for Estimating Non-Energy Greenhouse Gas Emissions from Industrial Processes", August 2004. Referred to as "EIIP" below.

Source Category	Time Period for which Data Available	Required Data for SIT	Data Source
Iron and Steel Production	1992-2005	t of crude steel produced by production method.	Iowa DNR provided crude steel production using the Electric Arc Furnace (EAF) method for 1992-2005; 1990-1991 data are not available so 1992 production data was used as a surrogate for 1990-1991 production.
Nitric Acid Production	1992-1994, 1996-1998, 1999-2005	t of nitric acid produced	Iowa DNR provided nitric acid production data for years 1992-1994, 1996-2005. Data for 1990-1991 and 1998 are not available, so 1992 production data was used as surrogate for 1990-1991 production and an average of 1997 and 1999 production data was used for 1998 production. The missing 1995 nitric acid production data was due to plant explosion in late 1994 that resulted in no nitric acid production in 1995.
ODS Substitutes	1990 – 2005	Based on state's population and estimates of emissions per capita from the US EPA national GHG inventory.	National emissions from *US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005*, US EPA, Report #430-R-07-002, April 2007 (http://epa.gov/climatechange/emissions/ usinventoryreport.html). References for US Census Bureau national and state population figures are cited under the data sources for soda ash above.
Electric Power T&D Systems	1990 – 2005	Emissions from 1990 to 2005 based on the national emissions per kilowatt-hour (kWh) and state's electricity use provided in SIT.	National emissions are apportioned to the state based on the ratio of state-to-national electricity sales data provided in the Energy Information Administration's (EIA) Electric Power Annual (http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html). Reference for US EPA national emissions is cited under the data sources for ODS substitutes above.

Table D2 lists the data and methods that were used to estimate future activity levels related to industrial process emissions and the annual compound growth rates computed from the data/methods for the reference case projections. Because available forecast information is generally for economic sectors that are too broad to reflect trends in the specific emissions producing processes, the majority of projections are based on historical activity trends. In particular, state historical trends were analyzed for three periods: 1990-2005, 1995-2005, and 2000-2005 (or the closest available approximation of these periods). In cases where the historical periods indicated either continual growth or decline, the smallest annual rate of growth/decline was selected from the values computed for each period. This conservative assumption was adopted because of the uncertainty associated with utilizing historical trends to estimate future emission activity levels.

Table D2. Approach to Estimating Projections for 2005 through 2025

			Annual Growth Rates (%)			
Source Category	**Projection Assumptions**	**Data Source**	**2005 to 2010**	**2010 to 2015**	**2015 to 2020**	**2020 to 2025**
Cement Manufacture	Annual growth rate computed from Nonmetallic Mineral Production Manufacturing employment forecast for state.	2004-2014 employment projections from Iowa Workforce Information Network (http://iwin.iwd.state.ia.us/pubs/statewide/indprojstatewide.pdf).	1.0	1.0	1.0	1.0
Lime Manufacture	Smallest historical annual increase in state production from each of three periods analyzed (1995-2005).	Annual change in Iowa lime production: 1990-2005 = +3.2%; 1995-2005 = +2.9%; and 2000-2005 = +9.4%	2.9	2.9	2.9	2.9
Limestone and Dolomite Consumption	Smallest historical annual decline in state consumption from each of three periods analyzed (1994-2004; pre-1994 and 2005 data were not available).	Annual change in Iowa limestone and dolomite consumption: 1994-2004 = -1.1%; 1995-2004 = -5.0%; and 2000-2004 = -3.6%	-1.1	-1.1	-1.1	-1.1
Soda Ash Consumption	Smallest historical annual decline in state consumption from each of three periods analyzed (1990-2005).	Annual change in Iowa soda ash consumption: 1990-2005 = -1.1%; 1995-2005 = -1.2%; and 2000-2005 = -1.3%	-1.1	-1.1	-1.1	-1.1
Ammonia Production and Urea Application	Smallest historical annual decline in state ammonia production/urea application from each of three periods analyzed (2000-2005).	Annual change in Iowa ammonia production and urea consumption: 1990-2005 = -0.9%; 1995-2005 = -3.2%; and 2000-2005 = -0.7%	-0.7	-0.7	-0.7	-0.7
Iron and Steel Production	Smallest historical annual increase in state production from each of three periods analyzed (2000-2005).	Annual change in Iowa iron and steel production: 1992-2005 = +12.7%; 1995-2005 = +17.2%; and 2000-2005 = +5.4%	5.4	5.4	5.4	5.4
Nitric Acid Production	EPA's nitric acid national forecast production growth rate.	"U.S. Adipic Acid and Nitric Acid N2O Emissions 1990-2020: Inventories, Projections and Opportunities for Reductions," December 2001, accessed from http://www.epa.gov/nitrousoxide/projections.html	0.8	0.8	0.8	0.8
ODS Substitutes	National growth in emissions associated with the use of ODS substitutes.	Annual growth rates calculated based on sum of US national emissions projections from 2005-2020 for six categories of ODS substitutes presented in Appendix D, Tables D1 through D-6 in the US EPA report, *Global Anthropogenic Emissions of Non-CO_2 Greenhouse Gases 1990-2020*, EPA Report 430-R-06-003, http://www.epa.gov/nonco2/econ-inv/international.html.	8.7	6.4	5.0	5.0
Electric Power T&D Systems	National growth rate (based on technology adoption forecast scenario reflecting industry participation in EPA voluntary stewardship program to control emissions).	Annual growth rates calculated based on US national emissions projections from 2005-2020 presented in Appendix D, Table D8 in the US EPA report, *Global Anthropogenic Emissions of Non-CO_2 Greenhouse Gases 1990-2020* , EPA Report 430-R-06-003; http://www.epa.gov/nonco2/econ-inv/international.html.	-1.6	-0.8	-0.7	-0.7

Results

Figures D1 and D2 show historical and projected emissions for the industrial processes sector from 1990 to 2025. Table D3 shows the historical and projected emission values upon which Figures D1 and D2 are based. Total gross Iowa GHG emissions were about 2.74 $MMtCO_2e$ in 1990, 4.59 $MMtCO_2e$ in 2005, and are projected to increase to about 8.14 $MMtCO_2e$ in 2025. Emissions from the overall industrial processes category are expected to grow by about 2.9% annually from 2005 through 2025, as shown in Figures D1 and D2, with emissions growth primarily associated with increasing use of HFCs and PFCs in refrigeration and air conditioning equipment.

Cement Manufacture

Iowa has three Portland cement plants – Holcim Inc, LaFarge Corporation, and Lehigh Cement Company that produce clinker. Clinker is an intermediate product from which finished Portland and masonry cement are made. Clinker production releases CO_2 when calcium carbonate ($CaCO_3$) is heated in a cement kiln to form lime (calcium oxide) and CO_2 (see Chapter 6 of EIIP guidance document). Emissions are calculated by multiplying annual clinker production by emission factors to estimate emissions associated with the clinker production process (0.507 metric ton (t) of CO_2 emitted per t of clinker produced) and cement kiln dust (0.020 tCO_2 emitted per t of clinker CO_2 emitted).

Masonry cement requires additional lime, over and above the lime used in the clinker. During the production of masonry cement, non-plasticizer additives such as lime, slag, and shale are added to the cement, increasing its weight by 5%. Lime accounts for approximately 60% of the added substances. About 0.0224 tCO_2 is emitted for every t of masonry cement produced, relative to the CO_2 emitted during the production of a t of clinker (see Chapter 6 of EIIP guidance document).

As shown in Figure D2 (see black line) and Table D3, emissions from this source are estimated to be about 1.18 $MMtCO_2e$ in 1990 and are projected to increase to about 1.56 $MMtCO_2e$ by 2025. Iowa DNR provided clinker production data for 1992-2005 (see Table D1); 1990 and 1991 data were not available from Iowa DNR and so 1992 production was used as a surrogate for both years. The default emission factors in SIT were used to calculate CO_2 emissions for 1990-2005. No masonry cement production data was provided by Iowa DNR and those emissions were not estimated. Emissions are projected to increase at a rate of 0.98% per year based on Nonmetallic Mineral Production Manufacturing sector employment projections available from the State of Iowa (note that these projections are available for 2014—in lieu of other information, the same rate of increase was used throughout the forecast period to 2025).

Lime Manufacture

Lime is a manufactured product that is used in many chemical, industrial, and environmental applications including steel making, construction, pulp and paper manufacturing, and water and sewage treatment. Lime is manufactured by heating limestone (mostly $CaCO_3$) in a kiln, creating calcium oxide and CO_2. The CO_2 is driven off as a gas and is normally emitted to the atmosphere, leaving behind a product known as quicklime. Some of this quicklime undergoes slaking (combining with water), which produces hydrated lime. The consumption of lime for certain uses, specifically the production of precipitated $CaCO_3$ and refined sugar, results in the reabsorption of some airborne CO_2 (see Chapter 6 of EIIP guidance document).

Iowa has one lime production facility, Linwood Mining and Minerals, that produces lime. However, production data from Iowa DNR were not available, so SIT default production data were used. Emissions associated with lime manufacture were estimated for 1993-2000 and 2003-2005 using the amount of lime produced and an emission factor of 0.75 tCO_2 per ton high-calcium lime and 0.87 tCO_2 per ton dolomitic lime produced. Lime production data from 1990-1992 and 2001-2002 were not available for Iowa; therefore, production for 1993 was used as a surrogate to estimate emissions for 1990-1992, production for 2000 was used as a surrogate for 2001, and 2003 production was used as a surrogate for 2002. Relative to total industrial non-combustion process emissions, CO_2 emissions from lime production are relatively low (about 0.06 $MMtCO_2e$ in 1990, increasing to about 0.09 $MMtCO_2e$ in 2005), and therefore, appear at the bottom of the graph (see orange line at the bottom of Figure D2). The annual rate of increase in Iowa lime production over the 1995-2005 period (2.9% per year) was used to project emissions from 2006 to 2025.

Figure D1. GHG Emissions from Industrial Processes, 1990-2025

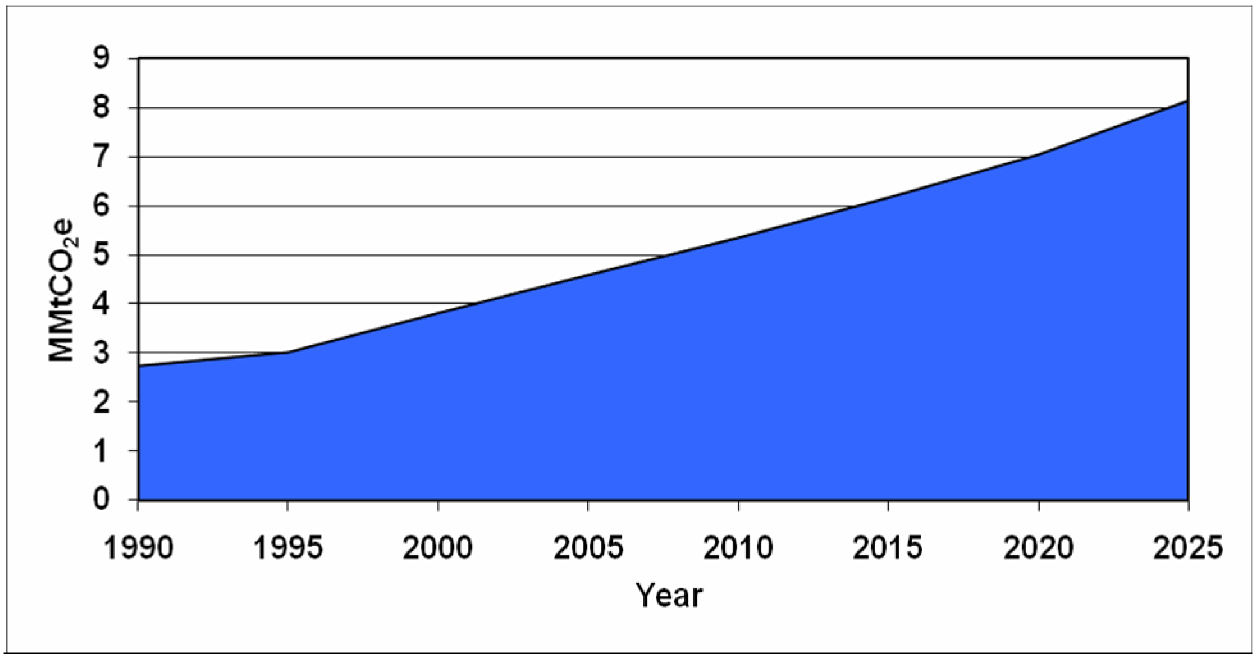
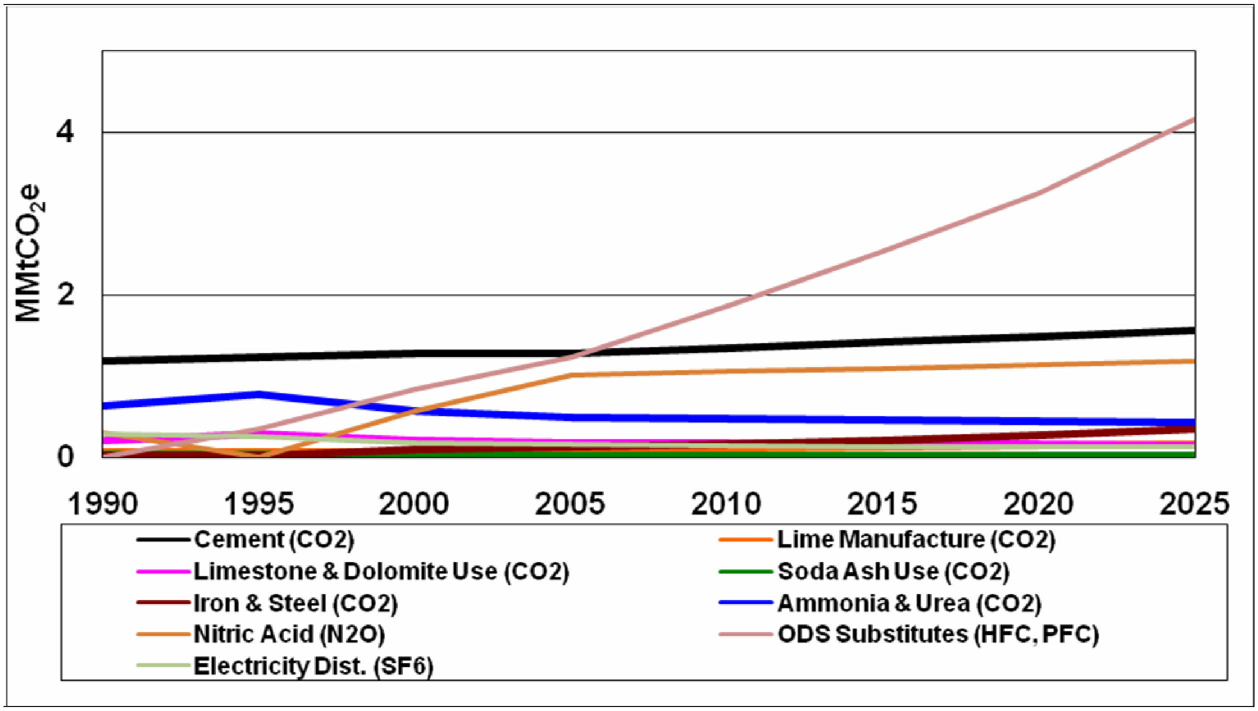


Figure D2. GHG Emissions from Industrial Processes, 1990-2025, by Source



Source: Calculations based on approach described in text.

Table D3. Historical and Projected Emissions for the Industrial Processes Sector ($MMtCO_2e$)

Industry / Pollutant	1990	1995	2000	2005	2010	2015	2020	2025
Cement (CO_2)	1.18	1.23	1.28	1.28	1.35	1.41	1.48	1.56
Lime Manufacture (CO_2)	0.06	0.07	0.06	0.09	0.11	0.12	0.14	0.17
Limestone & Dolomite Use (CO_2)	0.20	0.29	0.21	0.18	0.17	0.16	0.15	0.15
Soda Ash Use (CO_2)	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
Iron & Steel (CO_2)	0.03	0.03	0.10	0.12	0.16	0.21	0.27	0.36
Ammonia & Urea (CO_2)	0.64	0.78	0.56	0.49	0.47	0.46	0.44	0.43
Nitric Acid (N_2O)	0.30	--	0.57	1.01	1.05	1.10	1.14	1.19
ODS Substitutes (HFC, PFC)	0.00	0.35	0.83	1.23	1.87	2.54	3.25	4.15
Electricity Dist. (SF_6)	0.29	0.25	0.17	0.15	0.14	0.14	0.13	0.13
Total	**2.74**	**3.02**	**3.82**	**4.59**	**5.35**	**6.17**	**7.04**	**8.14**

Source: Calculations based on approach described in text.

Limestone and Dolomite Consumption

Limestone and dolomite are basic raw materials used by a wide variety of industries, including the construction, agriculture, chemical, glass manufacturing, and environmental pollution control industries, as well as in metallurgical industries such as magnesium production. Emissions associated with the use of limestone and dolomite to manufacture steel and glass and for use in flue-gas desulfurization scrubbers to control sulfur dioxide emissions from the combustion of coal in boilers are included in the industrial processes sector.[61]

Historical limestone and dolomite consumption (sales) data for Iowa obtained from the USGS (see Table D1) and the default emission factors in SIT were used to calculate CO_2 emissions for 1994-2004. Data were not available for Iowa for the years 1990-1993 and 2005; therefore 1994 production data were used as a surrogate for 1990-1993 data, and 2004 data were used as a surrogate for 2005 production. The annual rate of decrease in Iowa limestone and dolomite consumption over the 1994-2004 period (-1.1% per year) was used to project emissions from 2006 to 2025. Relative to total industrial non-combustion process emissions, CO_2 emissions from limestone and dolomite consumption are small (about 0.20 $MMtCO_2e$ in 1990, 0.18 $MMtCO_2e$ in 2005, and 0.15 $MMtCO_2e$ in 2025), and appears towards the bottom of the graph (see pink line towards bottom of Figure D2).

Soda Ash Consumption

Commercial soda ash (sodium carbonate) is used in many consumer products such as glass, soap and detergents, paper, textiles, and food. Carbon dioxide is also released when soda ash is consumed (see Chapter 6 of EIIP guidance document). SIT estimates historical emissions (see green line in Figure D2) based on the state's population and national per capita soda ash consumption from the US EPA national GHG inventory. Relative to total industrial non-combustion process emissions, CO_2 emissions from soda ash consumption are very low (0.03 $MMtCO_2e$ per year from 1990 through 2005), and therefore, appear at the bottom of the graph because of scaling effects (see green line at the bottom of Figure D2). Emission projections from 2005 to 2025 are assumed to decrease at a rate of -1.1 percent per year, reflecting the negative trend observed for the historical periods analyzed.

Ammonia Production/Urea Application

Ammonia (NH_3) and urea ($(NH_2)_2CO$) are both synthetically created chemicals with a wide variety of uses. Ammonia is primarily used as a fertilizer, though it also has applications as a refrigerant, a disinfectant, and in the production of chemicals such as urea and nitric acid. Ammonia production involves the conversion of a fossil fuel hydrocarbon into pure hydrogen, which is then combined with nitrogen to create NH_3. This process involves the release of carbon dioxide as a byproduct. Urea, a different type of synthetic chemical, is also primarily used as a fertilizer, though it is also used commercially in several industrial and chemical processes. Urea is created by a chemical process with ammonia as a key component.

Ammonia production/urea consumption constitutes a significant portion of the total GHG emissions in Iowa's Industrial Processes sector. SIT default production data, along with default emission factors for ammonia and urea, were used to calculate CO_2 emissions in Iowa. These emissions were 0.64 $MMtCO_2e$ in 1990 and decreased to 0.49 $MMtCO_2e$ in 2005 (see blue line in Figure D2). Emission projections from 2005 to 2025 are assumed to decrease at a rate of -0.7 percent per year, reflecting the negative trend observed for the historical periods analyzed.

[61] In accordance with EIIP Chapter 6 methods, emissions associated with the following uses of limestone and dolomite are not included in this category: (1) crushed limestone consumed for road construction or similar uses (because these uses do not result in CO_2 emissions), (2) limestone used for agricultural purposes (which is counted under the methods for the agricultural sector), and (3) limestone used in cement production (which is counted in the methods for cement production).

Iron and Steel Production

Iowa has two iron and steel production facilities – IPSCO, Inc in Muscatine and Gerdau Ameristeel in Wilton. The production of iron and steel generates process-related CO_2 emissions. Iron is produced by reducing iron ore with metallurgical coke in a blast furnace to produce pig iron; this process emits CO_2 emissions. Pig iron is used as a raw material in the production of steel. The steel can be produced in basic oxygen furnace at integrated mills with coke ovens, basic oxygen furnace at integrated mills without coke ovens, electric arc furnaces, and open hearth furnaces. The production of metallurgical coke from coking coal produces CO_2 emissions as well.

The EPA SIT software was used to estimate Iowa's CO_2 emissions from steel production (see Table D1). The basic activity data needed are the quantities of crude steel produced (defined as first cast product suitable for sale or further processing) by production method. Plant-specific production data by the Electric Arc Furnace (EAF) method were provided by Iowa DNR for the years 1992-2005. Missing 1990 and 1991 data were set equal to 1992 production. The default SIT emission factor for the EAF method was applied to estimate CO_2 emissions for 1990-2005. As shown in Figure D2 (see brown line) and Table D3, emissions from iron and steel increased from 0.03 $MMtCO_2e$ in 1990 to 0.12 $MMtCO_2e$ in 2005. The annual rate of increase in Iowa iron and steel production over the 2000-2005 period (5.4% per year) was used to project emissions from 2006 to 2025.

Nitric Acid Production

Iowa has two Nitric Acid Production facilities – Terra Nitrogen (Port Neal Complex) and Koch Nitrogen (Fort Dodge). The manufacture of nitric acid (HNO_3) produces N_2O as a by-product, via the oxidation of ammonia. Nitric acid is a raw material used primarily to make synthetic commercial fertilizer. It is also a major component in the production of adipic acid (a feedstock for nylon) and explosives. Relatively small quantities of nitric acid are also employed for stainless steel pickling, metal etching, rocket propellants, and nuclear fuel processing.[62] The SIT uses a default emission factor of 0.008 metric tons of N_2O emissions per metric ton of nitric acid produced based on a weighted-average calculated over the different types of emissions control technologies typically employed by nitric acid plants nationwide.[63]

Iowa DNR provided production data for nitric acid for the years 1992-1994, 1996-1997, and 1999-2005. Production data for 1990-1991 and 1998 were not available, therefore 1992 production data was used as a surrogate for 1990 and 1991, and an average of 1997 and 1999 production data was used for 1998. There was no nitric acid production in Iowa in 1995 due to a plant closing. Emissions are projected to increase at a rate of 0.8% per year based on EPA's

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[62] EIIP, Volume VIII: Chapter. 6. "Methods for Estimating Non-Energy Greenhouse Gas Emissions from Industrial Processes", August 2004.

[63] According to Chapter 6 of the EIIP guidance document, the nitric acid industry controls for oxides of nitrogen through two technologies: non-selective catalytic reduction (NSCR) and SCR. Only one of these technologies, NSCR, is effective at destroying N_2O emissions in the process of destroying oxides of nitrogen emissions. NSCR technology was widely installed in nitric acid plants built between 1971 and 1977. Due to high-energy costs and associated high gas temperatures, this technology has not been popular with modern plants. Only about 20% of the current plants have NSCR technology installed. All other plants have installed SCR technology. Since 80% of the current plants have SCR technology installed and 20% have NSCR technology, the weighted-average emission factor used in the SGIT is equal to (0.0095 x 0.80) x (0.002 x 0.20) = 0.008 metric tons N_2O per metric ton of nitric acid produced.

nitric acid production growth rate (note that these projections are available for 2006-2020—in lieu of other information, the same rate of increase was used throughout the forecast period to 2025). As seen from Figure D2, nitric acid emissions has become one of the more significant industrial process emissions in Iowa, with 0.30 MMtCO_2e emitted in 1990 and 1.01MMtCO_2e emitted in 2005; projected 2025 emissions are 1.19 MMtCO_2e.

Substitutes for Ozone-Depleting Substances (ODS)

HFCs and PFCs are used as substitutes for ODS, most notably chlorofluorocarbons (CFCs are also potent warming gases, with global warming potentials on the order of thousands of times that of CO_2 per unit of emissions) in compliance with the *Montreal Protocol* and the *Clean Air Act Amendments of 1990*.[64] Even low amounts of HFC and PFC emissions, for example, from leaks and other releases associated with normal use of the products, can lead to high GHG emissions on a CO_2e basis. Emissions have increased from less than 0.01 MMtCO_2e in 1990 to about 1.23 MMtCO_2e in 2005, and are expected to continue increasing rapidly until 2025 due to substitutions of these gases for ODS (see beige colored line in Figure D2). The projected rate of increase for these emissions is based on projections for national emissions from the US EPA report referenced in Table D2.

Electric Power Transmission and Distribution

Emissions of SF_6 from electrical equipment have experienced declines since the mid-1990s (see tan line in Figure D2), mostly due to voluntary action by industry. Sulfur hexafluoride is used as an electrical insulator and interrupter in the electric power T&D system. The largest use for SF_6 is as an electrical insulator in electricity T&D equipment, such as gas-insulated high-voltage circuit breakers, substations, transformers, and transmission lines, because of its high dielectric strength and arc-quenching abilities. Not all of the electric utilities in the US use SF_6; use of the gas is more common in urban areas where the space occupied by electric power T&D facilities is more valuable.[65]

As shown in Figure D2 and Table D3, SF_6 emissions from electric power T&D are about 0.29 MMtCO_2e in 1990 and 0.15 MMtCO_2e in 2005. Emissions in Iowa from 1990 to 2005 were estimated based on the estimates of emissions per kilowatt-hour (kWh) of electricity consumed from the US EPA GHG inventory, and the ratio of Iowa's to the US electricity consumption (sales) estimates available from the Energy Information Administration's (EIA) Electric Power Annual and provided in the SIT (see Table D1). The national trend in US emissions estimated for 2005-2025 for the technology-adoption scenario shows expected decreases in these emissions at the national level (see Table D2), and the same rate of decline is assumed for emissions in Iowa. The decline in SF_6 emissions in the future reflects expectations of future actions by the electric power industry to reduce these emissions.

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[64] As noted in EIIP Chapter 6, ODS substitutes are primarily associated with refrigeration and air conditioning, but also many other uses including as fire control agents, cleaning solvents, aerosols, foam blowing agents, and in sterilization applications. The applications, stocks, and emissions of ODS substitutes depend on technology characteristics in a range of equipment types. For the US national inventory, a detailed stock vintaging model was used to track ODS substitutes uses and emissions, but this modeling approach has not been completed at the state level.

[65] US EPA, Draft User's Guide for Estimating Carbon Dioxide, Nitrous Oxide, HFC, PFC, and SF_6 Emissions from Industrial Processes Using the State Inventory Tool, prepared by ICF International, March 2007.

Ethanol Production

The IPCC considers the CO_2 from fermentation as a biogenic source of CO_2, so no accounting methods have been developed for fermentation (only anthropogenic GHG sources have IPCC methods). In the case of process emissions (outside of fuel combustion), neither EPA nor the IPCC has a methodology to include fermentation off-gases in any sort of accounting scheme. To account for emissions from an ethanol production plant, the only focus is on the combustion technologies at the plant, and what fossil fuels are being combusted. The emissions as a result of fuel combustion are accounted for under the industrial fuel use sector category.

Iowa produces a significant quantity of ethanol from corn. In 2007, 28 dry mills operated in Iowa, producing 1,452 million gallons of denatured ethanol in that year. Iowa DNR estimates that in 2007, emissions of 3.94 $MMtCO_2e$ were produced in the State from the from the fermentation process at these dry mill ethanol plants. In addition, four wet mills were in operation in Iowa in 2007, producing 503 million gallons of denatured ethanol. Emissions from the fermentation process at these mills resulted in 1.36 $MMtCO_2e$ of emissions in 2007.[66]

Key Uncertainties

Key sources of uncertainty underlying the estimates above are as follows:

- Since emissions from industrial processes are determined by the level of production and the production processes of a few key industries—and in some cases, a few key plants—there is relatively high uncertainty regarding future emissions from the industrial processes category as a whole. Future emissions depend on the competitiveness of Iowa manufacturers in these industries, and the specific nature of the production processes used in Iowa.
- The projected largest source of future industrial emissions, HFCs and PFCs used in cooling applications, is subject to several uncertainties as well. Emissions through 2025 and beyond will be driven by future choices regarding mobile and stationary air conditioning technologies and the use of refrigerants in commercial applications, for which several options currently exist.
- Due to the lack of reasonably specific projection surrogates, historical trend data were used to project emission activity level changes for multiple industrial processes. There is significant uncertainty associated with any projection, including a projection that assumes that past historical trends will continue in future periods. Reflecting this uncertainty, the lowest historical annual rate of increase/decrease was selected as a conservative assumption for use in projecting future activity level changes. These assumptions on growth should be reviewed by industry experts and revised to reflect their expertise on future trends especially for the cement and lime manufacture, iron and steel production, and ammonia production industries.
- For the industries for which EPA default activity data and methods were used to estimate historical emissions, future work should include efforts to obtain state-specific data to replace the default assumptions. Often in cases where years are missing, default data or the nearest available year is used as a surrogate, but the less often this occurs, the more accurate the forecast will be.

[66] *2007 Greenhouse Gas Emissions from Selected Iowa Source Categories*, Iowa Department of Natural Resources, Environmental Services Division, August 28, 2008, http://www.iowadnr.gov/air/prof/ghg/files/2007_Greenhouse_Gas_Inventory.pdf.

- For the electricity T&D, future efforts should include a survey of companies within these industries to determine the extent to which they are implementing techniques to minimize emissions to improve the emission projections for these industries.

Appendix E. Fossil Fuel Production Industry

Overview

The inventory for this subsector of the Energy Supply sector includes methane (CH_4) and carbon dioxide (CO_2) emissions associated with the transmission and distribution (T&D) of natural gas and coal mining in Iowa.[67] There is no oil production or refining or natural gas production or processing in Iowa. In 2005, emissions from the subsector accounted for an estimated 2.25 million metric tons (MMt) of CO_2 equivalent (CO_2e) of total gross greenhouse gas (GHG) emissions in Iowa, and are estimated to increase to about 3.78 MMtCO_2e by 2025.

Emissions and Reference Case Projections

Table E1 provides an overview of data sources and approaches used to develop historical fossil fuel production sector emission estimates for Iowa, including a description of the surrogate data that were used to back-cast natural gas pipeline mileage and service count estimates for the analysis period.

Gas Industry Emissions

Emissions of CH_4 and CO_2 can occur at several stages of transmission and distribution of natural gas. With nearly 25,000 miles of gas pipelines, there are inevitable uncertainties associated with estimates of Iowa's GHG emissions from this sector.[68] This is compounded by the fact that there are no regulatory requirements to track CH_4 and CO_2 emissions. Therefore, estimates based on emissions measurements in Iowa are not possible at this time.

Based on the information provided in the Emission Inventory Improvement Program (EIIP) guidance[69] for estimating emissions for this sector, transmission pipelines are large diameter, high-pressure lines that transport gas from production fields, processing plants, storage facilities, and other sources of supply over long distances to local distribution companies or to large volume customers. Sources of CH_4 emissions from transmission pipelines include chronic leaks, compressor fugitives, compressor exhaust, vents, and pneumatic devices. Distribution pipelines are extensive networks of generally small diameter, low-pressure pipelines. Gas enters distribution networks from transmission systems at city gate stations, where the pressure is reduced for distribution within cities or towns. Sources of CH_4 emissions from distribution pipelines are chronic leaks, meters, regulators, and mishaps. Carbon dioxide, CH_4, and nitrous oxide (N_2O) emissions occur as the result of the combustion of natural gas by internal combustion engines used to operate compressor stations.

[67] Note that emissions from natural gas consumed as lease fuel (used in well, field, and lease operations) and plant fuel (used in natural gas processing plants) are included in Appendix B in the industrial fuel combustion category.
[68] "Natural Gas Navigator," US DOE Energy Information Administration website, January 2008, Accessed at http://www.eia.doe.gov.
[69] Emission Inventory Improvement Program, Volume VIII: Chapter 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems," August 2004.

Table E1. Approach to Estimating Historical and Future Methane Emissions from Natural Gas Transmission and Distribution and Coal Mining

Activity	Approach to Estimating Historical Emissions		Surrogate Data Used to Back-cast Activity to 1990	Forecasting Approach
	Required SIT Data	**Data Source**		**Projection Assumption**
Natural Gas Transmission (CH_4)	Miles of transmission pipeline	Office of Pipeline Safety[70]	Average of volume of natural gas transported into IA and transported out of IA, as reported by EIA[71]	Application of smallest annualized increase in state transmission emissions (3.87%) from each of 3 historical periods analyzed (1995-2005).
	Number of gas transmission compressor stations	EIIP[72]		
	Number of gas storage compressor stations	EIIP[73]		
Natural Gas Distribution (CH_4)	Miles of distribution pipeline by pipeline material type	Office of Pipeline Safety[74]	Total number of natural gas consumers in IA as reported by EIA[75]	Application of *Annual Energy Outlook* (AEO) *2007* West North Central region natural gas consumption forecast growth rates.[76]
	Total number of services			
	Number of unprotected steel services			
	Number of protected steel services			
Natural Gas Pipeline Fuel Use (CO_2, CH_4, N_2O)	Volume of natural gas consumed by pipelines	EIA[77]		*AEO 2007* regional pipeline natural gas consumption forecast growth rates.[78]
Coal Mining (CH_4)	Methane emissions in million cubic feet	US Environ-mental Protection Agency (EPA)[79]		No change based on no coal mining emissions over the past 11 years.

The US Environmental Protection Agency's (EPA) State Greenhouse Gas Inventory Tool (SIT) facilitates the development of a rough estimate of state-level GHG emissions. Emissions were

[70] US Department of Transportation, Office of Pipeline Safety, "Distribution and Transmission Annuals Data: 1990 to 2005," accessed from http://ops.dot.gov/stats/DT98.htm, January 2008.
[71] US DOE, Energy Information Administration, "International and Interstate Movements of Natural Gas by State," accessed from http://tonto.eia.doe.gov/dnav/ng/ng_move_ist_a2dcu_SIA_a.htm, January 2008.
[72] Number of gas transmission compressor stations = miles of transmission pipeline x 0.006 – EIIP, Volume VIII: Chapter 5, March 2005.
[73] Number of gas storage compressor stations = miles of transmission pipeline x 0.0015 EIIP. Volume VIII: Chapter 5, March 2005.
[74] US Department of Transportation, Office of Pipeline Safety, "Distribution and Transmission Annuals Data: 1990 to 2005," accessed from http://ops.dot.gov/stats/DT98.htm, January 2008.
[75] US DOE, Energy Information Administration, "Number of Natural Gas Customers," accessed from http://tonto.eia.doe.gov/dnav/ng/ng_cons_num_a_EPG0_VN7_Count_a.htm, January 2008.
[76] US DOE, Energy Information Administration, "Annual Energy Outlook 2007 with Projections to 2030," accessed from http://www.eia.doe.gov/oiaf/archive/aeo07/index.html, January 2008.
[77] US DOE, Energy Information Administration, *State Energy Consumption, Price, and Expenditure Estimates (SEDS)*, (http://www.eia.doe.gov/emeu/states/_seds.html).
[78] US DOE, Energy Information Administration, "Annual Energy Outlook 2007 with Projections to 2030," accessed from http://www.eia.doe.gov/oiaf/archive/aeo07/index.html, January 2008.
[79] US Environmental Protection Agency, "Inventory Of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005, USEPA #430-R-07-002, April 2007.

estimated using the SIT, with reference to methods/data sources outlined in the Emission Inventory Improvement Program (EIIP) guidance document for natural gas and oil systems.[80] Methane emission from transmission and distribution pipelines are calculated by multiplying

emissions-related activity levels (e.g., miles of pipeline, number of compressor stations) by aggregate industry-average emission factors. Key sources for emissions activity estimates included the US Department of Transportation's Office of Pipeline Safety (OPS).[81] Emissions of CO_2, CH_4, and N_2O associated with the combustion of natural gas are estimated using SIT emission factors[82] and the US Department of Energy, Energy Information Administration (EIA)'s 1990-2005 natural gas data for Iowa for the "consumed as pipeline fuel" category.[83]

The OPS has not collected data from pipeline operators using a consistent set of reporting requirements over the 1990-2005 analysis period. In particular, OPS has only required operators to report state-level data for their transmission pipelines since 2001 and state-level data for their distribution pipelines since 2004. Before these dates, several Iowa pipeline operators report data as multi-state totals. To estimate a complete time-series of natural gas transmission and distribution pipeline mileage/service counts, CCS compiled surrogate data to back-cast the 2001 transmission pipeline mileage and the 2004 distribution pipeline mileage/service counts for each year back to 1990.[84]

Coal Production Emissions

Iowa has no currently active coal mines, however the US EPA reports limited coal mining-related emissions in the early 1990s.[85]

Emission Forecasts

Table E1 provides an overview of data sources and approaches used to forecast natural gas and coal emission estimates for Iowa. The approach to forecasting sector emissions/activity consisted of compiling and comparing two alternative sets of annualized growth rates for each emissions activity – one using *Annual Energy Outlook 2007* forecast data for each 5-year time-frame over the 2005-2025 forecast period, and the other using historical activity data for each of 3 periods (i.e., 1990 to 2005, 1995 to 2005, and 2000 to 2005). Because available AEO forecast information is for a broad region that may not reflect Iowa-specific trends (e.g., AEO forecasts of natural gas production are for the Midcontinent Region, which includes 7 states in addition to Iowa), the AEO forecast growth rates were only used when they were in-line with the Iowa

[80] Emission Inventory Improvement Program, Volume VIII: Chapter 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems," August 2004.

[81] US Department of Transportation, Office of Pipeline Safety, "Distribution and Transmission Annuals Data: 1990 to 2005," accessed from http://ops.dot.gov/stats/DT98.htm, January 2008.

[82] GHG emissions were calculated using SIT, with reference to *EIIP, Volume VIII*: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004, and Chapter 2 "Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion", August 2004.

[83] US DOE, Energy Information Administration, *State Energy Consumption, Price, and Expenditure Estimates (SEDS)*, (http://www.eia.doe.gov/emeu/states/_seds.html).

[84] Note that CCS estimated an additional 9,165 distribution pipeline miles in 2005 (the majority from MidAmerican Energy Company), 1,002 transmission pipeline miles in 2004, and less than 100 miles of distribution pipeline in 2004 for pipeline operators that did not report data to OPS in these years.

[85] US Environmental Protection Agency, "Inventory Of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005, USEPA #430-R-07-002, April 2007.

historical growth rates. In cases where of each the three historical periods indicated continual growth or decline, the period with the smallest annual rate of growth/decline was used in the projection. This conservative assumption was adopted because of the uncertainty associated with utilizing historical trends to estimate future emission activity levels.

It is important to note that potential improvements to pipeline technologies resulting in GHG emissions reductions are generally not accounted for in the projections analysis.

Results

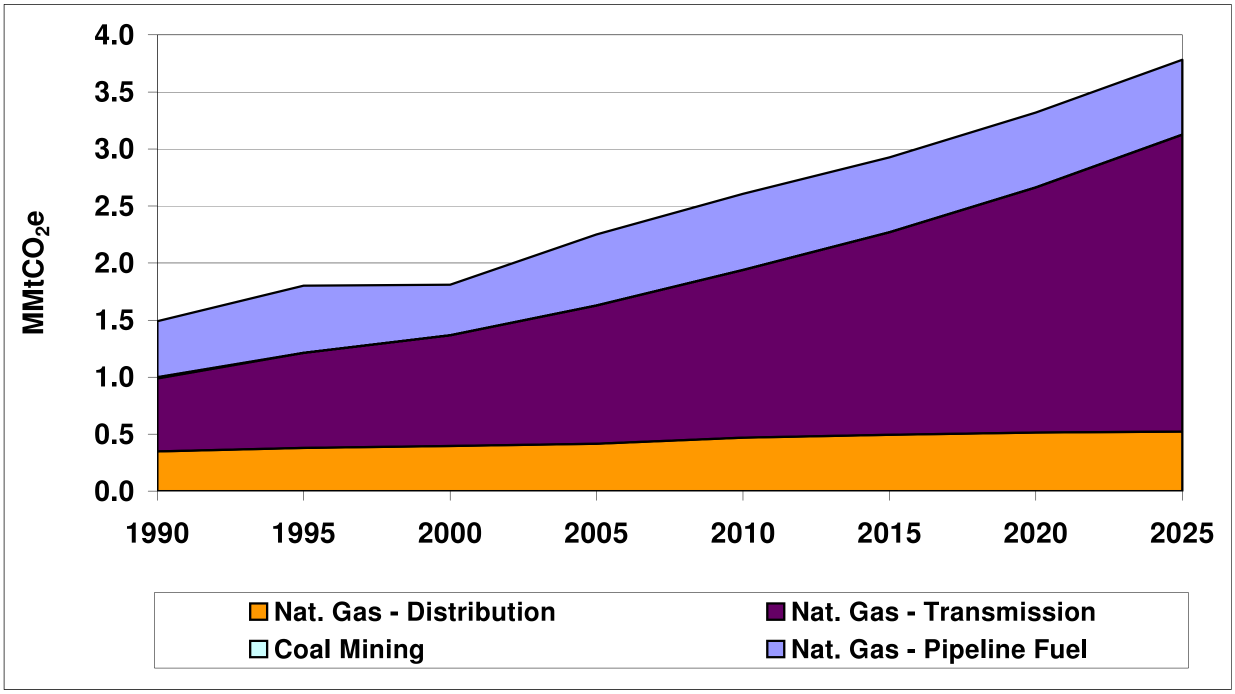
Table E2 displays the estimated emissions from the fossil fuel industry in Iowa for select years over the period 1990 to 2025. Emissions from this sector increased by 51% from 1990 to 2005 and are projected to increase by a further 68% between 2005 and 2025. Natural gas distribution is the major contributor to both historical emissions and emissions growth. Figure E1 displays process-level emission trends from natural gas systems and coal mining, on an $MMtCO_2e$ basis (note that the coal mining emissions can not be seen on this figure due to scaling).

Table E2. Historical and Projected Emissions for the Fossil Fuel Industry

(Million Metric Tons CO_2e)	1990	1995	2000	2005	2010	2015	2020	2025
Fossil Fuel Industry	1.49	1.80	1.81	2.25	2.61	2.93	3.32	3.78
Natural Gas Industry	1.48	1.80	1.81	2.25	2.61	2.93	3.32	3.78
Production	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Processing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flaring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Transmission	0.64	0.83	0.97	1.22	1.47	1.78	2.15	2.60
Distribution	0.35	0.38	0.40	0.41	0.47	0.49	0.51	0.52
Pipeline Fuel Use	0.49	0.59	0.44	0.62	0.67	0.65	0.66	0.66
Oil Industry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Production	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Refining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal Mining	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Source: Calculations based on approach described in text.

Figure E1. Fossil Fuel Industry Emission Trends ($MMtCO_2e$)



Source: Calculations based on approach described in text.

Key Uncertainties

Key sources of uncertainty underlying the estimates above are as follows:

- Current levels of fugitive emissions. These are based on industry-wide averages, and until estimates are available for local facilities, significant uncertainties remain.
- Due to data limitations associated with OPS reporting, it was necessary to estimate pipeline mileage for a few pipeline operators in select years. In addition, it was necessary to estimate natural gas transmission and distribution pipeline emissions in earlier years by assuming that changes in each emissions producing activity were related to changes in activity levels for surrogates for the emissions activity. Because distribution pipeline emissions are a function of both pipeline mileage/service counts and the type of pipeline material (e.g., plastic vs. cast iron), this approach does not account for emissions changes that would have occurred from any changes in pipeline material between 1990 and 2004.
- Projections of future production of fossil fuels. The assumptions used for the projections do not reflect all potential future changes that could affect GHG emissions, including potential changes in regulations and emissions-reducing improvements in pipeline technologies.

Appendix F. Agriculture

Overview

The emissions covered in this appendix refer to non-energy methane (CH_4) and nitrous oxide (N_2O) emissions from livestock and crop production. Emissions and sinks of carbon in agricultural soils due to changes in cultivation practices are also covered. Energy emissions (combustion of fossil fuels in agricultural equipment) are included in the residential, commercial, and industrial (RCI) sector estimates (see Appendix B). The primary GHG sources and sinks - livestock production, agricultural soils, and crop residue burning are further subdivided as follows:

- *Livestock production – enteric fermentation:* CH_4 emissions from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock. Microbes in the animal digestive system break down food and emit CH_4 as a by-product. More CH_4 is produced in ruminant livestock because of digestive activity in the large fore-stomach.
- *Livestock production – manure management:* CH_4 and N_2O emissions from the storage and treatment of livestock manure (e.g., in compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition. The environmental conditions of decomposition drive the relative magnitude of emissions. In general, the more anaerobic the conditions are, the more CH_4 is produced because decomposition is aided by CH_4-producing bacteria that thrive in oxygen-limited conditions. In contrast, N_2O emissions are increased under aerobic conditions. Emission estimates from manure management are based on manure that is stored and treated on livestock operations (e.g. dairies, feedlots, swine operations). Emissions from manure that is applied to agricultural soils as an amendment or deposited directly to pasture and grazing land by grazing animals are accounted for under agricultural soils emissions.
- *Agricultural soils – fertilizers:* The management of agricultural soils can result in N_2O emissions and net fluxes of carbon dioxide (CO_2) causing emissions or sinks. In general, soil amendments that add nitrogen to soils can also result in N_2O emissions. Nitrogen additions drive underlying soil nitrification and de-nitrification cycles, which produce N_2O as a by-product. The emissions estimation methodologies used in this inventory account for several sources of N_2O emissions from agricultural soils, including decomposition of crop residues, synthetic and organic fertilizer application, manure application, sewage sludge application, nitrogen fixation, and histosols (high organic soils, such as wetlands or peatlands) cultivation (see additional agricultural soils subsectors below). Both direct and indirect emissions of N_2O occur from the application of manure, fertilizer, and sewage sludge to agricultural soils. Direct emissions occur at the site of application and indirect emissions occur when nitrogen leaches to groundwater or in surface runoff and enters the nitrification/denitrification cycle.
- *Agricultural soils – crops:* this source sector covers N_2O emissions from decomposition of crop residues, production of nitrogen fixing crops, and the cultivation of histosols.
- *Agricultural soils – livestock:* this source sector covers N_2O emissions resulting from animal excretions left on agricultural soils (e.g. pasture or range).
- *Agricultural soils – liming:* the practice of adding limestone and dolomite to agricultural soils (for neutralizing acidic soil conditions) results in CO_2 emissions.
- *Agricultural soils – rice cultivation:* CH_4 emissions occur during rice cultivation; however, rice is not grown in Iowa.

- *Agricultural soils – soil carbon:* the net flux of CO_2 in agricultural soils depends on the balance of carbon losses from management practices and gains from organic matter inputs to the soil. Carbon dioxide is absorbed by plants through photosynthesis and ultimately becomes the carbon source for organic matter inputs to agricultural soils. When inputs are greater than losses, the soil accumulates carbon and there is a net sink of CO_2 into agricultural soils. In addition, soil disturbance from the cultivation of histosols releases large stores of carbon from the soil to the atmosphere in the form of CO_2 (Note: N_2O emissions from cultivation of histosols are covered under the *Agricultural soils - crops* sector above).
- *Crop residue burning:* CH_4 and N_2O emissions are produced when crop residues are burned.

Emissions and Reference Case Projections

Inventory Data

GHG emissions for 1990 through 2005 were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[86] In general, the SIT methodology applies emission factors developed for the US to activity data for the agriculture sector. Activity data include livestock population statistics, crop production statistics, amounts of fertilizer applied to crops, and trends in manure management practices. This methodology is based on international guidelines developed by sector experts for preparing GHG emissions inventories.[87]

Data on crop production in Iowa from 1990 to 2005 and the number of animals in the state from 1990 to 2005 were obtained from the United States Department of Agriculture (USDA) National Agriculture Statistical Service (NASS) and incorporated as defaults in SIT.[88] The default SIT manure management system assumptions for each livestock category were used for this inventory. SIT data on fertilizer usage came from *Commercial Fertilizers*, a report from the Fertilizer Institute. Details for each of the livestock and crop production subsectors are provided below.

Livestock production – enteric fermentation. SIT default data on livestock populations are taken from the USDA NASS and are available from 1990-2005. Methane emission factors specific to each type of animal by region (e.g. dairy cattle, beef cattle, sheep, goats, swine, and horses) are provided in SIT.

Livestock production – manure management. The same population data used above for enteric fermentation are also used as input to estimate CH_4 and N_2O emissions from manure management. Population estimates are multiplied by an estimate for typical animal mass and a volatile solids (VS) production rate to estimate the total VS produced. The VS estimate for each

[86] GHG emissions were calculated using SIT, with reference to EIIP, Volume VIII: Chapter 8. "Methods for Estimating Greenhouse Gas Emissions from Livestock Manure Management", August 2004; Chapter 10. "Methods for Estimating Greenhouse Gas Emissions from Agricultural Soil Management", August 2004; and Chapter 11. "Methods for Estimating Greenhouse Gas Emissions from Field Burning of Agricultural Residues", August 2004.
[87] Revised 1996 1ntergovermental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, published by the National Greenhouse Gas Inventory Program of the IPCC, available at (http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm; and Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, published in 2000 by the National Greenhouse Gas Inventory Program of the IPCC, available at: (http://www.ipcc-nggip.iges.or.jp/public/gp/english/).
[88] USDA, NASS (http://www.nass.usda.gov/Statistics_by_State/Iowa/index.asp).

animal type is then multiplied by a maximum potential CH_4 emissions factor and a weighted CH_4 conversion factor to derive total CH_4 emissions. The methane conversion factor adjusts the maximum potential methane emissions based on the types of manure management systems employed in Iowa.

Nitrous oxide emissions are derived using the same animal population estimates above multiplied by the typical animal mass and a total Kjeldahl nitrogen (K-nitrogen) production factor. The total K-nitrogen is multiplied by a non-volatilization factor to determine the fraction that is managed in manure management systems. The unvolatilized portion is then divided into fractions that get processed in either liquid (e.g. lagoons) or solid waste management systems (e.g. storage piles, composting). Each of these fractions is then multiplied by an N_2O emission factor, and the results summed, to estimate total N_2O emissions.

Agricultural soils - fertilizers, crops, and livestock. The fertilizers subsector covers direct and indirect N_2O emissions from the application of synthetic and organic fertilizers. The crops subsector covers N_2O emissions from nitrogen fixing crops, decomposition of crop residues, and cultivation of high organic content soils (histosols). The livestock category covers N_2O emissions from animal excretions directly onto the land area (rather than manure applied intentionally to farmland, which is captured under the *Agricultural soils – fertilizers* subsector).

Emissions of N_2O occur naturally as part of the nitrogen cycle. However, various soil management practices have significantly increased the amount of N_2O going into the atmosphere. There are three source categories of nitrous oxide emissions from soil management. The first is direct emissions from agricultural cropping practices, which occur primarily through applications of fertilizer or decomposition of crop residues, cultivation of histosols, and through the production of nitrogen fixing crops. Data inputs used to calculate the direct emissions from agricultural cropping practices include:

1. The amount of nitrogen applied to the soil through fertilizers (synthetic and organic);
2. Animal population, mass and N emitted per unit of animal mass;
3. Amount of manure intentionally applied to soils;
4. Amount of residue left on cropland and the N content of such residues; and
5. Acreage of histosols cultivated (these data were not available for Iowa).

A variety of factors can influence the amount of N_2O produced through these agricultural cropping practices, such as temperature, water content, soil pH, etc.

Direct emissions from livestock is another source category of N_2O emissions from agricultural soils, namely through animal excretions directly onto the land area. This requires data on animal population, mass and N emitted per unit of animal mass, as well as the amount of manure left on the soil.

The third source category is indirect emissions from nitrogen applied to soils. This can occur through the volatilization of ammonia and oxides of nitrogen (which can then be re-deposited, enter the nitrification/denitrification cycle, and be emitted as N_2O); or through leaching/runoff of N, which can enter the nitrification/denitrification cycle on or off-site, and then be emitted as N_2O. To calculate these emissions, the data used above on nitrogen inputs from fertilizers and animals to crop soils are used again along with factors on the fraction of nitrogen volatilized (10% for synthetic fertilizers and 20% for organic fertilizer nitrogen), and an IPCC-based emission factor for N_2O emissions from the re-deposited nitrogen (0.01 kg N_2O-N/kg N re-deposited).

Crop production data from USDA NASS were available through 2005; therefore, N_2O emissions from crop residues and crops that fix nitrogen were calculated through 2005. Data were not available to estimate nitrogen released by the cultivation of histosols (i.e., the number of acres of high organic content soils). Given that cultivation of organic soils is a source of CO_2 emissions in Iowa (see soil carbon discussion below), N_2O emissions are also probably occurring. CCS was unable to obtain the state-level cultivation data for histosols which would have allowed for an estimate of N_2O emissions.

Crop production – liming. Additions of lime for pH adjustment and urea fertilizer to soils release carbon dioxide as these materials are degraded. Data on limestone and dolomite application from 1990-2004 were available from the Land-Use Change and Forestry Module of SIT. The SIT emission factor of 0.06 Mt C/Mt limestone/dolomite was used to estimate CO_2 emissions. Limestone/dolomite application data are not specific to land use; however, CCS assumed that the applications were all applied to agricultural soils. Data specific to urea application were not readily available; hence, the emissions are not captured in this inventory. The data in SIT are provided in terms of total commercial fertilizer N applied.

Crop production – rice cultivation. Methane emissions occur during rice cultivation as a result of the anaerobic decomposition of organic materials in flooded fields. No rice cultivation occurs in Iowa.

Crop production – soil carbon. Net carbon fluxes from agricultural soils have been estimated by researchers at the Natural Resources Ecology Laboratory at Colorado State University and are reported in the US Inventory of Greenhouse Gas Emissions and Sinks[89] and the US Agriculture and Forestry Greenhouse Gas Inventory. The estimates are based on the Intergovernmental Panel on Climate Change (IPCC) methodology for soil carbon adapted to conditions in the US. Preliminary state-level estimates of CO_2 fluxes from mineral soils and emissions from the cultivation of organic soils were reported in the US Agriculture and Forestry Greenhouse Gas Inventory. The inventory also reports national estimates of CO_2 emissions from agricultural limestone and dolomite applications from the United States Geological Survey (USGS).[90] However, these are now included above under the *Agricultural soils – liming* subsector.

Carbon dioxide fluxes resulting from specific management practices were reported. These practices include: conversions of cropland resulting in either higher or lower soil carbon levels; additions of manure; participation in the Federal Conservation Reserve Program (CRP); and cultivation of organic soils (with high organic carbon levels). For Iowa, Table F1 shows a summary of soil carbon changes in the state.[91]

[89] US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005 (and earlier editions), US Environmental Protection Agency, Report # 430-R-07-002**,** April 2007. Available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

[90] State-level annual application rates of limestone and dolomite to agricultural purposes were provided from the Minerals Yearbook "Crushed Stone" from the USGS website: http://minerals.er.usgs.gov/minerals/pubs/commodity/stone_crushed/.

[91] This is a year 2000 estimate of the soil carbon sequestration in Iowa. This comes from a publication by William Stigliani, which references a 2001 study of soil carbon in Iowa. Brenner et al. "Quantifying the change in greenhouse gas emissions due to natural resource conservation practice application in Iowa" March, 2001. Natural Resource Ecology Laboratory, Natural Resource Conservation Service and Department of Energy.

Table F1. GHG Emissions from Soil Carbon Changes Due to Cultivation Practices ($MMtCO_2e$)

Cropland	-6.98
CRP Land	-3.09
Grass Conversion	-1.82
Tree Conversion	-0.04
Wetland Reversion	-0.07
Cultivated Organic Soils	0.62
State Total	**-11.37**

These data show that changes in agricultural practices are estimated to result in net sequestration of 11.4 million metric tons (MMt) of CO_2 equivalent (CO_2e) per year in Iowa; this is driven largely by sequestration occurring in cropland and CRP land. The data shown in Table F1 represent soil carbon sequestration in the year 2000. Since 2000 is the only year available with such data, soil carbon sequestration from agricultural practices is assumed to remain constant throughout the inventory and forecast periods.

Note that emissions from agricultural soils estimated using the SIT were multiplied by a national adjustment factor to reconcile differences between methodologies used in EPA's National Inventory of Greenhouse Gas Emissions and the SIT. The national adjustment factor varies substantially from year to year resulting in the introduction of noise into the agricultural soils categories.

Crop production – residue burning. There is some agricultural residue burning conducted in Iowa; however, emissions are estimated to be relatively small (<0.2 $MMtCO_2e$). Agricultural burning can result in emissions of both N_2O and CH_4. The default SIT method was used to calculate emissions along with NASS crop production data through 2005. The SIT methodology calculates emissions by multiplying the amount (e.g., bushels or tons) of each crop produced by a series of factors to calculate the amount of crop residue produced, the resultant dry matter, the carbon/nitrogen content of the dry matter, the fraction of dry matter burned, the combustion efficiency, and emission factors for N_2O and CH_4.

Forecast Data

Emissions from enteric fermentation and manure management were projected based on forecasted animal populations. Dairy cattle forecasts were based on state-level projections of dairy cows from the Food and Agricultural Policy Research Institute (FAPRI).[92] Projections for all other livestock categories except sheep and broilers were estimated based on linear forecasts of the historical 1990-2005 populations. Sheep populations were held at 2005 levels throughout the forecast period to prevent their population estimate from going negative. Only the broiler populations from the last five years (2000-2005) were used to predict population growth between 2006 and 2025. This was done because rapid growth between 1990-2000 caused unrealistic population estimates if the full fifteen year range is used to predict future growth. Livestock population growth rates are shown in Table F2.

[92] FAPRI Agricultural Outlook 2006, Food and Agricultural Policy Research Institute, http://www.fapri.iastate.edu/outlook2006.

Projections for agricultural burning and the various agricultural soils categories were based on linear extrapolation of the 1990-2005 historical data. Table F3 shows the 2005-2025 annual growth rates estimated for each category. In the case of liming of soils, there is only default data available for 1990-2004. Projections for this category begin with the year 2005, rather than 2006. For agricultural soil carbon, the net flux was held at the 2000 levels shown in Table F1, since there was only one year of data available.

Table F2. Growth Rates Applied for the Enteric Fermentation and Manure Management Categories

Livestock Category	2005-2025 Annual Growth
Dairy Cattle	-1.25%
Beef Cattle	-2.43%
Swine	0.53%
Sheep	0.00%
Goats	0.65%
Horses	0.81%
Turkeys	-6.39%
Layers	3.69%
Broilers	-2.30%

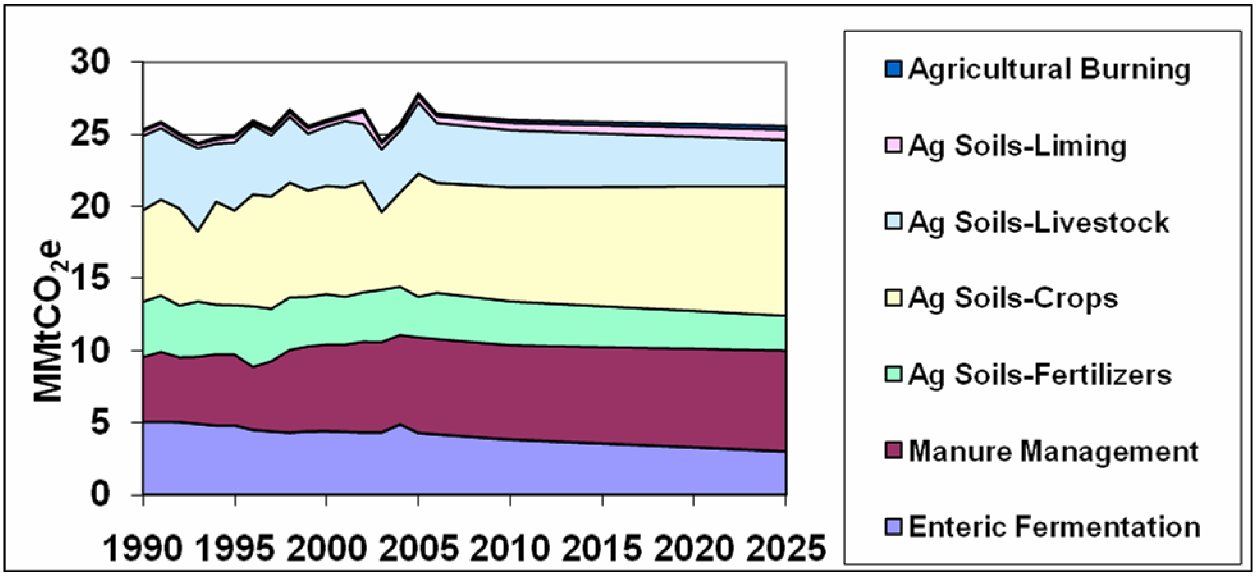
Table F3. Growth Rates Applied for the Agricultural Soils and Burning

Agricultural Category	2005-2025 Growth Rate
Agricultural Burning	1.57%
Liming of Agricultural Soils	2.21%
Agricultural Soils – Direct Emissions	
Fertilizers	-0.77%
Crop Residues	0.34%
Nitrogen-Fixing Crops	0.20%
Histosols	0.00%
Livestock	-3.89%
Agricultural Soils – Indirect Emissions	
Fertilizers	-0.73%
Livestock	-3.73%
Leaching/Runoff	-1.31%

Results

Figure F1 shows gross GHG emissions associated with the agricultural sector from 1990 through 2025. Table F4 displays the same information in table format, along with the net emissions resulting when the sequestrations from agricultural soils—cultivation practices is accounted for.

Figure F1. Gross GHG Emissions from Agriculture, 1990-2025



Source: Calculations based on approach described in text.
Notes: Ag Soils – Crops category includes: incorporation of crop residues and nitrogen fixing crops (no cultivation of histosols estimated); emissions for agricultural residue burning are too small to be seen in this chart.

Table F4. Gross and Net GHG Emissions from Agriculture in Iowa ($MMtCO_2e$)

Source	1990	1995	2000	2005	2010	2015	2020	2025
Enteric Fermentation	5.04	4.78	4.39	4.26	3.81	3.54	3.27	2.98
Manure Management	4.49	4.93	6.02	6.64	6.55	6.70	6.86	7.01
Ag Soils-Fertilizers	3.83	3.42	3.49	2.81	3.04	2.83	2.62	2.41
Ag Soils-Crops	6.35	6.58	7.52	8.55	7.93	8.28	8.64	9.00
Ag Soils-Livestock	5.17	4.72	4.12	4.95	3.96	3.71	3.46	3.21
Ag Soils-Liming	0.34	0.39	0.33	0.47	0.54	0.60	0.67	0.73
Agricultural Burning	0.13	0.14	0.16	0.19	0.20	0.22	0.24	0.26
Total Gross Emissions	***25.36***	***24.96***	***26.03***	***27.87***	***26.03***	***25.88***	***25.75***	***25.60***
Ag Soils-Cultivation Practices	-11.37	-11.37	-11.37	-11.37	-11.37	-11.37	-11.37	-11.37
Total Net Emissions	***13.99***	***13.59***	***14.66***	***16.50***	***14.66***	***14.51***	***14.38***	***14.23***

Source: Calculations based on approach described in text.

The largest source of emissions in the agricultural sector is the agricultural soils category, which includes crops (legumes and crop residues), fertilizer, manure application, application of limestone and dolomite, and indirect sources (leaching, runoff, and atmospheric deposition). Agricultural soils emissions are projected to hold steady from 1990 to 2025, accounting for 62% (15.7 $MMtCO_2e$) of total gross agricultural emissions in 1990 and 60% (15.4 $MMtCO_2e$) in 2025.

In 1990, enteric fermentation accounted for about 20% (5.04 $MMtCO_2e$) of total gross agricultural emissions. Enteric fermentation emissions decreased slightly to 4.26 $MMtCO_2e$ between 1990 and 2005 due to the decline in livestock populations in this time period. Both the dairy cattle and beef cattle populations are projected to decrease in the future, and enteric fermentation emissions are estimated to decrease to 2.98 $MMtCO_2e$ in 2025, or about 12% of agricultural emissions.

The manure management category accounted for 18% (4.49 $MMtCO_2e$) of total agricultural emissions in 1990 and increased to 24% (6.64 $MMtCO_2e$) by 2005. Manure management is projected to increase slightly by 2025, to account for 27% (7.01 $MMtCO_2e$) of total agricultural emissions at that time. This is largely due to the projection that the swine population will increase between 2005 and 2025.

The only standard IPCC source category missing from this report is N_2O emissions from the cultivation of histosols; there were no activity data available for Iowa.

Key Uncertainties

Emissions from enteric fermentation and manure management are dependent on the estimates of animal populations and the various factors used to estimate emissions for each animal type and manure management system (i.e., emission factors which are derived from several variables including manure production levels, volatile solids content, and CH_4 formation potential). Each of these factors has some level of uncertainty. Also, animal populations fluctuate throughout the year, and thus using point estimates introduces uncertainty into the average annual estimates of these populations. In addition, there is uncertainty associated with the original population survey methods employed by USDA. The largest contributors to uncertainty in emissions from manure management are the emission factors, which are derived from limited data sets.

As mentioned above, for emissions associated with changes in agricultural soil carbon levels, the only data currently available are for 2000. Given the potential for some CRP acreage to retire and possibly return to active cultivation prior to 2025, the emissions could be appreciably affected. Also, one of the agricultural cultivation practices addressed by EPA in their national assessment is cultivation of organic soils and a state-level estimate of the resultant CO_2 emissions has been included in this inventory; however, the associated acreage of organic soils cultivation was not available such that CCS could estimate the N_2O emissions that also occur as a result of cultivation of these soils (histosols).

Uncertainties in the estimates of emissions from liming result from both the emission factors and the activity data. It is uncertain what fraction of agricultural lime is dissolved by nitric acid – a process that releases CO_2 – and what portion reacts with carbonic acid (H_2CO_3), resulting in the uptake of CO_2. Also, there is uncertainty in the limestone and dolomite data (reported to USGS) as some producers do not distinguish between them, and report them both as limestone.

Uncertainty in agricultural soils is introduced by the national emissions factor, which reconciles differences between methodologies used in the National Inventory of Greenhouse Gas Emissions and the SIT. The national adjustment factor varies substantially from year to year resulting in the introduction of noise into the agricultural soils categories.

Another contributor to the uncertainty in the emission estimates is the forecast assumptions. The growth rates for most categories are assumed to continue growing at historical 1990-2005 growth rates. These historical trends may not reflect future projections (e.g. due to recent dramatic increases in the prices of agricultural commodities such as corn).

Appendix G. Waste Management

Overview

Greenhouse gas (GHG) emissions from waste management include:

- Solid waste management – methane (CH_4) emissions from municipal and industrial solid waste landfills (LFs), accounting for CH_4 that is flared or captured for energy production (this includes both open and closed landfills);[93]
- Solid waste combustion – CH_4, carbon dioxide (CO_2), and nitrous oxide (N_2O) emissions from the combustion of solid waste in incinerators and waste to energy plants not already accounted for in the electricity generating sector; and
- Wastewater management – CH_4 and N_2O from municipal wastewater (WW) and CH_4 from industrial wastewater treatment facilities.

Inventory and Reference Case Projections

Solid Waste Management

For solid waste management, the United States Environmental Protection Agency's (US EPA) State Inventory Tool (SIT) software was used to estimate emissions. These emissions were based on state population and national average landfilling rates. CCS did not apply the SIT assumption that 10% of CH_4 is oxidized as it travels through the surface layers of the landfill due to a lack of information to support this assumption. Iowa Department of Natural Resources (DNR) was contacted to provide state-specific data on waste emplacement and landfill emissions controls, however the state does not maintain landfill records

Emissions for industrial solid waste landfills were estimated using the SIT default activity data and emission factors. The activity data are based on national data indicating that industrial landfill methane emissions are approximately 7% of municipal solid waste (MSW) emissions nationally. It was assumed that industrial waste emplacement occurs beyond that already addressed in the emplacement rates for MSW sites described above.

The amount of CH_4 captured for flaring and use in landfill gas-to-energy (LFGTE) plants was estimated with SIT defaults that are based on data collected from vendors of flaring equipment, a database of landfill gas-to-energy (LFGTE) projects compiled by the EPA, and a database maintained by the Energy Information Administration (EIA) for the voluntary reporting of GHGs.[94] The amount of landfill gas flared in Iowa may be underestimated if Iowa flaring and LFGTE controls have been underreported to the EPA and EIA.

Growth rates were estimated by using the historical (1995-2005) growth rates of total net emissions from landfills. The annual growth rates are 1.6% for MSW landfills and 1.6% for industrial landfills.

[93] CCS acknowledges that N_2O and CH_4 emissions are also produced from the combustion of landfill gas; however, these emissions tend to be negligible for the purposes of developing a state-level inventory for policy analysis.
[94] See Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2005, Chapter 8 Waste, US EPA, Report #430-R-07-002, April 2007 (http://epa.gov/climatechange/emissions/ usinventoryreport.html).

Solid Waste Combustion

Sources of solid waste combustion in Iowa include municipal waste combustion, medical waste incinerators and hazardous waste incineration. The Iowa State University power plant in Ames is a waste-to-energy facility that burns refuse. Its emissions are included in the electricity generating sector instead of the waste sector. Annual tonnage incinerated in 2006 was obtained from the Iowa DNR and this amount was used to estimate amount incinerated for all years in the historical 1990-2005 period. The SIT defaults for emission factors waste characteristics were used. As described under Key Uncertainties below, the SIT emission factors are based on MSW, not medical or hazardous waste, and their use presents a source of uncertainty in the estimates (e.g. medical and hazardous waste could contain significantly different levels of fossil-based carbon than MSW).

Open burning of MSW at residential sites (e.g. backyard burn barrels) also contributes to GHG emissions. Iowa DNR provided a list of municipalities that had enacted a residential burning ban as of 2004-2005 and their respective populations. 2005 emissions from open burning were estimated using the population of municipalities without a burning ban. 1990 emissions from open burning were estimated using the US EPA's 2002 National Emissions Inventory (NEI) method of estimating the quantity of waste burned at residential sites in Iowa[95] and SIT emission factors and waste characteristics. Since it is not known when each municipality enacted its ban, a linear growth rate (in this case negative) was assumed from 1990 to 2005. The historical (1990-2005) growth rate of -1.0% for incineration and residential waste combustion combined was used to estimate future growth rates.

Wastewater Management

GHG emissions from municipal wastewater treatment were also estimated. For municipal wastewater treatment, emissions are calculated in EPA's SIT based on state population, assumed biochemical oxygen demand (BOD) and protein consumption per capita, and emission factors for N_2O and CH_4. The key SIT default values are shown in Table G1 below. Municipal wastewater emissions were projected based on the historical growth rate for 1990-2005 for a growth rate of 0.6% per year.

Table G1. SIT Key Default Values for Municipal Wastewater Treatment

Variable	Default Value
BOD	0.09 kilogram (kg) /day-person
Amount of BOD anaerobically treated	16.25%
CH_4 emission factor	0.6 kg/kg BOD
Iowa residents not on septic	75%
Water treatment N_2O emission factor	4.0 g N_2O/person-yr
Biosolids emission factor	0.01 kg N_2O-N/kg sewage-N

Source: US EPA State Greenhouse Gas Inventory Tool (SIT) – Wastewater Module.

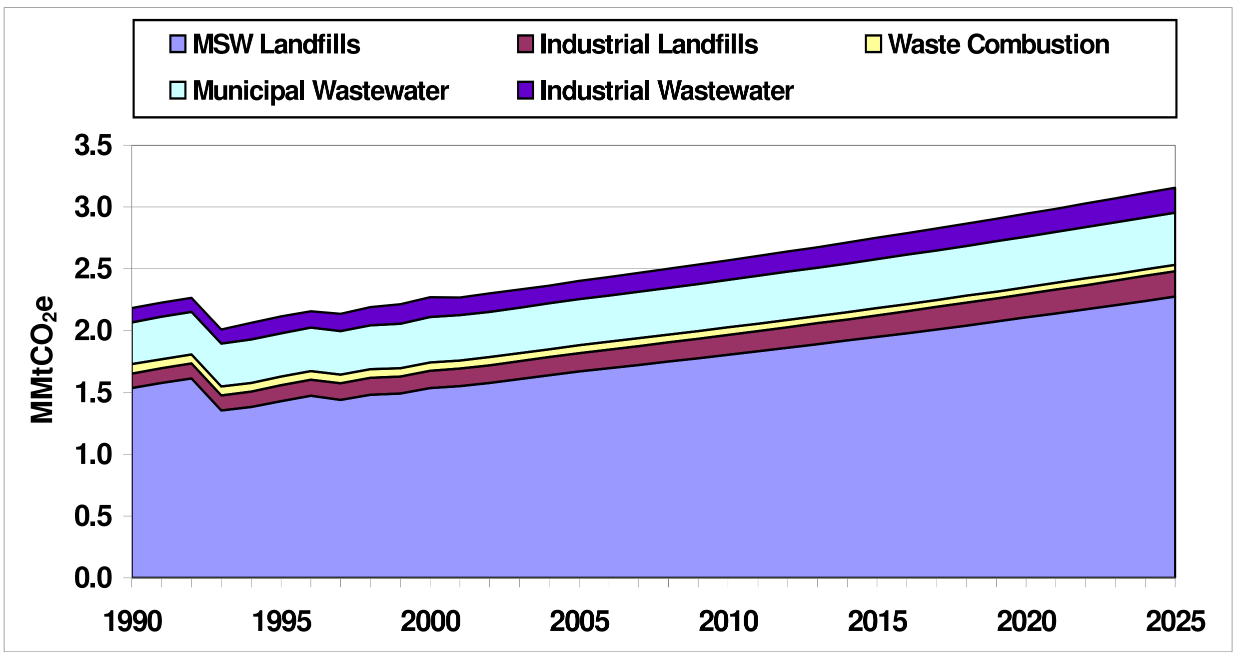
[95] EPA, ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/nonpoint/2002nei_final_nonpoint_documentation0206version.pdf.

For industrial wastewater emissions, SIT provides default assumptions and emission factors for three industrial sectors: Fruits & Vegetables, Red Meat & Poultry, and Pulp & Paper. The SIT default activity data were used to estimate emissions for red meat production; however, default data were not available for the other sectors. Emissions were projected to 2025 based on the 1990-2005 annual growth rate of 1.5%. See the Key Uncertainties section below for more information on industrial WW treatment.

Results

Figure G1 and Table G2 show the emission estimates for the waste management sector. Overall, the sector accounts for 2.40 $MMtCO_2e$ in 2005, and emissions are estimated to be 3.16 $MMtCO_2e$/yr in 2025. The largest contributor to waste management emissions is the solid waste sector, in particular, municipal landfills. In 2005, municipal landfills accounted for 69% of total waste management emissions and are expected to increase slightly to 72% by 2025. Industrial landfills accounted for about 6% of waste management emissions in 2005, and are expected to increase slightly to 7% in 2025.

Figure G1. Iowa GHG Emissions from Waste Management, 1990-2025



Source: Calculations based on approach described in text.

Table G2. Iowa GHG Emissions from Waste Management ($MMtCO_2e$)

Source	1990	1995	2000	2005	2010	2015	2020	2025
MSW Landfills	1.54	1.43	1.54	1.67	1.80	1.95	2.11	2.28
Industrial Landfills	0.12	0.13	0.14	0.15	0.16	0.18	0.19	0.21
Waste Combustion	0.07	0.07	0.07	0.06	0.06	0.06	0.05	0.05
Municipal Wastewater	0.34	0.35	0.37	0.37	0.38	0.40	0.41	0.42
Industrial Wastewater	0.12	0.14	0.16	0.15	0.16	0.17	0.19	0.20
Total	**2.18**	**2.12**	**2.27**	**2.40**	**2.57**	**2.75**	**2.95**	**3.16**

Source: Calculations based on approach described in text.

In 2005, about 15% of the waste management sector emissions were contributed by municipal wastewater treatment systems and 6% by the industrial wastewater subsector. Note that these estimates are based on the default parameters listed in Table G1 above, and might not adequately account for emissions, existing controls, or management practices (e.g. anaerobic digesters served by a flare or other combustion device). By 2025, the municipal wastewater treatment subsector is expected to contribute about 13% and industrial wastewater is expected to contribute about 6% to the waste management sector.

Emissions from waste combustion contributed 3% of waste sector emissions in 2005 and are expected to decrease to 2% by 2025.

Key Uncertainties

Municipal solid waste emissions were estimated with default data, which are based on a per capita approach to estimating waste tonnage. In addition, this inventory was calculated using default data in all of the historical years for MSW controls. A more accurate approach would involve allocating Iowa DNR landfill emplacement volumes by the portion of waste going to uncontrolled landfills, landfills with flares, and LFGTE facilities, so that control factors could more accurately be applied. However, Iowa DNR does not maintain state landfill records so the use of default data is a source of uncertainty. Since, this is a state-level assessment, the methods also do not adequately account for the points in time when controls were applied at individual sites. The modeling also does not account for uncontrolled landfills that will need to apply controls during the period of analysis due to triggering requirements of the federal New Source Performance Standards/Emission Guidelines.

For industrial landfills, emissions were estimated using national defaults (with industrial landfill emissions approximately 7% of MSW emissions). Depending on actual industrial landfill emissions in Iowa, this could be an over- or underestimate.

SIT defaults for waste composition that are optimized for municipal waste were used to estimate medical waste and hazardous combustion and incineration emissions. To the extent that medical and hazardous waste composition is significantly different than municipal waste, the resulting emissions may be a slight under- or overestimate. Facilities that burn refuse as an energy source, such as AgBio Power and the ISU power plant, are not included in the waste sector inventory but are addressed in the commercial fuel source or electricity inventory. Open burning of waste at residential sites was estimated using Iowa DNR data on municipal burn bans and a US EPA NEI methodology. Depending on actual burn rates, this could be an over- or underestimate. Emissions from open burning of yard waste were not estimated but are expected to be small (only the CH_4 and N_2O emissions would be of interest here, since the CO_2 would be considered to be biogenic).

For the wastewater sector, the key uncertainties are associated with the application of SIT default values for the parameters listed in Table G1 above (e.g. fraction of the Iowa population on septic; fraction of BOD which is anaerobically decomposed). The SIT defaults were derived from national data.

For industrial wastewater, emissions were only estimated for the red meat industry using default data; default data for fruits and vegetables, poultry, and pulp and paper were not available. Therefore, emissions from industrial wastewater are likely to be underestimated.
This inventory in its current state does not quantify current actions taken by the State of Iowa that may lower future emissions.

Appendix H. Forestry & Land Use

Overview

Forestland emissions refer to the net carbon dioxide (CO_2) flux[96] from forested lands in Iowa, which account for about 8% of the state's land area.[97] The dominant forest type in Iowa is Oak-hickory which makes up about 36% of forested lands. Other common forest types are Mixed upland hardwoods at 26%, Hackberry-elm-ash-cottonwood at 18%, Maple-beech-birch at 12%, and Elm-ash-cottonwood-willow at 5% of forested land. All other forest types make up less than 6% each of the State's forests.

Through photosynthesis, CO_2 is taken up by trees and plants and converted to carbon in biomass within the forests. Carbon dioxide emissions occur from respiration in live trees, decay of dead biomass, and combustion (both wildfires and biomass removed from forests for energy use). In addition, carbon is stored for long time periods when forest biomass is harvested for use in durable wood products. Carbon dioxide flux is the net balance of CO_2 removals from and emissions to the atmosphere from the processes described above.

The forestry sector CO_2 flux is categorized into two primary subsectors:

- *Forested Landscape:* this consists of carbon flux occurring on lands that are not part of the urban landscape. Fluxes covered include net carbon sequestration, carbon stored in harvested wood products (HWP) or landfills, and emissions from forest fires and prescribed burns.
- *Urban Forestry and Land Use:* this covers carbon sequestration in urban trees, flux associated with carbon storage from landscape waste and food scraps in landfills, and nitrous oxide (N_2O) emissions from settlement soils (those occurring as a result of application of synthetic fertilizers).

Inventory and Reference Case Projections

Forested Landscape

For over a decade, the United States Forest Service (USFS) has been developing and refining a forest carbon modeling system for the purposes of estimating forest carbon inventories. The methodology is used to develop national forest CO_2 fluxes for the official *US Inventory of Greenhouse Gas Emissions and Sinks*. The national estimates are compiled from state-level data. The Iowa forest CO_2 flux data in this report come from the national analysis and are provided by the USFS. See the footnotes below for the most current documentation for the forest carbon modeling.[98] Additional forest carbon information is in the form of specific carbon conversion factors.[99]

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[96] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.
[97] Total forested area and forest type percentages provided by P. Tauke, DNR to M. Stein, DNR on March 21, 2008. The total land area in Iowa is 35.8 million acres (http://www.50states.com/iowa.htm).
[98] The most current citation for an overview of how the USFS calculates the inventory based forest carbon estimates as well as carbon in harvested wood products is from the US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005 (and earlier editions), US Environmental Protection Agency, Report # USEPA #430-R-07-002, April 2007, available at: http://epa.gov/climatechange/emissions/usinventoryreport.html. Both Annex 3.12 and Chapter 7 LULUCF are useful sources of reference. See also Smith, J.E., L.S. Heath, and M.C. Nichols (in press), *US Forest*

The forest CO_2 flux methodology relies on input data in the form of plot-level forest volume statistics from the Forest Inventory and Analysis (FIA) Program. FIA data on forest volumes are converted to values for ecosystem carbon stocks (i.e., the amount of carbon stored in forest carbon pools) using the FORCARB2 modeling system. Coefficients from FORCARB2 are applied to the plot level survey data to give estimates of C density [megagrams (Mg) per hectare] for a number of separate C pools (see Table H1 for Iowa C pools). Additional background on the FORCARB system is provided in a number of publications.[100]

Carbon dioxide flux is estimated as the change in carbon mass for each carbon pool over a specified time-frame. Forest biomass data from at least two points in time are required. The change in carbon stocks between time intervals is estimated for specific carbon pools (Live Tree, Standing Dead Wood, Understory, Down & Dead Wood, Forest Floor, and Soil Organic Carbon) and divided by the number of years between inventory samples. Annual increases in carbon density reflect carbon sequestration in a specific pool; decreases in carbon density reveal CO_2 emissions or carbon transfers out of that pool (e.g., death of a standing tree transfers carbon from the live tree to standing dead wood pool). The amount of carbon in each pool is also influenced by changes in forest area (e.g., an increase in area could lead to an increase in the associated forest carbon pools and the estimated flux). The sum of carbon stock changes for all forest carbon pools yields a total net CO_2 flux for forest ecosystems.

In preparing these estimates, USFS estimates the amount of forest carbon in different forest types as well as different carbon pools. The different forests also include differences in ownership class: those in the national forest (NF) system and those that are not federally-owned (private and other public forests). Additional details on the forest carbon inventory methods can be found in Annex 3 to the US EPA's 2007 GHG inventory for the US.[101]

Carbon pool data for three FIA cycles to estimate flux for two different periods were available for Iowa. The carbon pool data for three points are shown in Table H1 below. Note that prior to 1999, the Northern FIA Program took periodic forest inventory surveys of Iowa (approximately on a 13-year schedule). Beginning in 1999, Iowa transitioned from periodic to annual inventories as modifications to the FIA program were applied. The annual inventories are on a 5-year cycle and sample 20% of the state forests each year. Iowa completed its first annual inventory cycle in 2003. The 2005 carbon pool data represent 40% of the current 5-year inventory cycle.

Carbon Calculation Tool User's Guide: Forestland Carbon Stocks and Net Annual Stock Change, Gen Tech Report, Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station.

[99] Smith, J.E., and L.S. Heath (2002). "A model of forest floor carbon mass for United States forest types," Res. Pap. NE-722. Newtown Square, PA: US Department of Agriculture, Forest Service, Northeastern Research Station. 37 p., or Jenkins, J.C., D.C. Chojnacky, L.S. Heath, R.A. Birdsey (2003), "National-scale biomass estimators for United States tree species", *Forest Science*, 49:12-35.

[100] Smith, J.E., L.S. Heath, and P.B. Woodbury (2004). "How to estimate forest carbon for large areas from inventory data", *Journal of Forestry*, 102: 25-31; Heath, L.S., J.E. Smith, and R.A. Birdsey (2003), "Carbon trends in US
forest lands: A context for the role of soils in forest carbon sequestration", In J. M. Kimble, L. S. Heath, R. A. Birdsey, and R. Lal, editors. *The Potential of US Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect.* CRC Press, New York; and Woodbury, Peter B.; Smith, James E.; Heath, Linda S. 2007, "Carbon sequestration in the US forest sector from 1990 to 2010", *Forest Ecology and Management*, 241:14-27.

[101] Annex 3 to EPA's 2007 report, which contains estimates for calendar year 2005, can be downloaded at: http://www.epa.gov/climatechange/emissions/downloads06/07Annex3.pdf.

The underlying FIA data, as shown in Table H1, displays a net increase in forested area for all inventory years: 615 thousand acres between 1990 and 2003 and 210 thousand acres between 2003 and 2005. This results in a net increase in forested area of 825 thousand acres in the 1990-2005 period. Most of the forested lands in Iowa are considered timberland, meaning that they are unreserved productive forest land producing, or capable of producing, crops of industrial wood. The timberland area is shown to have increased by 635 thousand acres between 1990 and 2003 while it increased 241 thousand acres between 2003 and 2005. This increase in timberland area resulted in the significant increase in carbon (52 million metric tons) from all forested areas between 1990 and 2005.

Table H1. USFS Forest Carbon Pool Data for Iowa

Forest Pool	**1990 (MMtC)**	**2003 (MMtC)**	**2005 (MMtC)**
Live Tree – Above Ground	49.3	66.7	71.6
Live Tree – Below Ground	9.4	12.7	13.6
Understory	1.4	1.9	2.1
Standing Dead	3.3	4.3	4.6
Down Dead	3.9	5.4	5.7
Forest Floor	13.7	15.7	16.4
Soil Carbon	50.2	64.5	68.9
Totals	**131**	**171**	**183**
Forest Area	**1990 (10^3 acres)**	**2003 (10^3 acres)**	**2005 (10^3 acres)**
All Forests	2,050	2,665	2,875
Timberland	1,944	2,579	2,820

MMtC = million metric tons of carbon. Positive numbers indicate net emission. Multiply MMtC by 3.667 (44/12) to convert to $MMtCO_2$.

Totals may not sum exactly due to independent rounding.

Data source: Smith, James, et al. *US Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change* (http://www.nrs.fs.fed.us/pubs/2394), December 2007.

Table H2 shows the annualized carbon stocks interpolated from Iowa FIA data using the Carbon Calculation Tool (CCT)[102]. These annualized carbon stocks differ from the carbon stocks in Table H1 in that they are interpolated values (between forest inventory years) to January 1st of each year. The difference in carbon between each consecutive year is the carbon flux for that year. The carbon fluxes for each period shown in Table H3 are based on these annualized carbon stock estimates.

[102] Smith, James, et al. *US Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change* (http://www.nrs.fs.fed.us/pubs/2394), November 2007.

Table H2. Annualized Forest Carbon Pool from Carbon Calculation Tool

Forest Pool	1990 (MMtC)	2003 (MMtC)	2005 (MMtC)
Live Tree – Above Ground	49.7	69.8	75.3
Live Tree – Below Ground	9.5	13.3	14.3
Understory	1.4	2.1	2.3
Standing Dead	3.3	4.5	4.8
Down Dead	4.0	5.6	6.0
Forest Floor	13.7	16.2	17.0
Soil Carbon	50.6	67.3	72.3
Totals	**132**	**179**	**192**
Forest Area	**1990 (10^3 acres)**	**2003 (10^3 acres)**	**2005 (10^3 acres)**
All Forests	2,065	2,799	3,035
Timberland	1,959	2,732	3,003

In addition to the forest carbon pools, additional carbon is stored in biomass removed from the forest for the production of harvested wood products (HWP). Carbon remains stored in the durable wood products pool or is transferred to landfills where much of the carbon remains stored over a long period of time. The USFS uses a model referred to as WOODCARB2 for the purposes of modeling national HWP carbon storage.[103] State-level information for Iowa was provided to CCS by USFS.[104]

As shown in Table H3, about 0.12 million metric tons (MMt) of CO_2 per year (yr) is estimated by the USFS to be sequestered annually (1990-2005) in wood products. Also, as shown in this table, the total flux estimate including all forest pools is -12.2 MMtCO_2e/yr between 1990 and 2003, and its -24.4 MMtCO_2e/yr between 2003 and 2005.[105] These totals include large sink estimates for soil carbon (-4.3 and -9.2 MMtCO_2/yr). Given the changes noted above in timberland, it appears that much of the negative trend in carbon flux (sequestration) is from the increase in timberland between 1990 and 2005.

[103] Skog, K.E., and G.A. Nicholson (1998), "Carbon cycling through wood products: the role of wood and paper products in carbon sequestration", *Forest Products Journal*, 48(7/8):75-83; or Skog, K.E., K. Pingoud, and J.E. Smith (2004), "A method countries can use to estimate changes in carbon stored in harvested wood products and the uncertainty of such estimates", *Environmental Management*, 33(Suppl. 1): S65-S73.
[104] Obtained from the Harvested Wood Product model developed by Ken Skog, USFS
[105] Jim Smith, USFS, *US. Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change* (http://www.nrs.fs.fed.us/pubs/2394), December 2007.

Table H3. USFS Annual Forest Carbon Fluxes for Iowa

Forest Pool	1990-2003 Flux ($MMtCO_2$)	2003-2005 Flux ($MMtCO_2$)
Forest Carbon Pools (non-soil)	-7.76	-15.1
Soil Organic Carbon	-4.28	-9.17
Harvested Wood Products	-0.12	-0.12
Totals	**-12.2**	**-24.4**
Totals (excluding soil carbon)	**-7.88**	**-15.3**

Totals may not sum exactly due to independent rounding.
Data source: Smith, James, et al. US Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change (http://www.nrs.fs.fed.us/pubs/2394), USFS, December 2007.

Based on discussions with the USFS, CCS recommends excluding the soil carbon pool from the overall forest flux estimates due to a high level of uncertainty associated with these estimates. The forest carbon flux estimates provided in the summary tables at the front of this report are those without the soil carbon pool.

For historical emission estimates, CCS used the 1990-2003 carbon flux to represent yearly forest carbon flux prior to 2003. Current flux estimates (2003-2005) are from the 2003 inventory and 2005 annual inventory stocks. For the reference case projections (2005-2025), the forest area and carbon densities of forestlands were assumed to remain at the same levels as in 2005. Information is not available on the near term effects of climate change and their impacts on forest productivity. Nor were data readily-available on projected losses/increases in forested area.

Urban Forestry & Land Use

GHG emissions for 1990 through 2005 were estimated using the EPA State Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[106] In general, the SIT methodology applies emission factors developed for the US to activity data for the urban forestry sector. Activity data include urban area, urban area with tree cover, amount of landfilled yard trimmings and food scraps, and the total amount of synthetic fertilizer applied to settlement soils (e.g., parks, yards, etc.). This methodology is based on international guidelines developed by sector experts for preparing GHG emissions inventories.[107] Table H4 displays the emissions and reference case projections for Iowa.

[106] GHG emissions were calculated using SIT, with reference to EIIP, Volume VIII: Chapter 8.
[107] Revised 1996 1ntergovermental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, published by the National Greenhouse Gas Inventory Program of the IPCC, available at

Table H4. Urban Forestry & Land Use Emissions and Reference Case Projections ($MMtCO_2e$)

	1990	2000	2005	2010	2020	2025
Urban Trees	-0.48	-0.54	-0.57	-0.57	-0.57	-0.57
Landfilled Yard Trimmings and Food Scraps	-2.49	-0.5	-0.51	-0.51	-0.51	-0.51
N_2O from Settlement Soils	0.38	0.39	0.46	0.46	0.46	0.46
Total	**-2.59**	**-0.65**	**-0.63**	**-0.63**	**-0.63**	**-0.63**

*Data for settlement soils was obtained from AAPFCO (2006) Commercial Fertilizers 2005. Association of American Plant Food Control Officials and The Fertilizer Institute, University of Kentucky, Lexington, KY.

Changes in carbon stocks in urban trees are equivalent to tree growth minus biomass losses resulting from pruning and mortality. Net carbon sequestration was calculated using data on crown cover area. The default urban area data in SIT (which varied from 1,893 square kilometers [km^2] to 2,229 km^2 between 1990 and 2005) was multiplied by the state estimate of the percent of urban area with tree cover (33% for Iowa) to estimate the total area of urban tree cover. These default SIT urban area tree cover data represent area estimates taken from the US Census and coverage for years 1990 and 2000.[108] Estimates of urban area in the intervening years (1990-1999) and subsequent years (2001-2005) are interpolated and extrapolated, respectively.

Estimates of net carbon flux of landfilled yard trimmings and food scraps were calculated by estimating the change in landfill carbon stocks between inventory years. The SIT estimates for the amount of landfilled yard trimmings decreased significantly during the 1990's. CCS believes that this is consistent with changes in the waste management industry during this period.

Settlement soils include all developed land, transportation infrastructure and human settlements of any size. Projections for urban trees, landfilled yard trimmings and food scraps, and settlement soils were kept constant at 2005 levels. Table H5 provides a summary of the estimated flux for the entire forestry and land use sector.

Forest Fires and Prescribed Burning

Biomass burned in forest and rangeland fires emits CO_2, methane (CH_4), and N_2O, in addition to many other gases and pollutants. Since CO_2 emissions in forests are captured under total carbon flux calculations, CCS intends to use the SIT software to estimate CH_4 and N_2O emissions. No default data were available for area burned by forest type for IA, so CCS requested available state data (1992-2005) from Iowa Department of Natural Resources (DNR). CCS also requested any information on rangeland acres burned in Iowa from Iowa DNR for the 1990-2007 timeframe. These data were not available, so no emission estimates for methane and nitrous oxide from forest fires and prescribed burning are shown in Table H5.

(http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm; and Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, published in 2000 by the National Greenhouse Gas Inventory Program of the IPCC, available at: (http://www.ipcc-nggip.iges.or.jp/public/gp/english/).

[108] Dwyer, John F.; Nowak, David J.; Noble, Mary Heather; Sisinni, Susan M. 2000. *Connecting people with ecosystems in the 21st century: an assessment of our nation's urban forests.* Gen. Tech. Rep. PNW-GTR-490

Table H5. Forestry and Land Use Flux and Reference Case Projections (MMtCO_2e)

Subsector	1990	1995	2000	2005	2010	2020	2025
Forested Landscape (excluding soil carbon)	-7.88	-7.88	-7.88	-15.3	-15.3	-15.3	-15.3
Urban Forestry and Land Use	-2.59	-1.31	-0.65	-0.63	-0.63	-0.63	-0.63
Forest Wildfires	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sector Total	**-10.5**	**-9.19**	**-8.53**	**-15.9**	**-15.9**	**-15.9**	**-15.9**

N/A – not available.

Key Uncertainties

Emissions from wildfires in Iowa have not been estimated due to a lack of availability of data of acres of forest and rangeland burned from 1990-2007. Based on work conducted in other states, CCS does not believe that these will have a significant effect on the estimated sink for the Forest & Land Use sector.

It is important to note that there were methodological differences in the three FIA cycles (used to calculate carbon pools and flux) that can produce different estimates of forested area and carbon density. For example, the FIA program modified the definition of forest cover for the woodlands class of forestland (considered to be non-productive forests). Earlier FIA cycles defined woodlands as having a tree cover of at least 10%, while the newer sampling methods used a woodlands definition of tree cover of at least 5% (leading to more area being defined as woodland). In woodland areas, the earlier FIA surveys might not have inventoried trees of certain species or with certain tree form characteristics (leading to differences in both carbon density and forested acreage). Given that the forested land in Iowa is dominated by timberlands (productive forests), CCS does not believe that the definitional differences noted above have had a significant impact on the forest flux estimates provided in this report.

Also, FIA surveys since 1999 include all dead trees on the plots, but data prior to that are variable in terms of these data. The modifications to FIA surveys are a result of an expanded focus in the FIA program, which historically was only concerned with timber resources, while more recent surveys have aimed at a more comprehensive gathering of forest biomass data. In addition, the FIA program has moved from periodic to annual inventory methods. The effect of these changes in survey methods has not been estimated by the USFS.

Much of the urban forestry & land use emission estimates rely on national default data and could be improved with state-specific information (e.g. landfill data, urban tree canopy data).

Appendix I. Greenhouse Gases and Global Warming Potential Values: Excerpts from the Inventory of U.S. Greenhouse Emissions and Sinks: 1990-2006

Original Reference: Material for this Appendix is taken from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2006*, US Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-08-005, April 2008 http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

Introduction

The *Inventory of U.S. Greenhouse Gas Emissions and Sinks* presents estimates by the United States government of US anthropogenic greenhouse gas emissions and removals for the years 1990 through 2006. The estimates are presented on both a full molecular mass basis and on a Global Warming Potential (GWP) weighted basis in order to show the relative contribution of each gas to global average radiative forcing.

In 2007, the IPCC published its Fourth Assessment Report (AR4), which provided an updated and more comprehensive scientific assessment of climate change. The GWPs of several gases were revised relative to the SAR and the IPCC's Third Assessment Report (TAR) (IPCC 2001).

Although the GWPs have been updated, estimates of emissions presented in the US *Inventory* continue to use the GWPs from the Second Assessment Report (SAR). The guidelines under which the *Inventory* is developed, the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines for national inventories[109] were developed prior to the publication of the TAR and AR4. Therefore, to comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using SAR GWP values. This excerpt of the US *Inventory* addresses in detail the differences between emission estimates using these three sets of GWPs. Overall, these revisions to GWP values do not have a significant effect on US emission trends.

Additional discussion on emission trends for the United States can be found in the complete *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006*.

What is Climate Change?

Climate change refers to long-term fluctuations in temperature, precipitation, wind, and other elements of the Earth's climate system. Natural processes such as solar-irradiance variations, variations in the Earth's orbital parameters, and volcanic activity can produce variations in climate. The climate system can also be influenced by changes in the concentration of various gases in the atmosphere, which affect the Earth's absorption of radiation.

The Earth naturally absorbs and reflects incoming solar radiation and emits longer wavelength terrestrial (thermal) radiation back into space. On average, the absorbed solar radiation is balanced by the outgoing terrestrial radiation emitted to space. A portion of this terrestrial radiation, though, is itself absorbed by gases in the atmosphere. The energy from this absorbed terrestrial radiation warms the Earth's surface and atmosphere, creating what is known as the

[109] See FCCC/CP/1999/7 at www.unfccc.de

"natural greenhouse effect." Without the natural heat-trapping properties of these atmospheric gases, the average surface temperature of the Earth would be about 33°C lower (IPCC 2001).

Under the UNFCCC, the definition of climate change is "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." Given that definition, in its Second Assessment Report of the science of climate change, the IPCC concluded that:

> *Human activities are changing the atmospheric concentrations and distributions of greenhouse gases and aerosols. These changes can produce a radiative forcing by changing either the reflection or absorption of solar radiation, or the emission and absorption of terrestrial radiation (IPCC 1996).*

Building on that conclusion, the more recent IPCC Third Assessment Report asserts that "[c]oncentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities" (IPCC 2001).

The IPCC went on to report that the global average surface temperature of the Earth has increased by between 0.6 ± 0.2°C over the 20th century (IPCC 2001). This value is about 0.15°C larger than that estimated by the Second Assessment Report, which reported for the period up to 1994, "owing to the relatively high temperatures of the additional years (1995 to 2000) and improved methods of processing the data" (IPCC 2001).

While the Second Assessment Report concluded, "the balance of evidence suggests that there is a discernible human influence on global climate," the Third Assessment Report states the influence of human activities on climate in even starker terms. It concludes that, "[I]n light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations" (IPCC 2001).

Greenhouse Gases

Although the Earth's atmosphere consists mainly of oxygen and nitrogen, neither plays a significant role in enhancing the greenhouse effect because both are essentially transparent to terrestrial radiation. The greenhouse effect is primarily a function of the concentration of water vapor, carbon dioxide, and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the Earth (IPCC 1996). Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC 1996). Holding everything else constant, increases in greenhouse gas concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth).

Climate change can be driven by changes in the atmospheric concentrations of a number of radiatively active gases and aerosols. We have clear evidence that human activities have affected concentrations, distributions and life cycles of these gases (IPCC 1996).

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as bromofluorocarbons (i.e., halons). Because CFCs, HCFCs, and halons are stratospheric ozone depleting substances, they are covered under the Montreal Protocol on Substances that Deplete the Ozone Layer. The UNFCCC defers to this earlier international treaty; consequently these gases are not included in national greenhouse gas inventories. Some other fluorine containing halogenated substances—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—do not deplete stratospheric ozone but are potent greenhouse gases. These latter substances are addressed by the UNFCCC and accounted for in national greenhouse gas inventories.

There are also several gases that, although they do not have a commonly agreed upon direct radiative forcing effect, do influence the global radiation budget. These tropospheric gases—referred to as ambient air pollutants—include carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and tropospheric (ground level) ozone (O_3). Tropospheric ozone is formed by two precursor pollutants, volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of ultraviolet light (sunlight). Aerosols—extremely small particles or liquid droplets—often composed of sulfur compounds, carbonaceous combustion products, crustal materials and other human induced pollutants—can affect the absorptive characteristics of the atmosphere. However, the level of scientific understanding of aerosols is still very low (IPCC 2001).

Carbon dioxide, methane, and nitrous oxide are continuously emitted to and removed from the atmosphere by natural processes on Earth. Anthropogenic activities, however, can cause additional quantities of these and other greenhouse gases to be emitted or sequestered, thereby changing their global average atmospheric concentrations. Natural activities such as respiration by plants or animals and seasonal cycles of plant growth and decay are examples of processes that only cycle carbon or nitrogen between the atmosphere and organic biomass. Such processes—except when directly or indirectly perturbed out of equilibrium by anthropogenic activities—generally do not alter average atmospheric greenhouse gas concentrations over decadal timeframes. Climatic changes resulting from anthropogenic activities, however, could have positive or negative feedback effects on these natural systems. Atmospheric concentrations of these gases, along with their rates of growth and atmospheric lifetimes, are presented in Table I1.

Table I1. Global Atmospheric Concentration (ppm Unless Otherwise Specified), Rate of Concentration Change (ppb/year) and Atmospheric Lifetime (Years) of Selected Greenhouse Gases

Atmospheric Variable	CO_2	CH_4	N_2O	SF_6[a]	CF_4[a]
Pre-industrial atmospheric concentration	278	0.715	0.270	0	40
Atmospheric concentration[a]	379	1.745	0.319	5.6	74
Rate of concentration change	1.4	0.005[a]	0.26% yr	Linear[b]	Linear[b]
Atmospheric Lifetime	50-200[d]	12[e]	114[e]	3,200	>50,000

Source: Pre-industrial atmospheric concentrations, current atmospheric concentrations, and rate of concentration changes for all gases are from IPCC (2007).
[a] The growth rate for atmospheric CH4 has been decreasing from 1.4 ppb/yr in 1984 to less than 0 ppb/yr in 2001, 2004, and 2005.
[b] IPCC (2007) identifies the rate of concentration change for SF6 and CF4 as linear.
[c] Source: IPCC (1996).
[d] No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes.
[e] This lifetime has been defined as an "adjustment time" that takes into account the indirect effect of the gas on its own residence time.

A brief description of each greenhouse gas, its sources, and its role in the atmosphere is given below. The following section then explains the concept of Global Warming Potentials (GWPs), which are assigned to individual gases as a measure of their relative average global radiative forcing effect.

Water Vapor (H_2O). Overall, the most abundant and dominant greenhouse gas in the atmosphere is water vapor. Water vapor is neither long-lived nor well mixed in the atmosphere, varying spatially from 0 to 2 percent (IPCC 1996). In addition, atmospheric water can exist in several physical states including gaseous, liquid, and solid. Human activities are not believed to directly affect the average global concentration of water vapor; however, the radiative forcing produced by the increased concentrations of other greenhouse gases may indirectly affect the hydrologic cycle. A warmer atmosphere has an increased water holding capacity; yet, increased concentrations of water vapor affects the formation of clouds, which can both absorb and reflect solar and terrestrial radiation. Aircraft contrails, which consist of water vapor and other aircraft emittants, are similar to clouds in their radiative forcing effects (IPCC 1999).

Carbon Dioxide (CO_2). In nature, carbon is cycled between various atmospheric, oceanic, land biotic, marine biotic, and mineral reservoirs. The largest fluxes occur between the atmosphere and terrestrial biota, and between the atmosphere and surface water of the oceans. In the atmosphere, carbon predominantly exists in its oxidized form as CO_2. Atmospheric carbon dioxide is part of this global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. Carbon dioxide concentrations in the atmosphere increased from approximately 280 parts per million by volume (ppmv) in pre-industrial times to 379 ppmv in 2005, a 35 percent increase (IPCC 2007 and Hofmann 2004).[110][111] The IPCC definitively states that "the present atmospheric CO_2 increase is caused by anthropogenic emissions of CO_2" (IPCC 2001). The predominant source of anthropogenic CO_2 emissions is the

[110] The pre-industrial period is considered as the time preceding the year 1750 (IPCC 2001).
[111] Carbon dioxide concentrations during the last 1,000 years of the pre-industrial period (i.e., 750-1750), a time of relative climate stability, fluctuated by about ±10 ppmv around 280 ppmv (IPCC 2001).

combustion of fossil fuels. Forest clearing, other biomass burning, and some non-energy production processes (e.g., cement production) also emit notable quantities of carbon dioxide.

In its second assessment, the IPCC also stated that "[t]he increased amount of carbon dioxide [in the atmosphere] is leading to climate change and will produce, on average, a global warming of the Earth's surface because of its enhanced greenhouse effect—although the magnitude and significance of the effects are not fully resolved" (IPCC 1996).

Methane (CH_4). Methane is primarily produced through anaerobic decomposition of organic matter in biological systems. Agricultural processes such as wetland rice cultivation, enteric fermentation in animals, and the decomposition of animal wastes emit CH_4, as does the decomposition of municipal solid wastes. Methane is also emitted during the production and distribution of natural gas and petroleum, and is released as a by-product of coal mining and incomplete fossil fuel combustion. Atmospheric concentrations of methane have increased by about 143 percent since 1750, from a pre-industrial value of about 722 ppb to 1,774 ppb in 2005, although the rate of increase has been declining. The IPCC has estimated that slightly more than half of the current CH_4 flux to the atmosphere is anthropogenic, from human activities such as agriculture, fossil fuel use and waste disposal (IPCC 2007).

Methane is removed from the atmosphere by reacting with the hydroxyl radical (OH) and is ultimately converted to CO_2. Minor removal processes also include reaction with Cl in the marine boundary layer, a soil sink, and stratospheric reactions. Increasing emissions of methane reduce the concentration of OH, a feedback which may increase methane's atmospheric lifetime (IPCC 2001).

Nitrous Oxide (N_2O). Anthropogenic sources of N_2O emissions include agricultural soils, especially production of nitrogen-fixing crops and forages, the use of synthetic and manure fertilizers, and manure deposition by livestock; fossil fuel combustion, especially from mobile combustion; adipic (nylon) and nitric acid production; wastewater treatment and waste combustion; and biomass burning. The atmospheric concentration of nitrous oxide (N_2O) has increased by 18 percent since 1750, from a pre industrial value of about 270 ppb to 319 ppb in 2005, a concentration that has not been exceeded during the last thousand years. Nitrous oxide is primarily removed from the atmosphere by the photolytic action of sunlight in the stratosphere (IPCC 2007).

Ozone (O_3). Ozone is present in both the upper stratosphere, where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere, where it is the main component of anthropogenic photochemical "smog." During the last two decades, emissions of anthropogenic chlorine and bromine-containing halocarbons, such as chlorofluorocarbons (CFCs), have depleted stratospheric ozone concentrations. This loss of ozone in the stratosphere has resulted in negative radiative forcing, representing an indirect effect of anthropogenic emissions of chlorine and bromine compounds (IPCC 1996). The depletion of stratospheric ozone and its radiative forcing was expected to reach a maximum in about 2000 before starting to recover, with detection of such recovery not expected to occur much before 2010 (IPCC 2001).

The past increase in tropospheric ozone, which is also a greenhouse gas, is estimated to provide the third largest increase in direct radiative forcing since the pre-industrial era, behind CO_2 and CH_4. Tropospheric ozone is produced from complex chemical reactions of volatile organic compounds mixing with nitrogen oxides (NO_x) in the presence of sunlight. Ozone, carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter are included in the category referred to as "criteria pollutants" in the United States under the Clean Air Act and its subsequent amendments. The tropospheric concentrations of ozone and these other pollutants are short-lived and, therefore, spatially variable.

Halocarbons, Perfluorocarbons, and Sulfur Hexafluoride (SF_6). Halocarbons are, for the most part, man-made chemicals that have both direct and indirect radiative forcing effects. Halocarbons that contain chlorine—chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methyl chloroform, and carbon tetrachloride—and bromine—halons, methyl bromide, and hydrobromofluorocarbons (HBFCs)—result in stratospheric ozone depletion and are therefore controlled under the Montreal Protocol on Substances that Deplete the Ozone Layer. Although CFCs and HCFCs include potent global warming gases, their net radiative forcing effect on the atmosphere is reduced because they cause stratospheric ozone depletion, which is itself an important greenhouse gas in addition to shielding the Earth from harmful levels of ultraviolet radiation. Under the Montreal Protocol, the United States phased out the production and importation of halons by 1994 and of CFCs by 1996. Under the Copenhagen Amendments to the Protocol, a cap was placed on the production and importation of HCFCs by non-Article 5 countries beginning in 1996, and then followed by a complete phase-out by the year 2030. The ozone depleting gases covered under the Montreal Protocol and its Amendments are not covered by the UNFCCC.

Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) are not ozone depleting substances, and therefore are not covered under the Montreal Protocol. They are, however, powerful greenhouse gases. HFCs—primarily used as replacements for ozone depleting substances but also emitted as a by-product of the HCFC-22 manufacturing process—currently have a small aggregate radiative forcing impact; however, it is anticipated that their contribution to overall radiative forcing will increase (IPCC 2001). PFCs and SF_6 are predominantly emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. Currently, the radiative forcing impact of PFCs and SF_6 is also small; however, they have a significant growth rate, extremely long atmospheric lifetimes, and are strong absorbers of infrared radiation, and therefore have the potential to influence climate far into the future (IPCC 2001).

Carbon Monoxide (CO). Carbon monoxide has an indirect radiative forcing effect by elevating concentrations of CH_4 and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g., the hydroxyl radical, OH) that would otherwise assist in destroying CH_4 and tropospheric ozone. Carbon monoxide is created when carbon-containing fuels are burned incompletely. Through natural processes in the atmosphere, it is eventually oxidized to CO_2. Carbon monoxide concentrations are both short-lived in the atmosphere and spatially variable.

Nitrogen Oxides (NO_x). The primary climate change effects of nitrogen oxides (i.e., NO and NO_2) are indirect and result from their role in promoting the formation of ozone in the troposphere and, to a lesser degree, lower stratosphere, where it has positive radiative forcing effects. Additionally, NO_x emissions from aircraft are also likely to decrease methane concentrations, thus having a negative radiative forcing effect (IPCC 1999). Nitrogen oxides are created from lightning, soil microbial activity, biomass burning – both natural and anthropogenic fires – fuel combustion, and, in the stratosphere, from the photo-degradation of nitrous oxide

(N_2O). Concentrations of NO_x are both relatively short-lived in the atmosphere and spatially variable.

Nonmethane Volatile Organic Compounds (NMVOCs). Nonmethane volatile organic compounds include compounds such as propane, butane, and ethane. These compounds participate, along with NO_x, in the formation of tropospheric ozone and other photochemical oxidants. NMVOCs are emitted primarily from transportation and industrial processes, as well as biomass burning and non-industrial consumption of organic solvents. Concentrations of NMVOCs tend to be both short-lived in the atmosphere and spatially variable.

Aerosols. Aerosols are extremely small particles or liquid droplets found in the atmosphere. They can be produced by natural events such as dust storms and volcanic activity, or by anthropogenic processes such as fuel combustion and biomass burning. They affect radiative forcing in both direct and indirect ways: directly by scattering and absorbing solar and thermal infrared radiation; and indirectly by increasing droplet counts that modify the formation, precipitation efficiency, and radiative properties of clouds. Aerosols are removed from the atmosphere relatively rapidly by precipitation. Because aerosols generally have short atmospheric lifetimes, and have concentrations and compositions that vary regionally, spatially, and temporally, their contributions to radiative forcing are difficult to quantify (IPCC 2001).

The indirect radiative forcing from aerosols is typically divided into two effects. The first effect involves decreased droplet size and increased droplet concentration resulting from an increase in airborne aerosols. The second effect involves an increase in the water content and lifetime of clouds due to the effect of reduced droplet size on precipitation efficiency (IPCC 2001). Recent research has placed a greater focus on the second indirect radiative forcing effect of aerosols.

Various categories of aerosols exist, including naturally produced aerosols such as soil dust, sea salt, biogenic aerosols, sulphates, and volcanic aerosols, and anthropogenically manufactured aerosols such as industrial dust and carbonaceous aerosols (e.g., black carbon, organic carbon) from transportation, coal combustion, cement manufacturing, waste incineration, and biomass burning.

The net effect of aerosols is believed to produce a negative radiative forcing effect (i.e., net cooling effect on the climate), although because they are short-lived in the atmosphere—lasting days to weeks—their concentrations respond rapidly to changes in emissions. Locally, the negative radiative forcing effects of aerosols can offset the positive forcing of greenhouse gases (IPCC 1996). “However, the aerosol effects do not cancel the global-scale effects of the much longer-lived greenhouse gases, and significant climate changes can still result” (IPCC 1996).

The IPCC’s Third Assessment Report notes that “the indirect radiative effect of aerosols is now understood to also encompass effects on ice and mixed-phase clouds, but the magnitude of any such indirect effect is not known, although it is likely to be positive” (IPCC 2001). Additionally, current research suggests that another constituent of aerosols, elemental carbon, may have a positive radiative forcing (Jacobson 2001). The primary anthropogenic emission sources of elemental carbon include diesel exhaust, coal combustion, and biomass burning.

Global Warming Potentials

A global warming potential (GWP) is a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas (see Table I2). It is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kilogram (kg) of a trace substance relative to that of 1 kg of a reference gas (IPCC 2001). Direct radiative effects occur when the gas itself absorbs radiation. Indirect radiative forcing occurs when chemical transformations involving the original gas produce a gas or gases that are greenhouse gases, or when a gas influences other radiatively important processes such as the atmospheric lifetimes of other gases. The reference gas used is CO_2, and therefore GWP weighted emissions are measured in teragrams of CO_2 equivalent (Tg CO_2 Eq.).[112] The relationship between gigagrams (Gg) of a gas and Tg CO_2 Eq. can be expressed as follows:

$$\text{Tg CO}_2\text{ Eq} = (\text{Gg of gas}) \times (\text{GWP}) \times \left(\frac{\text{Tg}}{1{,}000\text{ Gg}}\right) \text{where,}$$

Tg CO_2 Eq. = Teragrams of Carbon Dioxide Equivalents
Gg = Gigagrams (equivalent to a thousand metric tons)
GWP = Global Warming Potential
Tg = Teragrams

GWP values allow for a comparison of the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of ±35 percent. The parties to the UNFCCC have also agreed to use GWPs based upon a 100-year time horizon although other time horizon values are available.

> *Greenhouse gas emissions and removals should be presented on a gas-by-gas basis in units of mass... In addition, consistent with decision 2/CP.3, Parties should report aggregate emissions and removals of greenhouse gases, expressed in CO_2 equivalent terms at summary inventory level, using GWP values provided by the IPCC in its* Second Assessment Report... *based on the effects of greenhouse gases over a 100-year time horizon.*[113]

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. The short-lived gases such as water vapor, carbon monoxide, tropospheric ozone, other ambient air pollutants (e.g., NO_x, and NMVOCs), and tropospheric aerosols (e.g., SO_2 products and black carbon), however, vary spatially, and consequently it is difficult to quantify their global radiative forcing impacts. GWP values are generally not attributed to these gases that are short-lived and spatially inhomogeneous in the atmosphere.

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[112] Carbon comprises 12/44th of carbon dioxide by weight.
[113] Framework Convention on Climate Change; <http://unfccc.int/resource/docs/cop8/08.pdf>; 1 November 2002; Report of the Conference of the Parties at its eighth session; held at New Delhi from 23 October to 1 November 2002; Addendum; Part One: Action taken by the Conference of the Parties at its eighth session; Decision -/CP.8; Communications from Parties included in Annex I to the Convention: Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention, Part 1: UNFCCC reporting guidelines on annual inventories; p. 7. (UNFCCC 2003).

Table I2. Global Warming Potentials (GWP) and Atmospheric Lifetimes (Years) Used in the Inventory

Gas	Atmospheric Lifetime	GWP[a]
CO_2	50-200	1
CH_4	12+/-3	21
N_2O	120	310
HFC-23	264	11,700
HFC-32	5.6	650
HFC-125	32.6	2,800
HFC-134a	14.6	1,300
HFC-143a	48.3	3,800
HFC-152a	1.5	140
HFC-227ea	36.5	2,900
HFC-236fa	209	6,300
HFC-4310mee	17.1	1,300
CF_4	50,000	6,500
C_2F_6	10,000	9,200
C_4F_{10}	2,600	7,000
C_6F_{14}	3,200	7,400
SF_6	3,200	23,900

Source: IPCC (1996)
[a] 100-year time horizon
[b] The GWP of methane includes the 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.

In 2007, the IPCC published its Fourth Assessment Report (AR4), which provided an updated and more comprehensive scientific assessment of climate change. Within this report, the GWPs of several gases were revised relative to the SAR and the IPCC's Third Assessment Report (TAR) (IPCC 2001). Thus the GWPs used in this report have been updated twice by the IPCC; although the SAR GWPs are used throughout this report, it is interesting to review the changes to the GWPs and the impact such improved understanding has on the total GWP-weighted emissions of the United States. Since the SAR and TAR, the IPCC has applied an improved calculation of CO_2 radiative forcing and an improved CO_2 response function. The GWPs are drawn from IPCC/TEAP (2005) and the TAR, with updates for those cases where new laboratory or radiative transfer results have been published. Additionally, the atmospheric lifetimes of some gases have been recalculated. In addition, the values for radiative forcing and lifetimes have been recalculated for a variety of halocarbons, which were not presented in the SAR. Table I3 presents the new GWPs, relative to those presented in the SAR.

Table I3. Comparison of 100-Year GWPs

Gas	SAR	TAR	AR4	Change from SAR	
				TAR	AR4
CO_2	1	1	1	NC	0
CH_4*	21	23	25	2	4
N_2O	310	296	298	(14)	(12)
HFC-23	11,700	12,000	14,800	300	3,100
HFC-32	650	550	675	(100)	25
HFC-125	2,800	3,400	3,500	600	700
HFC-134a	1,300	1,300	1,430	NC	130
HFC-143a	3,800	4,300	4,470	500	670
HFC-152a	140	120	124	(20)	(16)
HFC-227ea	2,900	3,500	3,220	600	320
HFC-236fa	6,300	9,400	9,810	3,100	3,510
HFC-4310mee	1,300	1,500	1,640	200	340
CF_4	6,500	5,700	7,390	(800)	890
C_2F_6	9,200	11,900	12,200	2,700	3,000
C_4F_{10}	7,000	8,600	8,860	1,600	1,860
C_6F_{14}	7,400	9,000	9,300	1,600	1,900
SF_6	23,900	22,200	22,800	(1,700)	(1,100)

Source: (IPCC 2007, IPCC 2001)
NC (No Change)
Note: Parentheses indicate negative values.
*The GWP of CH4 includes the 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.

To comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using SAR GWP values. The UNFCCC reporting guidelines for national inventories[114] were updated in 2002 but continue to require the use of GWPs from the SAR so that current estimates of aggregate greenhouse gas emissions for 1990 through 2006 are consistent and comparable with estimates developed prior to the publication of the TAR and AR4.

[114] See <http://unfccc.int/resource/docs/cop8/08.pdf>.

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