Final Arkansas
Greenhouse Gas Inventory and
Reference Case Projections, 1990-2025

Center for Climate Strategies
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Executive Summary

The Center for Climate Strategies (CCS) prepared this report for the Arkansas Governor's Commission on Global Warming (GCGW). 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 inventory and forecast estimates served as a starting point to assist the GCGW with an initial comprehensive understanding of Arkansas' current and possible future GHG emissions, and thereby informed the identification and analysis of policy options for mitigating GHG emissions.[1] The GCGW and its Technical Work Groups (TWGs) have reviewed, discussed, and evaluated the draft inventory and methodologies 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 to comments provided and approved by the GCGW.

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

Arkansas' 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 Arkansas-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 Arkansas, 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 Arkansas accounted for approximately 85.4 million metric tons (MMt) of *gross*[4] CO_2e emissions (consumption basis) in 2005, an amount equal to about

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[1] "Draft Arkansas Greenhouse Gas Inventory and Reference Case Projections, 1990-2025," prepared by the Center for Climate Strategies for the Arkansas Governor's Commission on Global Warming, May 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 (IPCC, 2001). 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 and excluding GHG emissions associated with exported electricity.

1.2% of total US gross GHG emissions (based on 2005 US data).[5] Arkansas' gross GHG emissions are rising faster than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). Arkansas' gross GHG emissions increased by about 30% from 1990 to 2005, while national emissions rose by 16% from 1990 to 2005. The growth in Arkansas' emissions from 1990 to 2005 is primarily associated with the electricity consumption and transportation sectors.

Estimates of carbon sinks within Arkansas' 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 20.9 MMtCO$_2$e were stored in Arkansas forest and agricultural biomass in 2005. This leads to *net* emissions of 64.6 MMtCO$_2$e in Arkansas in 2005, an amount equal to 1.0% of total US net GHG emissions.

Figure ES-1 illustrates the State's emissions per capita and per unit of economic output.[6] On a per capita basis, Arkansas residents emitted about 28 metric tons (t) of gross CO$_2$e in 1990, higher than the 1990 national average of 25 tCO$_2$e. Per capita emissions in Arkansas increased to 31 tCO$_2$e in 2005. National per capita emissions for the US decreased slightly to 24 tCO$_2$e from in 2005. Figure ES-1 also shows that while per capita emissions have increased from 1990 to 2000 in Arkansas and then began to decrease from 2000 to 2005, per capita emissions for the nation as a whole remained fairly flat from 1990 to 2005. The higher per capita emission rates in Arkansas are driven by emissions growth in the electricity supply, transportation, and agricultural sectors. (Agricultural sector emissions are twice the national average.) Like the nation as a whole, Arkansas' 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 23% in Arkansas and by about 26% nationally.[7]

The principal sources of Arkansas' GHG emissions in 2005 are the electricity consumption and transportation sectors, accounting for 32% and 26% of Arkansas' gross GHG emissions in 2005, respectively.

As illustrated in Figure ES-2 and shown numerically in Table ES-1, under the reference case projections, Arkansas' gross GHG emissions continue to grow, and are projected to climb to about 114 MMtCO$_2$e by 2025, reaching 74% above 1990 levels. As shown in Figure ES-3, the electricity consumption sector is projected to be the largest contributor to future emissions growth in Arkansas, followed by emissions associated with the transportation sector. The

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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] Population Projections from Center for Business and Economic Research, University of Arkansas http://cber.uark.edu/default.asp?show=population
Time Series Extrapolations, 2005-2030 http://www.aiea.ualr.edu/research/demographic/population/default.html
[7] 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 from the 2008 version of EPA's GHG inventory report (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

industrial processes sector is projected to have the most rapid growth between 1990 and 2025, increasing by 235% over the period.

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

GHG Reductions from Recent Federal Actions[8]

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 GCGW 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 Arkansas. The GHG emission reductions projected to be achieved by these actions are summarized in Table ES-2. This table shows a total reduction of about 4.15 MMtCO$_2$e in 2025 from the business-as-usual reference case emissions, or a 3.6% reduction from the business-as-usual emissions in 2025 for all sectors combined.

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

Table ES-1. Arkansas Historical and Reference Case GHG Emissions, by Sector[a]

MMtCO$_2$e	1990	2000	2005	2010	2015	2020	2025	Explanatory Notes for Projections
Energy Use (CO$_2$, CH$_4$, N$_2$O)	**50.7**	**70.4**	**67.2**	**74.3**	**80.5**	**85.0**	**89.6**	
Electricity Use (Consumption)	**17.4**	**28.0**	**27.2**	**30.7**	**34.1**	**35.7**	**37.4**	Totals include emissions for electricity production plus emissions associated with net imported/ exported electricity.
Electricity Production (in-state)	22.5	27.4	27.2	30.7	34.1	35.7	37.4	*See electric sector assumptions*
Coal	19.7	24.8	23.1	27.1	30.5	30.5	30.5	*in appendix A.*
Natural Gas	2.64	2.37	3.98	3.49	3.45	5.05	6.69	
Oil	0.07	0.17	0.15	0.15	0.15	0.15	0.15	
MSW/Landfill Gas	0.06	0.07	0.00	0.00	0.00	0.00	0.00	
Biomass	0.008	0.010	0.009	0.009	0.009	0.009	0.009	
Other Wastes	0.000	0.003	0.000	0.000	0.000	0.000	0.000	
Pumped Storage	0.03	0.00	0.00	0.00	0.00	0.00	0.00	
Imported/Exported Electricity	-5.03	0.56	0.00	0.00	0.00	0.00	0.00	Negative values represent net exported electricity
Residential/Commercial/Industrial (RCI) Fuel Use	**13.7**	**17.1**	**15.1**	**16.7**	**17.0**	**17.5**	**18.1**	
Coal	0.55	0.90	0.87	0.90	0.89	0.89	0.90	Based on US DOE regional projections
Natural Gas	10.1	11.0	8.17	9.55	9.67	10.0	10.3	Based on US DOE regional projections
Petroleum	2.90	5.03	5.92	6.08	6.30	6.40	6.66	Based on US DOE regional projections
Wood (CH$_4$ and N$_2$O)	0.14	0.16	0.15	0.17	0.18	0.19	0.20	Based on US DOE regional projections
Transportation	**16.9**	**22.4**	**22.0**	**23.9**	**26.2**	**28.6**	**31.1**	
Onroad Gasoline	10.9	12.4	12.4	13.3	14.4	15.4	16.5	Based on linear regression of historical data
Onroad Diesel	3.78	5.37	6.08	7.22	8.29	9.55	10.8	Based on linear regression of historical data
Rail, Natural Gas, LPG, other	0.57	0.87	1.10	1.11	1.12	1.13	1.14	Based on US DOE regional projections
Marine Vessels	0.93	1.79	1.84	1.73	1.86	1.98	2.11	Based on historical trends in activity
Jet Fuel and Aviation Gasoline	0.72	2.01	0.53	0.50	0.51	0.52	0.53	Based on FAA operations projections
Fossil Fuel Industry	**2.72**	**2.88**	**2.82**	**2.97**	**3.18**	**3.11**	**3.04**	
Natural Gas Industry	2.58	2.79	2.73	2.89	3.10	3.04	2.98	Based on AEO regional projection data and historical activity data
Oil Industry	0.13	0.09	0.10	0.09	0.08	0.07	0.06	Based on AEO regional refining capacity projection data and historical activity data
Coal Mining	0.003	0.001	0.000	0.000	0.000	0.000	0.000	Based on AEO 2007 Western Interior coal production projections
Industrial Processes	**2.23**	**3.41**	**4.03**	**4.92**	**5.67**	**6.46**	**7.45**	
Cement Manufacture (CO$_2$)	0.31	0.65	0.68	0.74	0.79	0.86	0.92	Cement & Concrete Product Mfg employment projections from AR Labor Market Information (LMI)
Lime Manufacture (CO$_2$)	0.05	0.07	0.28	0.48	0.48	0.48	0.48	Lime production forecasts provided by Arkansas Department of Environmental Quality (ADEQ)
Limestone and Dolomite Use (CO$_2$)	0.07	0.06	0.07	0.07	0.07	0.08	0.08	Other Nonmetallic Mineral Product Manufacturing

MMtCO$_2$e	1990	2000	2005	2010	2015	2020	2025	Explanatory Notes for Projections
								employment projections from AR LMI
Soda Ash (CO$_2$)	0.03	0.03	0.02	0.02	0.02	0.02	0.02	Based on historical consumption
Ammonia and Urea (CO$_2$)	0.53	0.30	0.28	0.28	0.28	0.28	0.28	No growth assumed, based on analysis of historical data
Iron & Steel (CO$_2$)	0.09	0.36	0.38	0.42	0.48	0.55	0.62	Steel production forecasts from ADEQ
Nitric Acid (N$_2$O)	0.88	1.00	0.99	0.99	0.99	0.99	0.99	No growth assumed, based on analysis of historical data
ODS Substitutes (HFC, PFC)	0.00	0.76	1.16	1.76	2.40	3.06	3.91	Used annual growth rates calculated based on national emissions for 2005-2020
Electric Power T&D (SF$_6$)	0.27	0.18	0.17	0.15	0.15	0.14	0.14	Used annual growth rates calculated from US national emissions for 2005-2020
Waste Management	**2.01**	**2.05**	**2.40**	**2.89**	**3.49**	**4.24**	**5.17**	
Landfills	1.45	1.49	1.81	2.26	2.82	3.53	4.41	Based on default data; Used growth rate calculated for 1996-2005 emissions growth
Wastewater Management	0.48	0.56	0.59	0.63	0.67	0.72	0.77	Used growth rate calculated for 1990-2005 emissions growth
Waste Combustion	0.07	0.00	0.00	0.00	0.00	0.00	0.00	Estimated using NEI method – residential open burning banned post 1999
Agriculture	**10.7**	**10.7**	**11.7**	**11.2**	**11.4**	**11.6**	**11.9**	
Enteric Fermentation	2.02	2.05	2.08	2.10	2.17	2.24	2.30	Based on projected livestock population
Manure Management	1.68	1.45	1.31	1.37	1.43	1.49	1.55	Based on projected livestock population
Agricultural Soils	4.76	4.62	5.24	4.56	4.42	4.29	4.15	Based on historical 1990-2005 emissions growth
Rice Cultivation	2.14	2.52	2.92	3.06	3.27	3.49	3.70	Based on historical 1990-2005 emissions growth
Agricultural Burning	0.05	0.06	0.11	0.11	0.13	0.14	0.16	Based on historical 1990-2005 emissions growth
Forest Wildfires	**0.17**	**0.18**	**0.18**	**0.18**	**0.18**	**0.18**	**0.18**	Assumed no change after 2005
Gross Emissions (Consumption Basis, Excludes Sinks)	**65.8**	**86.8**	**85.4**	**93.5**	**101.3**	**107.5**	**114.2**	
increase relative to 1990		*32%*	*30%*	*42%*	*54%*	*63%*	*74%*	
Emissions Sinks	**-38.5**	**-20.8**	**-20.9**	**-20.9**	**-20.9**	**-20.9**	**-20.9**	
Forestry and Land Use	**-36.7**	**-19.0**	**-19.1**	**-19.1**	**-19.1**	**-19.1**	**-19.1**	
Forested Landscape	-34.2	-18.2	-18.2	-18.2	-18.2	-18.2	-18.2	Based on estimates from the USFS
Urban Forestry and Land Use	-2.43	-0.83	-0.91	-0.91	-0.91	-0.91	-0.91	Assumed no change after 2005
Agricultural Soils (Cultivation Practices)	**-1.80**	**-1.80**	**-1.80**	**-1.80**	**-1.80**	**-1.80**	**-1.80**	Based on 1997 USDA Data for AR
Net Emissions (Consumption Basis, Includes Forestry and Land Use Sinks)	**27.3**	**66.0**	**64.6**	**72.6**	**80.4**	**86.6**	**93.4**	
increase relative to 1990		*141%*	*136%*	*166%*	*194%*	*217%*	*242%*	

MMtCO$_2$e = million metric tons of carbon dioxide equivalent; CH$_4$ = methane; N$_2$O = nitrous oxide; MSW = municipal solid waste; LPG = liquefied petroleum gas; ODS = ozone-depleting substance; HFC = hydrofluorocarbon; PFC = perfluorocarbon; SF$_6$ = sulfur hexafluoride; T&D = transmission and distribution.

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

**Figure ES-1. Historical Arkansas and US Gross GHG Emissions,
Per Capita and Per Unit Gross Product**
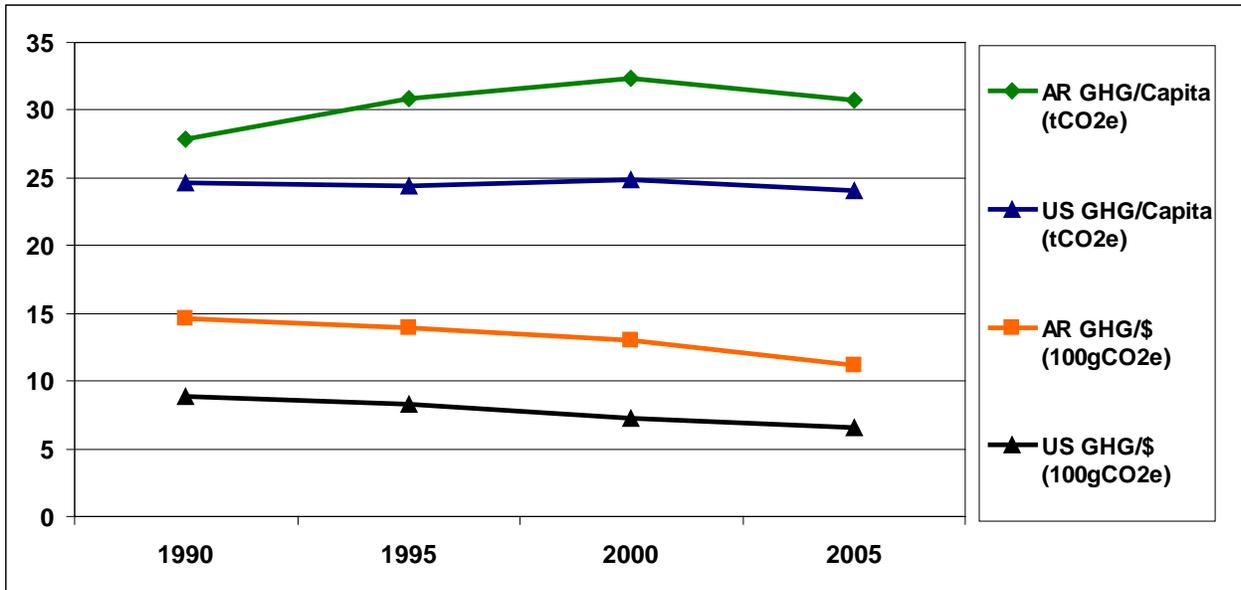
**Figure ES-2. Arkansas Gross GHG Emissions by Sector, 1990-2025:
Historical and Projected**
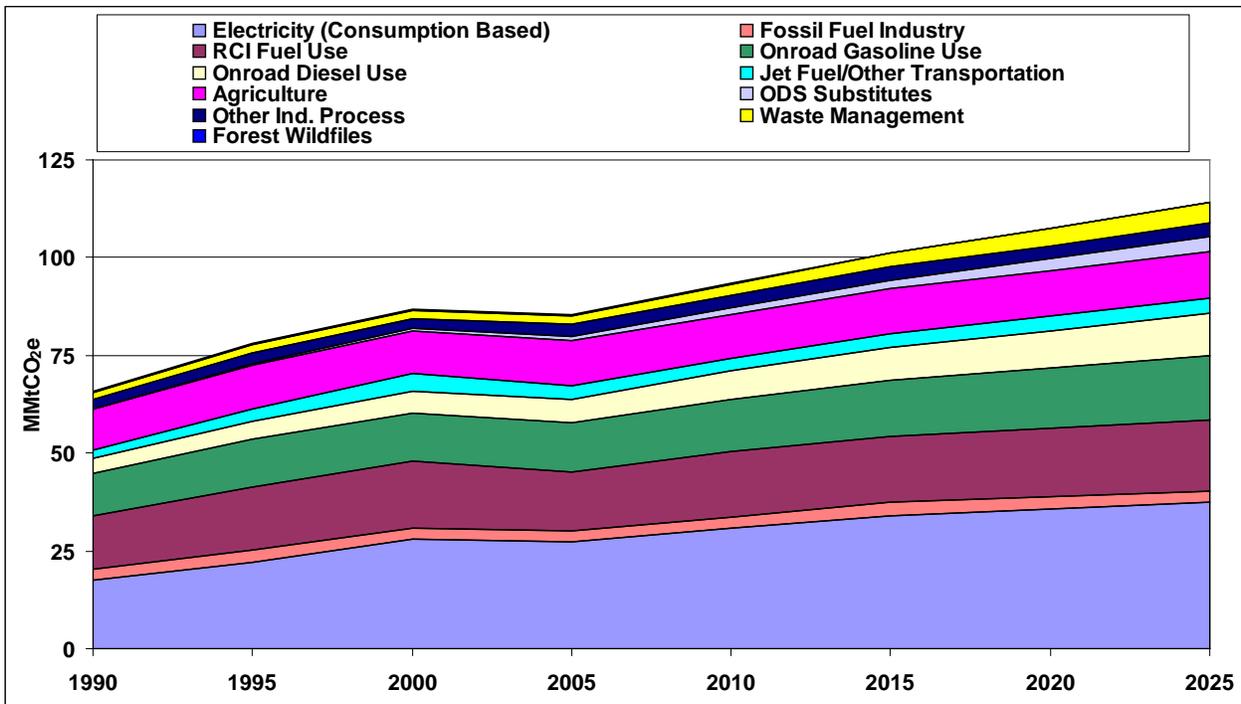
RCI – direct fuel use in residential, commercial, and industrial sectors. ODS – ozone-depleting substance.

**Figure ES-3. Sector Contributions to Gross Emissions Growth in Arkansas,
1990-2025: Reference Case Projections (MMtCO$_2$e 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 Federal
Actions in Arkansas (consumption-basis, gross emissions)**

	GHG Reductions (MMtCO$_2$e)		GHG Emissions (MMtCO$_2$e)	
			Business as Usual	With Recent Actions
Sector / Recent Action	2015	2025	2025	2025
Residential, Commercial and Industrial (RCI) Federal Improved Standards for Appliances and Lighting Requirements	0.34	0.89	18. 1	17.2
Transportation and Land Use (TLU) Federal Corporate Average Fuel Economy (CAFE) Requirements	1.02	3.26	31.1	27.8
Total (RCI + TLU Sectors)	**1.36**	**4.15**	**49.2**	**45.0**
Total (All Sectors)			**114.2**	**110.1**

GHG = greenhouse gas; MMtCO$_2$e = million metric tons of carbon dioxide equivalent.

Table of Contents

Acronyms and Key Terms

AEO2007 – EIA's Annual Energy Outlook 2007

ADEQ – Arkansas Department of Environmental Quality

AOGG – Arkansas Oil and Gas Commission

APSC – Arkansas Public Service Commission

bbls – Barrels

Bcf – Billion Cubic Feet

BOD – Biochemical Oxygen Demand

Btu – British Thermal Unit

C – Carbon*

$CaCO_3$ – Calcium Carbonate

CAFE – Corporate Average Fuel Economy

CCT – Carbon Calculation Tool

CCS – Center for Climate Strategies

CFCs – Chlorofluorocarbons*

CH_4 – Methane*

CHP – Combined Heat and Power

CO – Carbon Monoxide*

CO_2 – Carbon Dioxide*

CO_2e – Carbon Dioxide Equivalent*

CRP – Federal Conservation Reserve Program

DOE – US Department of Energy

DOT – US Department of Transportation

EAF – Electric Arc Furnace

EIA – US DOE Energy Information Administration

EIIP – Emission Inventory Improvement Program

EISA – Energy Independence and Security Act of 2007

FAA – Federal Aviation Administration

FAPRI – Food and Agricultural Policy Research Institute

FERC – Federal Energy Regulatory Commission

FHWA – Federal Highway Administration

FIA – Forest Inventory Analysis

GCGW – Arkansas Governor's Commission on Global Warming

Gg – Gigagrams

GHG – Greenhouse Gas*

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

IPCC – Intergovernmental Panel on Climate Change*

kg – Kilogram

km^2 – Square Kilometers

kWh – Kilowatt-hour

lb – Pound

LF – Landfill

LFG – Landfill Gas

LFGTE –Landfill-Gas-to-Energy

LMI – Arkansas Labor Market Information

LPG – Liquefied Petroleum Gas

Mg – Megagrams

MMBtu – Million British Thermal Units

MMt – Million Metric Tons

MMtC – Million Metric Tons Carbon

$MMtCO_2e$ – Million Metric tons Carbon Dioxide equivalent

MSW – Municipal Solid Waste

Mt – Metric Ton (equivalent to 1.102 short tons)

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

NGCC – Natural Gas Combined Cycle

$(NH_2)_2CO$ – Urea

NH_3 – Ammonia

NMVOC – Nonmethane Volatile Organic Compound*

NO_2 – Nitrogen Dioxide*

NO_x – Nitrogen Oxides*

NSCR – Non-selective Catalytic Reduction

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*

SCR – Selective Catalytic Reduction

SED – State Energy Data

SERC – Southeastern Reliability Council

SF_6 – Sulfur Hexafluoride*

SIT – State Greenhouse Gas Inventory Tool

Sinks – Removals of carbon from the atmosphere, with the carbon stored in forests, soils, landfills, wood structures, or other biomass-related products.

SO_2 – Sulfur Dioxide*

SPP – Southwest Power Pool

t – Metric Ton (equivalent to 1.102 short tons)

T&D – Transmission and Distribution

TAR – Third Assessment Report*

TLU – Transportation and Land Use

TWG – Technical Work Group

UNFCCC – United Nations Framework Convention on Climate Change

US – United States

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

VOC – 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 Arkansas, as well as in neighboring States, and at federal agencies. Thanks go to in particular the staff at Arkansas Department of Environmental Quality (ADEQ) and other Arkansas agencies for their inputs, and in particular to Karen Bassett of the Arkansas Department of Environmental Quality and members of the Advisory Body to the Arkansas Governor's Commission on Global Warming (GCGW) who provided key guidance for and review of this analytical effort.

The authors would also like to express their appreciation to Steve Roe and Katie Pasko of the Center for Climate Strategies (CCS) who provided valuable review comments during development of this report. Thanks also to Michael Gillenwater for directing preparation of Appendix I.

Summary of Preliminary Findings

Introduction

The Center for Climate Strategies (CCS) prepared this report for the Arkansas Governor's Commission on Global Warming (GCGW). This report presents estimates of the State's base year and projected greenhouse gas (GHG) emissions and anthropogenic sinks (carbon storage) for the period from 1990 to 2025. The preliminary draft inventory and forecast estimates served as a starting point to assist the GCGW and Technical Work Groups (TWGs) with an initial comprehensive understanding of Arkansas' current and possible future GHG emissions, and thereby informed the identification and analysis of policy options for mitigating GHG emissions.[9] The GCGW and TWGs have reviewed, discussed, and evaluated the draft inventory and methodologies 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 GCGW.

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

Historical GHG emission estimates (1990 through 2005)[10] 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 Arkansas-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 Arkansas, 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.[11]

It is important to note that the preliminary emissions estimates reflect the *GHG emissions associated with the electricity sources used to meet Arkansas' demand,* corresponding to a consumption-based approach to emissions accounting (see "Approach" section below). Another

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way to look at electricity emissions is to consider the *GHG emissions produced by electricity generation facilities in the State.* This report covers both methods of accounting for emissions, but for consistency, all total results are reported as *consumption-based.*

Arkansas Greenhouse Gas Emissions: Sources and Trends

Table 1 provides a summary of GHG emissions estimated for Arkansas by sector for the years 1990, 2000, 2005, 2010, 2020 and 2025. Details on the methods and data sources used to construct these draft 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. Arkansas Historical and Reference Case GHG Emissions, by Sector[a]

MMtCO$_2$e	1990	2000	2005	2010	2015	2020	2025	Explanatory Notes for Projections
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Electricity Use (Consumption)	**17.4**	**28.0**	**27.2**	**30.7**	**34.1**	**35.7**	**37.4**	Totals include emissions for electricity production plus emissions associated with net imported/ exported electricity.
Electricity Production (in-state)	22.5	27.4	27.2	30.7	34.1	35.7	37.4	*See electric sector assumptions*
Coal	19.7	24.8	23.1	27.1	30.5	30.5	30.5	*in appendix A.*
Natural Gas	2.64	2.37	3.98	3.49	3.45	5.05	6.69	
Oil	0.07	0.17	0.15	0.15	0.15	0.15	0.15	
MSW/Landfill Gas	0.06	0.07	0.00	0.00	0.00	0.00	0.00	
Biomass	0.008	0.010	0.009	0.009	0.009	0.009	0.009	
Other Wastes	0.000	0.003	0.000	0.000	0.000	0.000	0.000	
Pumped Storage	0.03	0.00	0.00	0.00	0.00	0.00	0.00	
Imported/Exported Electricity	-5.03	0.56	0.00	0.00	0.00	0.00	0.00	Negative values represent net exported electricity
Residential/Commercial/Industrial (RCI) Fuel Use	**13.7**	**17.1**	**15.1**	**16.7**	**17.0**	**17.5**	**18.1**	
Coal	0.55	0.90	0.87	0.90	0.89	0.89	0.90	Based on US DOE regional projections
Natural Gas	10.1	11.0	8.17	9.55	9.67	10.0	10.3	Based on US DOE regional projections
Petroleum	2.90	5.03	5.92	6.08	6.30	6.40	6.66	Based on US DOE regional projections
Wood (CH$_4$ and N$_2$O)	0.14	0.16	0.15	0.17	0.18	0.19	0.20	Based on US DOE regional projections
Transportation	**16.9**	**22.4**	**22.0**	**23.9**	**26.2**	**28.6**	**31.1**	
Onroad Gasoline	10.9	12.4	12.4	13.3	14.4	15.4	16.5	Based on linear regression of historical data
Onroad Diesel	3.78	5.37	6.08	7.22	8.29	9.55	10.8	Based on linear regression of historical data
Rail, Natural Gas, LPG, other	0.57	0.87	1.10	1.11	1.12	1.13	1.14	Based on US DOE regional projections
Marine Vessels	0.93	1.79	1.84	1.73	1.86	1.98	2.11	Based on historical trends in activity
Jet Fuel and Aviation Gasoline	0.72	2.01	0.53	0.50	0.51	0.52	0.53	Based on FAA operations projections
Fossil Fuel Industry	**2.72**	**2.88**	**2.82**	**2.97**	**3.18**	**3.11**	**3.04**	
Natural Gas Industry	2.58	2.79	2.73	2.89	3.10	3.04	2.98	Based on AEO regional projection data and historical activity data
Oil Industry	0.13	0.09	0.10	0.09	0.08	0.07	0.06	Based on AEO regional refining capacity projection data and historical activity data
Coal Mining	0.003	0.001	0.000	0.000	0.000	0.000	0.000	Based on AEO 2007 Western Interior coal production projections
Industrial Processes	**2.23**	**3.41**	**4.03**	**4.92**	**5.67**	**6.46**	**7.45**	
Cement Manufacture (CO$_2$)	0.31	0.65	0.68	0.74	0.79	0.86	0.92	Cement & Concrete Product Mfg employment projections from AR Labor Market Information (LMI)
Lime Manufacture (CO$_2$)	0.05	0.07	0.28	0.48	0.48	0.48	0.48	Lime production forecasts provided by Arkansas Department of Environmental Quality (ADEQ)
Limestone and Dolomite Use (CO$_2$)	0.07	0.06	0.07	0.07	0.07	0.08	0.08	Other Nonmetallic Mineral Product Manufacturing employment projections

MMtCO$_2$e	1990	2000	2005	2010	2015	2020	2025	Explanatory Notes for Projections
								from AR LMI
Soda Ash (CO$_2$)	0.03	0.03	0.02	0.02	0.02	0.02	0.02	Based on historical consumption
Ammonia and Urea (CO$_2$)	0.53	0.30	0.28	0.28	0.28	0.28	0.28	No growth assumed, based on analysis of historical data
Iron & Steel (CO$_2$)	0.09	0.36	0.38	0.42	0.48	0.55	0.62	Steel production forecasts from ADEQ
Nitric Acid (N$_2$O)	0.88	1.00	0.99	0.99	0.99	0.99	0.99	No growth assumed, based on analysis of historical data
ODS Substitutes (HFC, PFC)	0.00	0.76	1.16	1.76	2.40	3.06	3.91	Used annual growth rates calculated based on national emissions for 2005-2020
Electric Power T&D (SF$_6$)	0.27	0.18	0.17	0.15	0.15	0.14	0.14	Used annual growth rates calculated from US national emissions for 2005-2020
Waste Management	**2.01**	**2.05**	**2.40**	**2.89**	**3.49**	**4.24**	**5.17**	
Landfills	1.45	1.49	1.81	2.26	2.82	3.53	4.41	Based on default data; Used growth rate calculated for 1996-2005 emissions growth
Wastewater Management	0.48	0.56	0.59	0.63	0.67	0.72	0.77	Used growth rate calculated for 1990-2005 emissions growth
Waste Combustion	0.07	0.00	0.00	0.00	0.00	0.00	0.00	Estimated using NEI method – residential open burning banned post 1999
Agriculture	**10.7**	**10.7**	**11.7**	**11.2**	**11.4**	**11.6**	**11.9**	
Enteric Fermentation	2.02	2.05	2.08	2.10	2.17	2.24	2.30	Based on projected livestock population
Manure Management	1.68	1.45	1.31	1.37	1.43	1.49	1.55	Based on projected livestock population
Agricultural Soils	4.76	4.62	5.24	4.56	4.42	4.29	4.15	Based on historical 1990-2005 emissions growth
Rice Cultivation	2.14	2.52	2.92	3.06	3.27	3.49	3.70	Based on historical 1990-2005 emissions growth
Agricultural Burning	0.05	0.06	0.11	0.11	0.13	0.14	0.16	Based on historical 1990-2005 emissions growth
Forest Wildfires	**0.17**	**0.18**	**0.18**	**0.18**	**0.18**	**0.18**	**0.18**	Assumed no change after 2005
Gross Emissions (Consumption Basis, Excludes Sinks)	**65.8**	**86.8**	**85.4**	**93.5**	**101.3**	**107.5**	**114.2**	
increase relative to 1990		*32%*	*30%*	*42%*	*54%*	*63%*	*74%*	
Emissions Sinks	**-38.5**	**-20.8**	**-20.9**	**-20.9**	**-20.9**	**-20.9**	**-20.9**	
Forestry and Land Use	**-36.7**	**-19.0**	**-19.1**	**-19.1**	**-19.1**	**-19.1**	**-19.1**	
Forested Landscape	-34.2	-18.2	-18.2	-18.2	-18.2	-18.2	-18.2	Based on estimates from the USFS
Urban Forestry and Land Use	-2.43	-0.83	-0.91	-0.91	-0.91	-0.91	-0.91	Assumed no change after 2005
Agricultural Soils (Cultivation Practices)	**-1.80**	**-1.80**	**-1.80**	**-1.80**	**-1.80**	**-1.80**	**-1.80**	Based on 1997 USDA Data for AR
Net Emissions (Consumption Basis, Includes Forestry and Land Use Sinks)	**27.3**	**66.0**	**64.6**	**72.6**	**80.4**	**86.6**	**93.4**	
increase relative to 1990		*141%*	*136%*	*166%*	*194%*	*217%*	*242%*	

MMtCO$_2$e = million metric tons of carbon dioxide equivalent; CH$_4$ = methane; N$_2$O = nitrous oxide; MSW = municipal solid waste; LPG = liquefied petroleum gas; ODS = ozone-depleting substance; HFC = hydrofluorocarbon; PFC = perfluorocarbon; SF$_6$ = sulfur hexafluoride; T&D = transmission and distribution.

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

Historical Emissions

Overview

In 2005, activities in Arkansas accounted for approximately 85 million metric tons of CO_2-equivalent (MMtCO_2e) emissions, an amount equal to about 1.2% of total US gross GHG emissions (based on 2005 US emissions[12]). Arkansas' gross GHG emissions are rising faster than the nation as a whole (gross emissions exclude carbon sinks, such as forests). Gross GHG emissions in Arkansas rose by 30% between 1990 and 2005, whereas national emissions rose by 16% from 1990 to 2005.

Figure 1 illustrates the State's emissions per capita and per unit of economic output.[13] On a per capita basis, Arkansas residents emitted about 28 metric tons (t) of CO_2e in 1990, higher than the 1990 national average of 25 tCO_2e. Per capita emissions in Arkansas increased to 31 tCO_2e in 2005. National per capita emissions for the US decreased slightly to 24 tCO_2e from 1990 to 2005. Figure ES-1 also shows that while per capita emissions have increased from 1990 to 2000 in Arkansas and then began to decrease from 2000 to 2005, per capita emissions for the nation as a whole remained fairly flat from 1990 to 2005. The higher per capita emission rates in Arkansas are driven by emissions growth in the electricity supply, transportation, and agricultural sectors. (Agricultural sector emissions are twice the national average.) Like the nation as a whole, Arkansas' 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 23% in Arkansas and by about 26% nationally.[14]

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[12] 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).

[13] Population Projections from Center for Business and Economic Research, University of Arkansas http://cber.uark.edu/default.asp?show=population
Time Series Extrapolations, 2005-2030 http://www.aiea.ualr.edu/research/demographic/population/default.html

[14] 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 from the 2008 version of EPA's GHG inventory report (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

**Figure 1. Historical Arkansas and US Gross GHG Emissions,
Per Capita and Per Unit Gross Product**
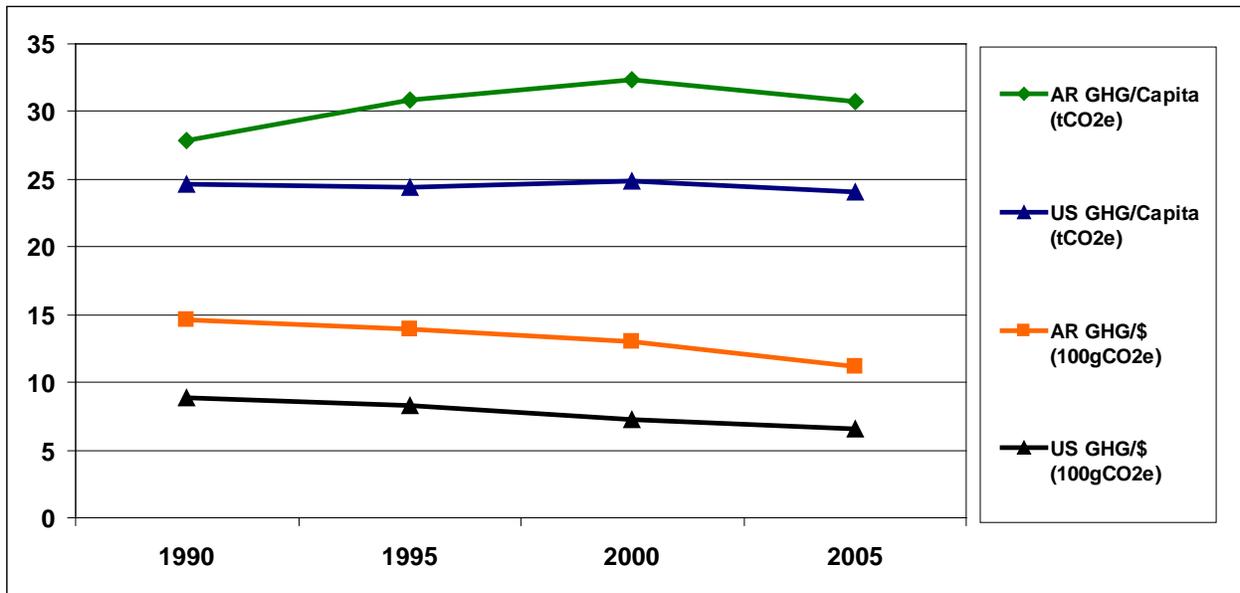
Figure 2 compares gross GHG emissions estimated for Arkansas to emissions for the U.S. for 2005. Principal sources of Arkansas' GHG emissions are electricity consumption, and the transportation sector, accounting for 32% and 26% of Arkansas' gross GHG emissions in 2005, respectively.

Activities in the residential, commercial, and industrial (RCI)[15] sectors produce GHG emissions when fuels are combusted to provide space heating, process heating, and other applications. In 2005, combustion of oil, natural gas, coal, and wood in the RCI sectors contributed about 18% (about 15 MMtCO$_2$e) of Arkansas' gross GHG emissions, slightly lower than the RCI sector contribution for the nation (22%). Emissions from the RCI sector are projected to increase 20% between 2005 and 2025, a slower rate than the increases predicted for all GHG emissions in the state as a whole.

The agricultural and forest wildfire sectors together account for 14% of the gross GHG emissions in Arkansas in 2005. This is higher than the portion of emissions contributed nationally by agricultural emissions and forest fires in 2005 (7%). These emissions primarily come from agricultural soils, rice cultivation, enteric fermentation, and manure management. Agricultural soils can have GHG emissions from nitrogen fertilizers and manure as well as decomposition of crop residues. Enteric fermentation occurs as a result of normal digestive processes of livestock, and this results in methane emissions. Manure management can result in CH$_4$ emissions as a result of manure breaking down. All of these processes can result in emissions of N$_2$O.

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[15] The industrial sector includes emissions associated with agricultural energy use and fuel used by the fossil fuel production industry.

Emissions from the agricultural sector are projected to increase 2% between 2005 and 2025, significantly less than emissions growth in the state as a whole.

While the industrial processes sector accounted for 5% of gross GHG emissions in 2005, emissions in this sector are increasing rapidly. Industrial process emissions are estimated to increase 85% between 2005 and 2025. Industrial Process emissions are rising primarily due to the increasing use of HFCs as substitutes for ozone-depleting chlorofluorocarbons (CFCs)[16]. Other industrial process emissions result from CO_2 released during production of ammonia, urea, cement, lime, and iron and steel, and soda ash, limestone, and dolomite use. The production of nitric acid results in N_2O emissions. In addition, SF_6 is released in the use of electric power transmission and distribution (T&D) equipment.

Methane emissions associated with the natural gas and oil industries and coal mining, all included in the fossil fuel industry category, accounted for 3% of the State's gross GHG emissions in 2005. This category also includes CO_2 emissions from flaring and pipeline fuel use. Waste management also accounted for about 3% of Arkansas' gross GHG emissions in 2005. This sector includes emissions from landfills, wastewater management, and residential open burning.

Forestry activities in Arkansas are estimated to be net sinks for GHG emissions, and forested lands and urban forestry and land use account for a sink of about 19 MMtCO$_2$e per year in 2005. Agricultural soils are also a net sink and account for a sink of 2 MMtCO$_2$e per year.

Figure 2. Gross GHG Emissions by Sector, 2005, Arkansas and US
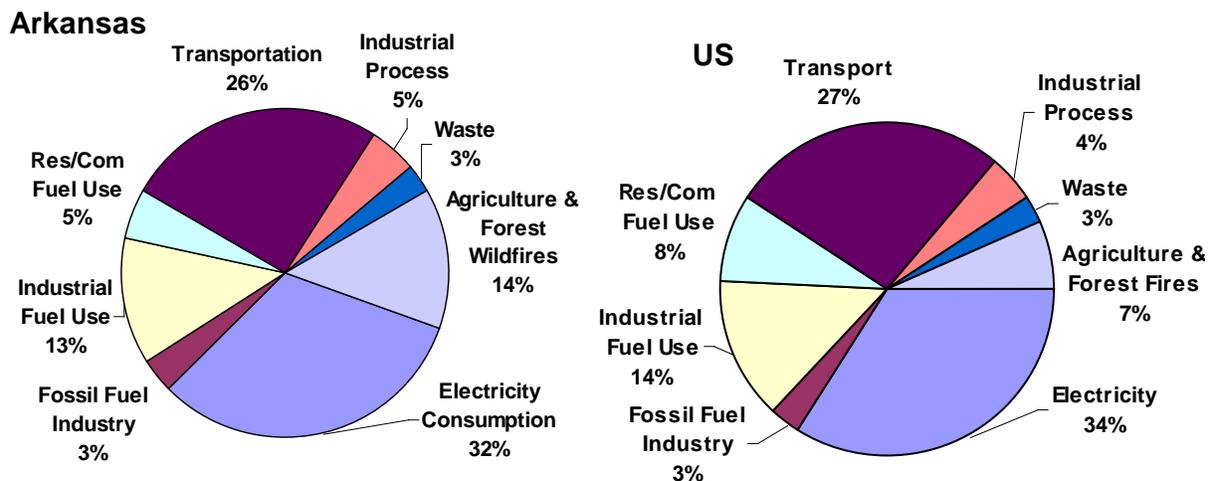
Notes: Res/Comm = residential and commercial fuel use sectors; emissions for the residential, commercial, and industrial fuel use sectors are associated with the direct use of fuels (natural gas, petroleum, coal, and wood) to provide space heating, water heating, process heating, cooking, and other energy end-uses. The commercial sector

[16] 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.

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 are low (~2% of total agricultural and forest wildfire emissions in 2005). Electricity = electricity generation sector emissions on a consumption basis (including emissions associated with electricity imported from outside of Arkansas and excluding emissions associated with electricity exported from Arkansas to other states).

A Closer Look at the two Major Sources: Electricity Consumption and Transportation

Electricity Supply Sector

As shown in Figure 2, electricity consumption accounted for about 32% of Arkansas' gross GHG emissions in 2005 (about 27 $MMtCO_2e$), which was very similar to the national average share of emissions from electricity consumption (34%).[17] Electricity generation in Arkansas comes primarily from coal (45% of Arkansas generation in 2005) and nuclear energy (27%). Arkansas is a net exporter of electricity from 1990 through 2004, except in 2000, when it was a net importer of electricity. The GHG emissions associated with Arkansas' electricity consumption sector increased by almost 10 $MMtCO_2e$ between 1990 and 2005, 50% of the total growth in Arkansas gross GHG emissions over this period.

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

In 2005, emissions associated with Arkansas' electricity consumption (27.2 $MMtCO_2e$) were the same as those associated with electricity production (27.2 $MMtCO_2e$). From 2005 through 2025, the forecast assumes that Arkansas is self-sufficient in electricity production, neither importing nor exporting electricity. The reference case projection projects that emissions associated with both electricity consumption and electricity production will increase by about 10.2 $MMtCO_2e$ from 2005 to 2025, for a total of 37.4 $MMtCO_2e$ in 2025.

Transportation Sector

As shown in Figure 2, the transportation sector accounted for about 26% of Arkansas' gross GHG emissions in 2005 (about 22 $MMtCO_2e$), which was slightly lower than the national average share of emissions from transportation fuel consumption (27%). The GHG emissions associated with Arkansas' transportation sector increased by 5 $MMtCO_2e$ between 1990 and 2005.

From 1990 through 2005, Arkansas' GHG emissions from transportation fuel use have risen steadily at an average rate of about 1.8% annually. In 2005, onroad gasoline vehicles accounted for about 57% of transportation GHG emissions. Onroad diesel vehicles accounted for another

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[17] 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.

28% of transportation 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 15% of transportation emissions. GHG emissions from onroad gasoline use increased 15% between 1990 and 2005. During the same time period, GHG emissions from onroad diesel use rose 61%, 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, Arkansas gross GHG emissions continue to grow steadily, climbing to about 114 MMtCO$_2$e by 2025, 74% above 1990 levels. This equates to an annual rate of growth of 1.5% per year from 2005 to 2025. Relative to 2005, the share of emissions associated with electricity consumption and the transportation sector both increase slightly to 33% and 27%, respectively, in 2025. The share of emissions from the RCI fuel use and agriculture sectors both decrease to 16% and 11%, respectively, of Arkansas' gross GHG emissions in 2025. The share of emissions from the industrial processes and waste management sectors is projected to increase slightly to 7% and 5%, respectively, by 2025. The portion of emissions contributed by the fossil fuel industry remains constant at 3% in 2025.

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 Arkansas reference case projections as well as the sources of these data.

GCGW Revisions

The following identifies the revisions that the GCGW made to the inventory and reference case projections, thus explaining the differences between this report and the initial assessment completed during May 2008:

- Energy Supply:

The GCGW approved the following revisions to the fuel-mix for the forecast as follows:

  o Gross coal-fired generation: The GCGW approved including both the Plum Point and Hempstead County (Turk) coal plants in the reference case projections (both of these plants were included in the May 2008 draft forecast). The GCGW revised the start year for the plants; changing the on-line start date for Plum Point from 2009 to 2010 and for Hempstead County from 2011 to 2012. The GCGW also approved a faster ramp-up of output from the Plum Point and Hempstead plants relative to the draft forecast.
  o Net Imports: Assumes no net imports (or exports) during the forecast period (2005-2025). The draft forecast assumed Arkansas would be a net importer of electricity from 2005 to 2010 and a net exporter of electricity from 2011 to 2025.

- o Gross natural gas-fired generation and primary energy use: Includes natural gas combined cycle capacity to satisfy the criteria that (1) Arkansas be self-sufficient in electricity production, and (2) that there be no net imports over the revised forecast period (2005-2025); the earlier forecast did not include this assumption.
    - o Gross oil-fired generation and primary energy use: About 20% - 25% higher than the draft forecast for 2005-2025.
    - o Gross nuclear generation and primary energy use: 36% less than the draft forecast in the 2020-2025 period.
    - o All other gross generation and primary energy use: About 3% higher than the draft forecast for 2005-2025.

- • Agriculture:

    - o A preliminary estimate was made of the likely emissions coming from catfish farms in Arkansas. This emission estimate was relatively low and has been documented in Appendix F. However, the GCGW determined that the uncertainty associated with this estimate was too great for these emissions to be included in the overall agricultural emissions totals included in this section of the report.

    - o Two additional tables have been added to Appendix F that categorize manure management emissions by pollutant (N_2O and CH_4) and by animal (chicken, dairy, etc). This does not change the manure management emissions total.

- • Waste Management:
    - o Arkansas Department of Environmental Quality (ADEQ) provided 2002-2005 municipal solid waste (MSW) landfill disposal data, which was used in place of default EPA data.
    - o ADEQ also provided a growth rate for MSW landfill disposal, which replaced the original growth rate based on historical data.

Reference Case Projections with Recent Federal Actions[18]

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 GCGW process, sufficient information was identified (e.g., implementation schedules) to estimate GHG emission reductions associated with the implementing the Corporate Average Fuel Economy (CAFE) requirements and energy efficiency requirements for new appliances and lighting in Arkansas. The GHG emission reductions projected to be achieved by these actions are summarized in Table 3. This table shows a total reduction of about 4.2 $MMtCO_2e$ in 2025 from the business-as-usual reference case emissions, or a 3.6% reduction from the business-as-usual 2025 emissions for all sectors combined.

The following provides a brief summary of each of the three components of the EISA that were analyzed as recent actions.

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

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 transportation, electricity demand, and RCI fuel use growth rates that will be major determinants of Arkansas' 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.

Figure 3. Arkansas Gross GHG Emissions by Sector, 1990-2025: Historical and Projected
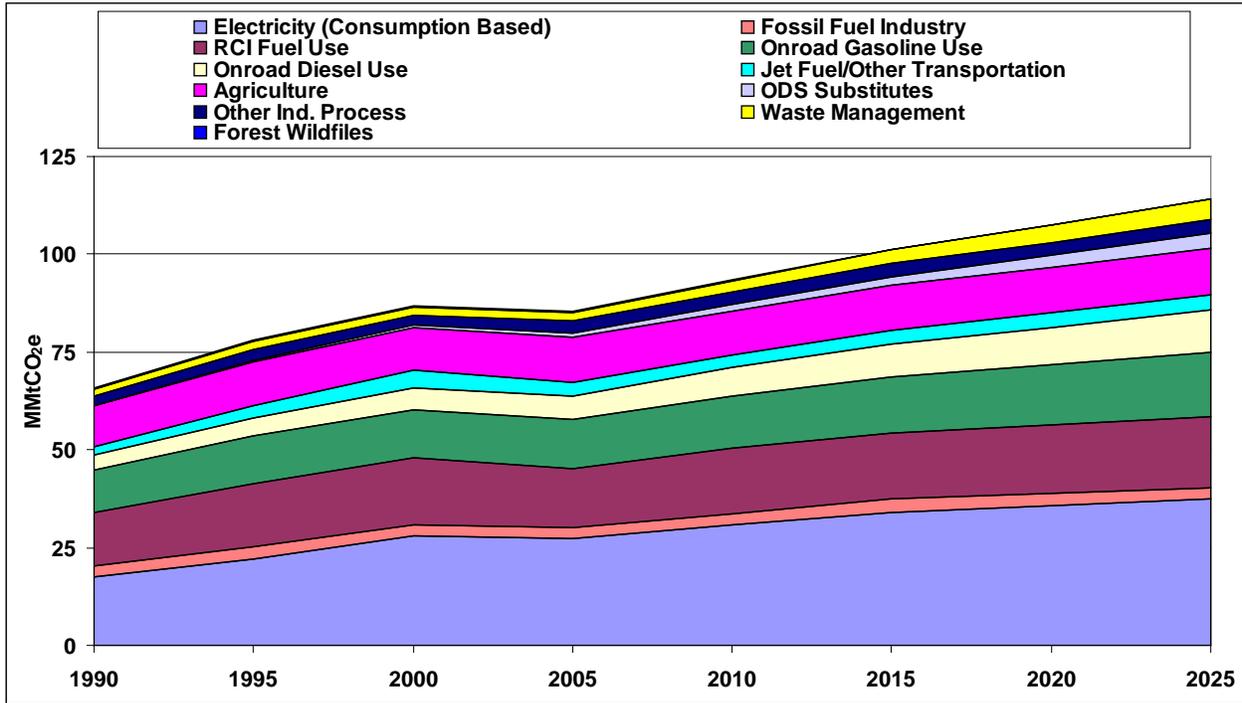
RCI – direct fuel use in residential, commercial, and industrial sectors. ODS – ozone depleting substance.

Figure 4. Sector Contributions to Gross Emissions Growth in Arkansas, 1990-2025: Historical and Reference Case Projections (MMtCO₂e Basis)
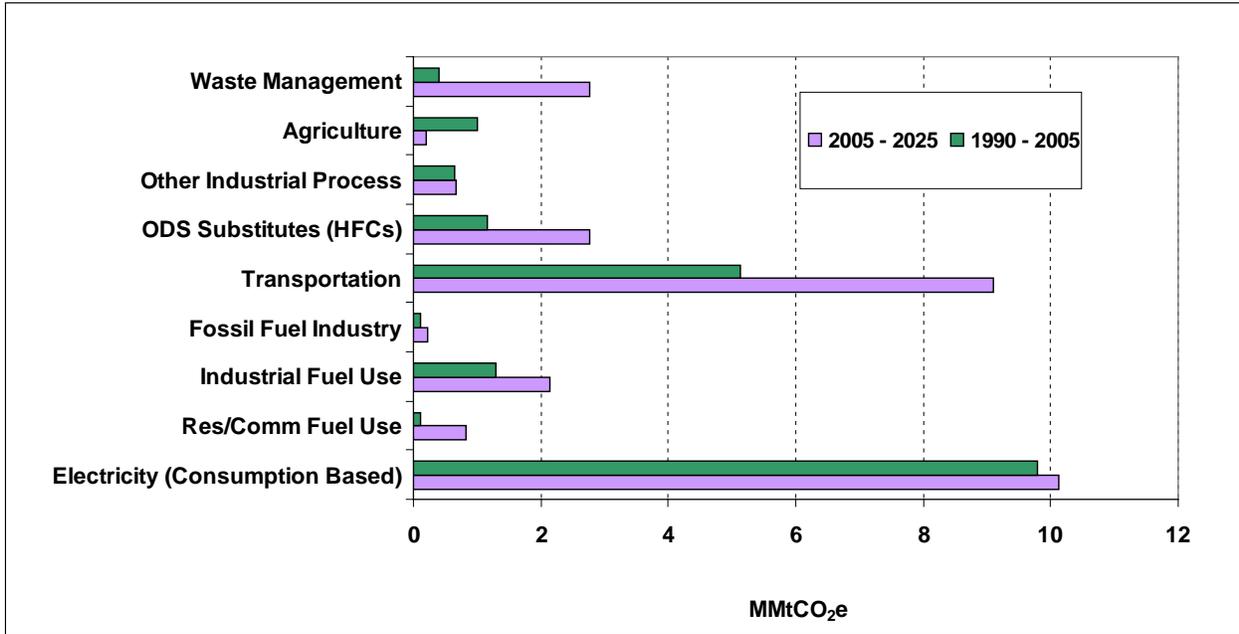
Res/Comm – direct fuel use in residential and commercial sectors. ODS – ozone depleting substance. HFCs – hydrofluorocarbons. Emissions associated with other industrial processes include all of the industries identified in Appendix D except emissions associated with ODS substitutes which are shown separately in this graph because of high expected growth in emissions for ODS substitutes.

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

	1990-2005	2005-2025	Sources
Population	1.10%	0.81%	1990-2004 from Historical Data from US Census Bureau, Intercensal Population Estimates at: http://cber.uark.edu/data/population/Geographic_Regions.xls Arkansas County and State Population Projections: Time Series Extrapolations, 2005-2030 http://www.aiea.ualr.edu/research/demographic/population/default.html
Electricity Sales	3.55%	1.37%	For 1990-2005, annual growth rate in total electricity sales for all sectors combined in Arkansas calculated from EIA State Electricity Profiles (Table 8) and sales by Arkansas generators calculated from EIA State Electricity Profiles (Table 5) http://www.eia.doe.gov/cneaf/electricity/st_profiles/arkansas.html For 2005-2025, annual growth rates are based on average growth rates in the SERC and SPP regions in which Arkansas is located.
Vehicle Miles Traveled	2.7%	1.7%	Based on SIT default Federal Highway Administration VMT for 1990-1992; 1993-2005 VMT provided by Arkansas Highway and Transportation Department; VMT for 2006-2025 calculated by linear regression based on 1990-2005 VMT.

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

Sector / Recent Action	GHG Reductions (MMtCO$_2$e)		GHG Emissions (MMtCO$_2$e)	
			Business as Usual	With Recent Actions
	2015	2025	2025	2025
Residential, Commercial and Industrial (RCI) Federal Improved Standards for Appliances and Lighting Requirements	0.34	0.89	18.1	17.2
Transportation and Land Use (TLU) Federal Corporate Average Fuel Economy (CAFE) Requirements	1.02	3.26	31.1	27.8
Total (RCI + TLU Sectors)	**1.36**	**4.15**	**49.2**	**45.0**
Total (All Sectors)			**114.2**	**110.1**

GHG = greenhouse gas; MMtCO$_2$e = million metric tons of carbon dioxide equivalent.

Approach

The principal goal of compiling the inventories and reference case projections presented in this document is to provide the State of Arkansas with a general understanding of Arkansas' 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 Arkansas.

General Methodology

We prepared this analysis in close consultation with Arkansas agencies, in particular, with the staff at ADEQ. 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[19] and its guidelines for States.[20] These inventory guidelines were developed based on the guidelines from the IPCC, the international organization responsible for developing coordinated methods for national GHG inventories.[21] 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.

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[19] *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)..
[20] http://yosemite.epa.gov/oar/globalwarming.nsf/content/EmissionsStateInventoryGuidance.html.
[21] http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

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 Arkansas. 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 Arkansas. For example, we reported emissions associated with the electricity consumed in Arkansas. 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.

Table 4. Key Sources for Arkansas 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) forms; State Energy Data (SED)	EIA SED provides energy use data in each State, annually to 2005 for all RCI sectors and fuels, except for commercial wood consumption for which 2003 is the latest year for which data are available from EIA, and for transportation fuels. EIA forms (759, 906) provide generation and primary energy use data at electric power generators.	EIA SED is the source for most energy use data. Emission factors from US EPA SIT are used to calculate energy-related emissions. EIA forms (906, 759) were used to develop plant-specific generation and energy use profiles.
EIA State Electricity Profiles	EIA provides information on the electric power industry generation by primary energy source for 1990 – 2005.	EIA State Electricity Profiles were 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 2004 to 2030. Energy consumption is estimated on a regional basis. Also used to provide projected mix of onroad vehicles and aircraft efficiency gains for transportation sector.	EIA AEO2007 is used to project changes in fuel use by the RCI sectors.
Arkansas Highway and Transportation Department	Historical 1993-2005 VMT data.	Used in calculating historical CH_4 and N_2O from onroad vehicles and in developing projection year VMT data via linear regression.
Federal Aviation Administration (FAA)	Aircraft operation projections for Arkansas.	Projected aircraft operations data used to develop aviation sector growth factors, in combination with national commercial aircraft fuel efficiency gains data from *AEO2007*.

Source	Information provided	Use of Information in this Analysis
US Department of Transportation (DOT), Office of Pipeline Safety (OPS)	Natural gas gathering/transmission pipeline mileage for 2001-2005; distribution pipeline mileage and number of services for 1990–2005 (with revised values for select years provided by Arkansas Public Service Commission).	OPS data entered into SIT to calculate historical emissions. OPS transmission pipeline data backcasted to 1990 using EIA data on volume of natural gas transported into and out of Arkansas. OPS gathering pipeline data backcasted to 1990 using EIA data on natural gas production in Arkansas. Natural gas gathering/transmission pipeline emissions projected using AEO2007 regional natural gas pipeline use projections. Distribution emissions projected using smallest annualized rate of decrease in state distribution emissions (-0.26%), from each of 3 historical periods analyzed.
EIA Natural Gas Navigator	EIA provides the number of gas and gas condensate wells and amount of gas flared and vented in Arkansas for 1990-2005. Arkansas Oil and Gas Commission provides number of associated gas wells in state.	Natural Gas Navigator data entered into SIT to calculate historical emissions. Gas well emissions projected based on application of AEO2007 regional natural gas production forecast growth rates; flaring emissions projected based on no growth assumption due to conflicting observed historical trends.
PennWell Corporation Oil and Gas Journal	PennWell reports the number of gas processing plants in Arkansas for 1990-2005.	PennWell data entered into SIT to calculate historical emissions. Emissions projected based on smallest annualized increase in the number of gas processing plants in Arkansas (1.50%) from each of 3 periods analyzed (1990-2005; 1995-2005, and 2000-2005).
EIA Petroleum Navigator	Volume of crude oil production in Arkansas for 1990-2005, and regional crude oil input, regional refining capacity, and Arkansas' refining capacity for 1990-2005 (because data were not available to estimate 1996 and 1998 refining; these years' estimates were interpolated).	EIA data entered into SIT to calculate historical emissions. Oil production emissions projected based on smallest annualized decrease in state oil production (-2.37%) from each of 3 periods analyzed (i.e., 1990-2005, 1995-2005, and 2000-2005); oil refining emissions projected based on AEO2007 regional refining capacity forecast.
US EPA GHG Inventory and Sinks Report	CH_4 emissions from coal mining	Incorporated EPA estimates of coal mining GHG emissions in Arkansas directly into inventory for historical years.
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).
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 Arkansas. This entails accounting for the electricity sources used by Arkansas utilities to meet 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 Arkansas, 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 Use and Supply
- Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion
- Appendix C. Transportation Energy Use
- Appendix D. Industrial Processes
- Appendix E. Fossil Fuel Extraction and Distribution Industry
- Appendix F. Agriculture
- Appendix G. Waste Management
- Appendix H. Forestry

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 Arkansas. It also describes the data sources, key assumptions, and methodology used to develop a reference case projection (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 Arkansas GHG inventory for the electric supply sector.

❑ *Greenhouse Gas Forecast Methodology – Reference Case:* This section provides an overview of the methodological approach used to develop the Arkansas GHG forecast for the electric supply sector.

❑ *Greenhouse Gas Inventory Results:* This section provides an overview of key results of the Arkansas GHG inventory for the electric supply sector.

❑ *Greenhouse Gas Forecast Results:* This section provides an overview of key results of the Arkansas GHG forecast for the electric supply sector.

Major Data Sources Used to Develop the GHG Inventory for Energy Supply

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

❑ *State electricity sales data.* This information is available from the EIA. The database compiles total retail electricity sales by state. It was used to determine total sales of electricity across all sectors for the period 1990 through the Base Year of 2005. It can be accessed directly from http://www.eia.doe.gov/cneaf/electricity/page/sales_revenue.xls.

❑ *State electricity generation data.* This information is available from the EIA. The database compiles total net electricity generation by state. It was used to determine total net generation of electricity across all fuel types for the period 1990 through the Base Year of 2005. It can be accessed directly from http://www.eia.doe.gov/cneaf/electricity/epa/generation_state.xls.

❑ *State primary energy use for electricity generation data.* This information is available from the EIA. The database compiles total primary energy consumption by state. It was used to determine total primary energy use across all fuel types for the period 1990 through the Base Year of 2005. It can be accessed directly from http://www.eia.doe.gov/cneaf/electricity/epa/consumption_state.xls.

❑ *State combined heat and power (CHP) production characteristics.* This information is available from the EIA. The database compiles primary energy consumption by state for combined heat and power facilities, both commercial and industrial. It was used to determine total shares of energy use between commercial and industrial applications across all fuel types for the period 1990 through the Base Year of 2005. It can be accessed directly from http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html.

❑ *State renewable energy data.* This information is available from the EIA. The database compiles net generation by state for all types of renewable energy. Where 'other wastes' were noted in the EIA data tables, they are assumed to be biomass wastes (e.g., switchgrass, agricultural wastes, paper pellets). It was used to determine total shares of energy use between commercial and industrial applications across all fuel types for the period 1990 through the Base Year of 2005. It can be accessed directly from http://www.eia.doe.gov/cneaf/solar.renewables/page/renewelec.html.

Additional Data Sources Used to Develop the GHG Inventory for Energy Supply

We considered several additional sources of information in the development of the inventory and forecast of CO_2e emissions from Arkansas power plants, either for cross-checking purposes or for widely accepted conversion factor information. These are briefly summarized below:

❑ *State Electricity Profiles.* This information is available from the EIA. The database compiles capacity, net generation, and total retail electricity sales by state. It was used to cross check other data sources regarding Base Year levels for sales, generation, and primary energy use. It can be accessed directly from http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html.

❑ *Energy conversion factors.* This is based on Table Y-2 of Appendix Y in the USEPA's 2003 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://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/LHOD5MJTCL/$File/2003-final-inventory_annex_y.pdf.

❑ *Fuel combustion oxidation factors.* This is based on Appendix A of the USEPA's 2003 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 Appendix A of the USEPA's 2003 GHG inventory for the US. This information can be accessed directly from: http://www.epa.gov/climatechange/emissions/downloads06/06_Annex_Chapter2.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/pub/reports.htm.

Major Data Sources Used to Develop the GHG Forecast for Energy Supply

We considered several sources of information in the development of the inventory and forecast of CO_2e emissions from Arkansas power plants. These are briefly summarized below:

❑ *Sales forecast:* This was based on outputs from the Annual Energy Outlook 2007, an EIA analysis using the National Energy Modeling System (NEMS) to forecast electric expansion/electricity demand in the US. In particular, regional outputs for the Southwest Power Pool (SPP) region and the Southeastern Reliability Council (SERC) region were used.
Arkansas was assumed to be partly (85%) located in the SERC region and partly (15%) located in the SPP region (see map). The SPP and SERC results include forecasts of gross generation, net generation, combustion efficiency, total sales, 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 map is http://www.epis.com/EnergyLinks/Reliability%20Regions/reliability_regions.htm.

❑ *Planned Capacity additions/retirements:* Based on TWG inputs, it was assumed that there were no retirements of capacity in place in the 2005 Base year. Only two planned additions were assumed over the 2006-2025 period, namely the Plum point coal-fired station (The data source for the performance characteristics for this plant is http://sec.edgar-online.com/2007/02/08/0001193125-07-023538/Section19.asp) and the Hempstead coal-fired stations. (The data source for the performance characteristics for this plant is the direct testimony of James A. Kobyra in docket 06-1254-U)

❑ *Unplanned capacity additions:* Based on TWG inputs, it was assumed that Arkansas would not be either a net importer or a net exporter of electric power over the 2005-2025 planning period. To meet this criterion, natural gas combined cycle (NGCC) units were assumed to come online. The source for size and performance characteristics for such units are consistent with assumptions used in the AEO2007 source identified above.

❑ *Transmission and distribution losses:* As with trends in retail electricity sales, T&D losses were based on outputs from the Annual Energy Outlook 2007 for the 2005-2025 planning period. A weighted average of regional outputs for the SPP and SERC regions was used.

❑ *Parasitic load:* Parasitic load (i.e., electricity use at the power station itself) estimates were based on outputs from the Annual Energy Outlook 2007 for the 2005-2025 planning period. A weighted average of regional outputs for the SPP and SERC regions was used.

Greenhouse Gas Inventory Methodology and Results

The methodology used to develop the Arkansas 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 two fundamental premises of the GHG inventory developed for Arkansas, 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 Arkansas, regardless of ownership. Developing the consumption estimate involves tallying up the GHG emissions associated with consumption of electricity in Arkansas, regardless of where the electricity is produced.

❑ The GHG inventory should be estimated based on emissions at the point of electric generation only. That is, GHG emissions associated with the 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.

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.. A summary of the electric system characteristics in the base year is shown in Table A1 and in Figure A1.

❑ Determine the coal quality used in Arkansas power stations (i.e., share of anthracite, bituminous, lignite, sub-bituminous, and coal wastes used).

❑ Determine the oil quality used in Arkansas power stations (i.e., share of fuel oil #2, #4, #5, and #6 used).

❑ Determine gross annual primary energy consumption by Arkansas power and CHP stations by plant and fuel type.

❑ Determine gross annual generation associated with net power imports to satisfy Arkansas electricity demand.

❑ Multiply gross annual primary energy consumption by Arkansas power and CHP stations by CO_2e emission factors. This provides an estimate of the Arkansas GHG inventory on a production basis.

❑ Multiply annual gross generation associated with net power imports by the weighted average carbon emission intensity (in units of metric tons of CO_2e per megawatt-hour [tCO_2e/MWh]) of the SPP and SERC regions. This provides an estimate of the additional GHG emissions associated with meeting Arkansas electricity demand in excess of generation from local power plants.

❑ Add the emissions associated with net power imports to the production-based emissions. This provides an estimate of the GHG inventory on a consumption basis.

Table A1. Summary of Arkansas Electric Generator Characteristics for the 2005 Base Year

Fuel	Gross Generation (GWh)	Fuel use (Trillion Btu)	Heat rate (Btu/KWh)	Emissions (MMtCO$_2$e)
Coal	23,226	241	10,375	23.30
Natural Gas	4,854	38	7,920	2.06
Other Gases	0	0	0	0.00
Petroleum	208	2	9,889	0.15
Nuclear	13,802	146	10,582	0.00
Hydroelectric	3,108	32	10,320	0.00
Geothermal	0	0	10,500	0.00
Solar/PV	19	0	10,320	0.00
Wind	0	0	10,320	0.00
MSW Landfill gas	153	2	10,500	0.09
Biomass	1,555	16	10,500	0.01
Other wastes	0	0	10,500	0.00
Pumped storage	21	0	10,500	0.02
Imports	2,880	29		1.71
Total	**49,826**	**507**		**25.62**

Figure A1. Arkansas Generation and Emissions, 2005 Base Year
a. Gross Generation (51,683 GWh)
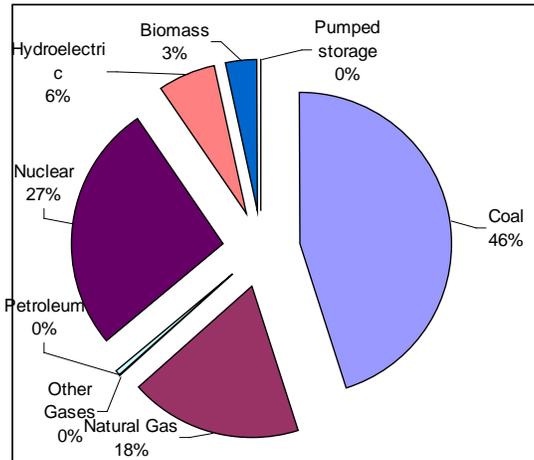
b. Primary Energy (503 Trillion Btu)
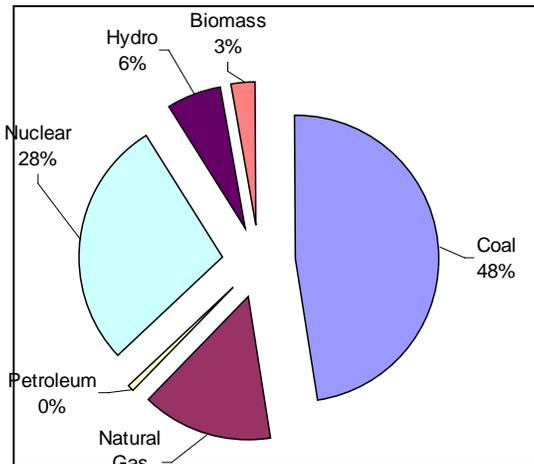
c. Emissions (27.23 MMtCO$_2$e)
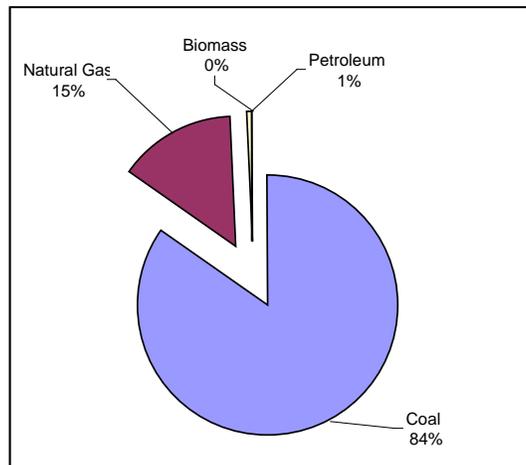
Total primary energy consumption associated with electricity generation in Arkansas during the inventory period is summarized in Figure A2.

Figure A2. Primary Energy Use in Arkansas Power Stations, Inventory Period (1990-2005)
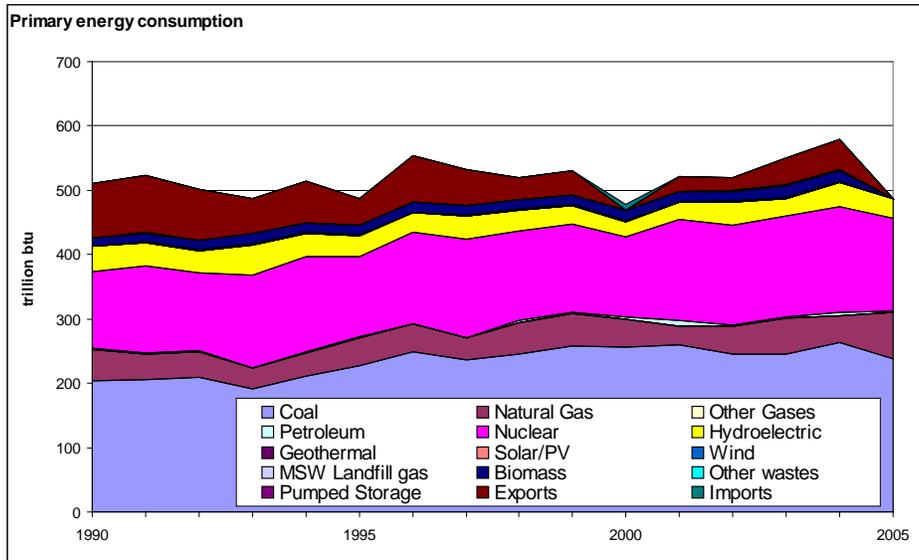
Total gross generation by Arkansas power plants during the inventory period is summarized in Figure A3. Gross generation in Arkansas is dominated by coal/nuclear steam units.

Figure A3. Gross Generation to Meet Arkansas Electricity Demand, Inventory Period (1990-2005)
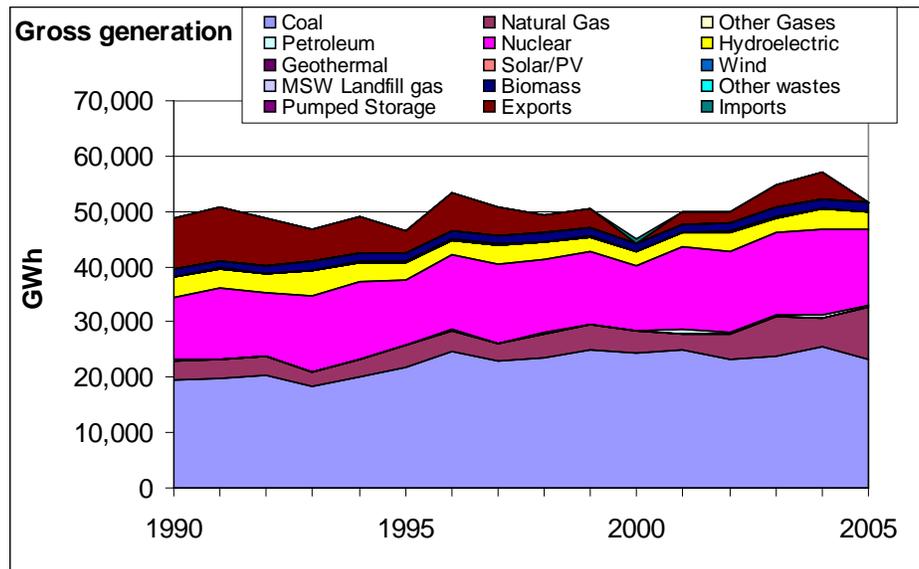
Total GHG emissions by Arkansas power plants during the inventory period is summarized in Figure A4.

Figure A4. GHG Emissions to Meet Arkansas Electricity Demand, Inventory Period (1990-2005)
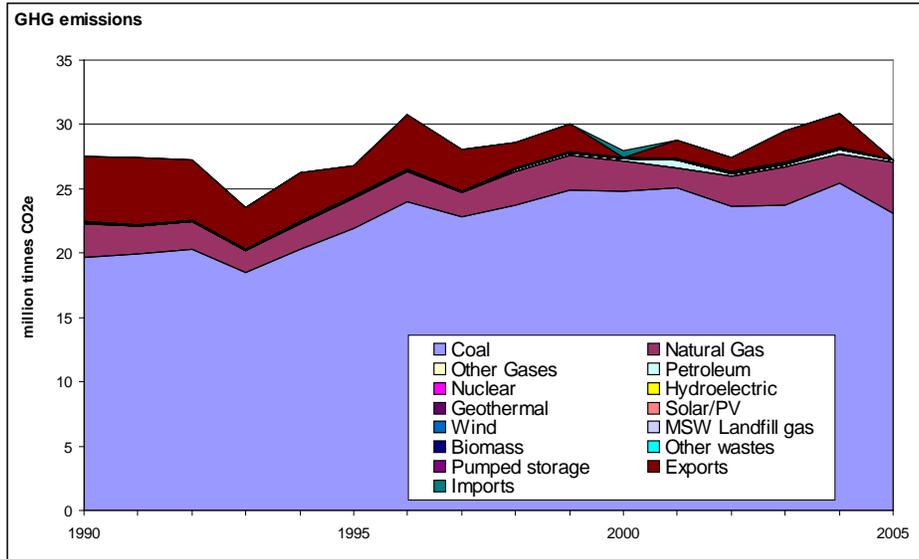
Greenhouse Gas Forecast Methodology and Results

The GHG forecast was developed using state-specific data regarding projected sales, gross in-state generation, planned capacity additions and retirements by plant type/vintage, and changes over time regarding losses associated with on-site use and transmission and distribution (T&D). The methodological steps used for forecasting CO_2e emissions are described below. A summary of the forecast results is shown in Table A2.

❑ *New coal stations.* There are two new coal stations that are included in the forecast, these are the Plum Point power station (665 megawatts (MW)) and the Hempstead plant (600 MW). It is assumed that the Plum Point station comes on line in 2010 and the Hempstead station comes online in 2012. Both plants are assumed to operate at a capacity factor of 75%, with heat rates of 9,425 btu/kWh and 9,000 btu/kWh, respectively.

❑ *Coal quality.* For the period 2006 through and including 2025, it was assumed that sub-bituminous coal is combusted in all coal-fired power stations in Arkansas.

❑ *Electricity imports/exports.* Given the TWG-established criterion on no net imports or net exports, the power sector in Arkansas is assumed to produce sufficient power to satisfy retail electricity demand in the state.

❑ *Gross generation.* Gross generation is defined as net generation plus parasitic load. It was assumed that all existing power stations as of 2005, operated at the same capacity factor throughout the planning period. For new stations (i.e., coal-fired and NGCC units), gross generation was assumed to be proportional to design capacity factors that are assumed to be in effect throughout the planning period (i.e., 75% for coal stations; 65% for NGCC stations).

❑ *Total sales.* For the Base Year of 2005, total retail sales in Arkansas were 46,165 gigawatt-hour (GWh). For the period 2006 through and including 2025, sales to meet the electricity demand were based on a growth rate of 1.37%/year, the weighted average for the SPP amnd SERC regions in which Arkansas is located.

❑ *Combustion efficiency.* Annual heat rates at Arkansas power stations was assumed to be the quotient of primary energy use and gross generation. Historical values for the 2005 base year, by fuel type, were available from the federal databases discussed earlier. It was assumed that this heat rate remained in effect throughout the planning period.

❑ *Primary energy use.* Primary energy is defined as total fuel input to yield gross generation levels. Given the previous assumptions that a) all existing power stations operated at the same capacity factor throughout the planning period, and b) there were no supply side efficiency improvements/declines, primary energy use in the base year was assumed constant throughout the planning period.

❑ *Carbon dioxide-equivalent emissions from Arkansas power stations:* Total CO_2e emissions from Arkansas power stations were calculated by multiplying primary energy levels by the emissions factors (in tonnes per mmbtu) of CO_2, CH_4, and N_2O. The global warming factors mentioned earlier were then applied to these results to obtain total tonnes of CO_2e.

Table A2. Key Results for the Forecast Period

Key Assumptions	2005	2025	Average Annual Growth / Change (%)
Arkansas electricity demand (GWh)	46,165	60,612	1.37%
Gross generation to meet Arkansas electricity demand (GWh)			
From Arkansas utilities/non-utilities	49,671	65,154	1.37%
From CHP facilities	2,012	2,012	0.00%
Total	51,683	67,165	1.32%
Power plant heat rate (Btu/kWh)			
Coal	10,285	10,005	-0.14%
Nuclear	10,582	10,582	0.00%
Natural Gas	7,713	7,422	-0.19%
Oil	10,869	10,869	0.00%
Municipal Solid Waste (MSW)	10,500	10,500	0.00%
Biomass	10,500	10,500	0.00%
Landfill Gas (LFG)	10,500	10,500	0.00%
Wind	10,320	10,320	0.00%
Hydroelectric	10,320	10,320	0.00%
Transmission and Distribution (T&D) Losses (%)	7.7%	7.6%	-0.11%

GWh = gigawatt-hour; Btu/kWh – British thermal unit per kilowatt-hour.

Total primary energy consumption associated with electricity generation in Arkansas is summarized in Figure A5. Primary energy consumption in Arkansas is dominated by coal and nuclear resources.

Figure A5. Primary Energy Use in Arkansas Power Stations, Forecast Period (2005-2025)
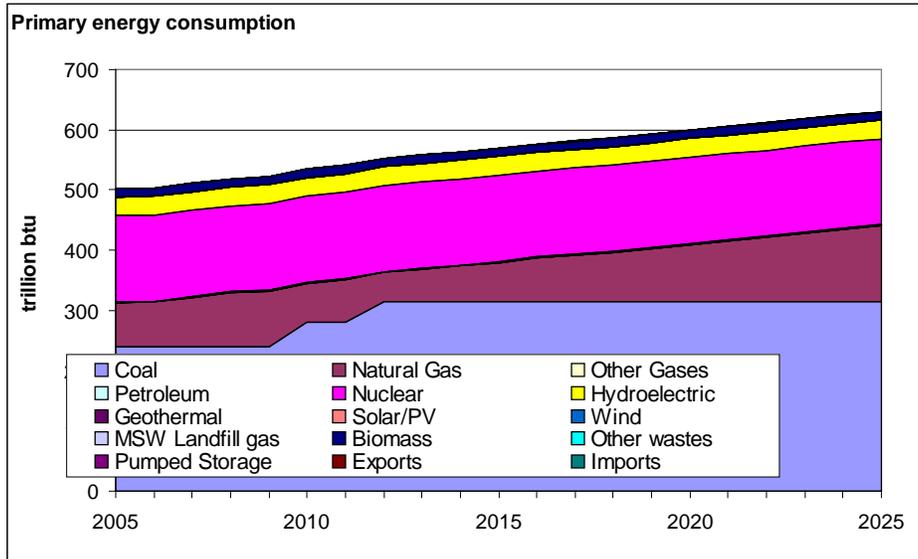
Total gross generation by Arkansas power plants is summarized in Figure A6. Gross generation in Arkansas is dominated by coal/nuclear steam units, and natural gas combined cycle units.

Figure A6. Gross Generation at Arkansas Power Stations, Forecast Period (2005-2025)
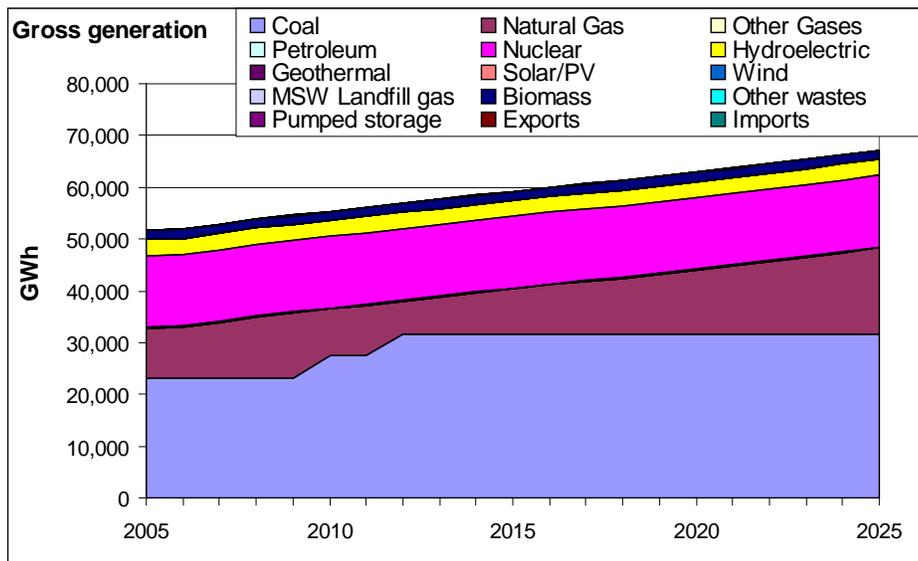
The total GHG emissions by Arkansas power plants over the forecast period are summarized in Figure A7.

Figure A7. GHG Emissions from Arkansas Power Stations, Forecast Period (2005-2025)
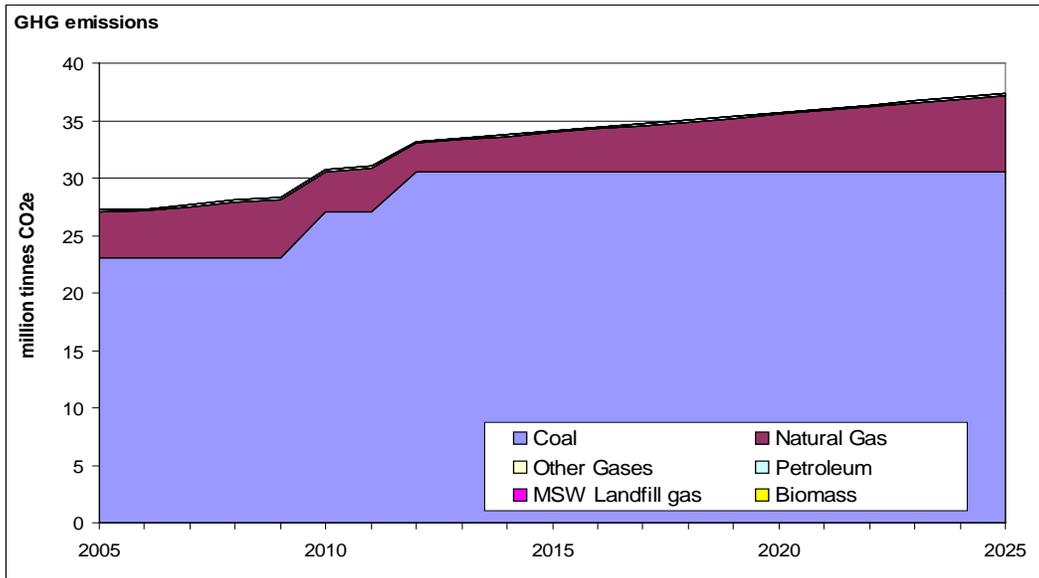
Source: Results in table based on approach described in text.

Integrated Results

Results for primary energy uise, gross genereationl, and CO_2e emissions are provided in the following figures.

Figure A8. Gross Primary Energy, 1990-2025
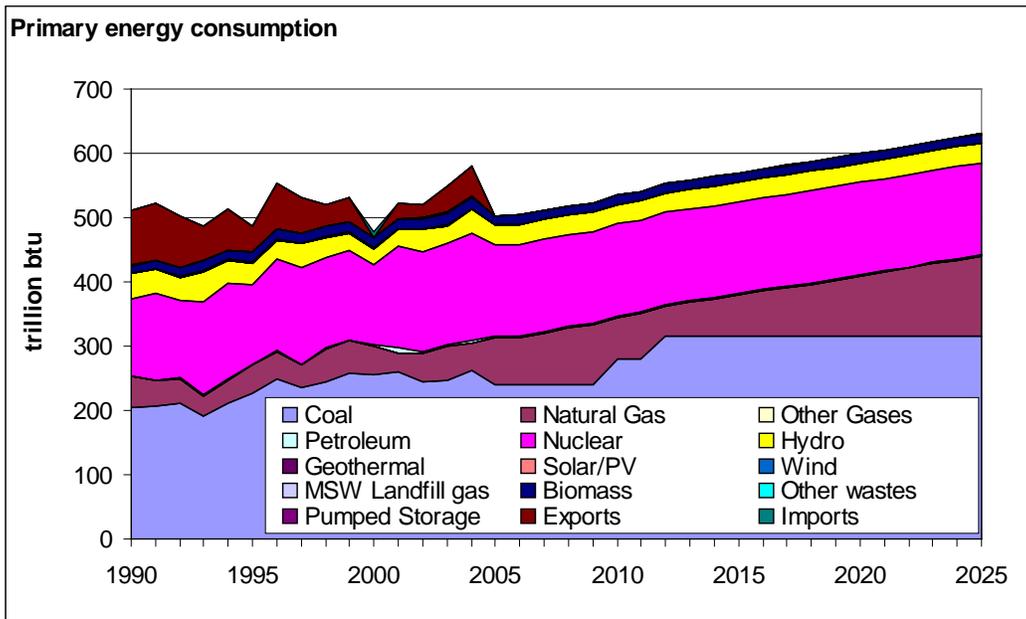
Source: Results in table based on approach described in text.

Figure A9. Gross Generation, 1990-2025
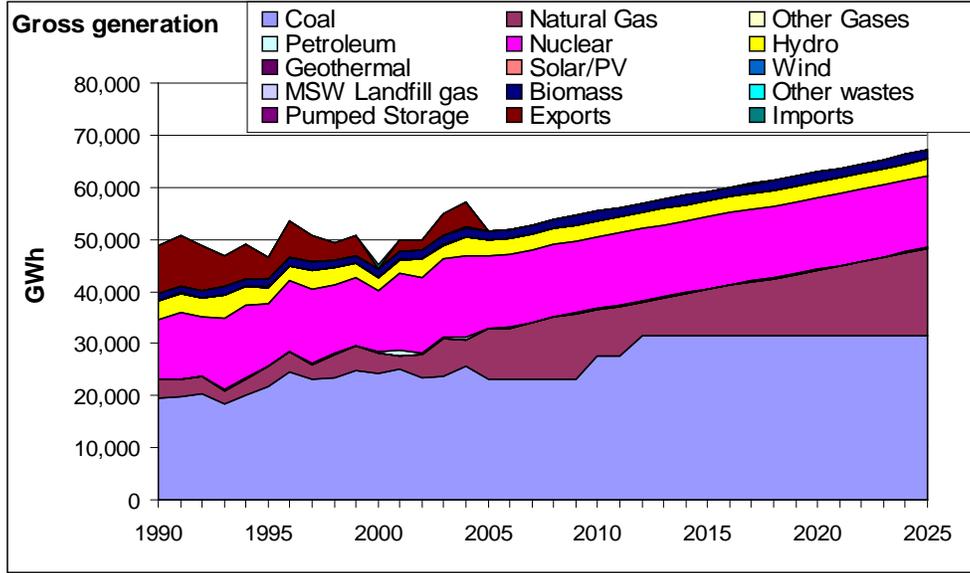
Source: Results in table based on approach described in text.

Figure A10. GHG Emissions, 1990-2025
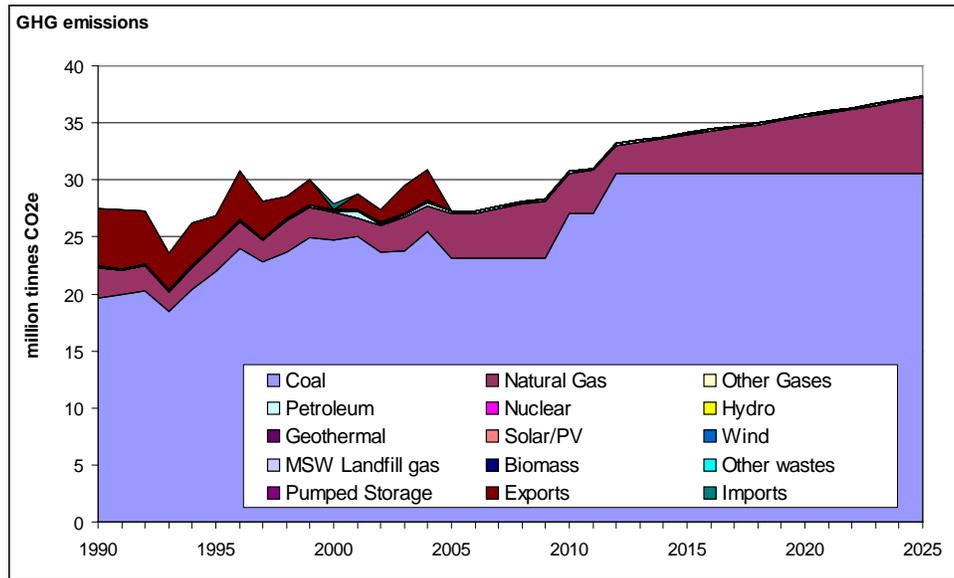
Source: Results in table based on approach described in text.

Key Uncertainties

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

- The methodologies used in this initial preliminary analysis rely on state-specific data on electricity generating units available from the EIA for the historical estimates of GHG emissions. The forecast relies on EIA data available from the AEO2007 forecast for the SPP and SERC regions for projected sales, T&D losses, and on-site electricity use at power

plants. Future work should focus on improving the forecast by compiling state-specific forecast data to estimating emissions for the electricity supply sector.

- There are uncertainties associated with the statewide fuel mix, emission factors, and conversion factors (to convert electricity from a heat input basis to electricity output) that should be reviewed and revised with data that is specific to Arkansas power generators.

- 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 over the forecast period. Although the effects of fuel price changes on the supply and demand of electricity are included in the EIA regional modeling used for this initial analysis, unanticipated events that affect fuel prices could affect the electricity forecast for Arkansas.

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

Overview

Activities in the RCI[22] 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 about 99% of these emissions on a million metric tons (MMt) of CO_2 equivalent (CO_2e) basis in Arkansas. 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.[23] Direct use of oil, natural gas, coal, and wood in the RCI sectors accounted for an estimated 15.1 MMtCO$_2$e of gross greenhouse gas (GHG) emissions in 2005.[24]

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.[25] The default data used in SIT for Arkansas 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 Arkansas for natural gas, petroleum, and coal for each of the RCI sectors and for wood for the residential and industrial sectors.[26]

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 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

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[22] The industrial sector includes emissions associated with agricultural energy use and fuel combustion by natural gas transmission and distribution (T&D) and oil and gas production industries.

[23] 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.

[24] 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.

[25] 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.

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

assumptions for these products are explained in detail in the EIIP guidance document.[27] The fossil fuel types for which the EIIP methods are applied in the SIT software to account for carbon storage are: 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,[28] 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.[29]

Table B1 shows historical and projected growth rates for electricity sales by sector. The 1990-2005 electricity sales data by RCI sector were obtained from EIA.[30] For 2005 to 2025, the annual growth rate in electricity sales for each sector was estimated from the sector growth rates projected for the Southwest Power Pool and Southeastern Electric Reliability Council regions as reported in EIA's *Annual Energy Outlook 2007* (AEO2007).[31] 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 by applying growth rates computed from fuel consumption forecasts from AEO2007 to 2005 historical emissions. For the RCI sectors, annual growth rates for natural gas, oil, wood, and coal were calculated from the AEO2007 forecasts that EIA prepared for the West South Central modeling region. For the residential sector, the AEO2007 annual fuel consumption growth rates were normalized using a combination of the AEO2007 regional population forecasts and Arkansas' population forecasts. Arkansas' annual population growth rate from 2005 to 2025 is expected to be 1.1% per year.[32] Growth rates for the commercial and industrial sectors were based on the AEO2007 West South 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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[27] *EIIP, Volume VIII*: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels," August 2004.

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

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

[30] Energy Information Administration, "Arkansas Electricity Profile," http://www.eia.doe.gov/cneaf/electricity/st_profiles/arkansas.html.

[31] EIA, *Annual Energy Outlook 2007 with Projections to 2030* (http://www.eia.doe.gov/oiaf/aeo07/index.html).

[32] UALR Institute for Economic Advancement, Population Estimates and Projections (http://www.aiea.ualr.edu/research/demographic/population/default.html).

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

Sector	1990-2005*	2005-2025**
Residential	3.3%	1.5%
Commercial	3.6%	2.2%
Industrial	3.8%	0.6%
Total	**3.5%**	**1.4%**

* 1990-2005 compound annual growth rates calculated from Arkansas electricity sales by year from EIA state electricity profiles (Table 8), http://www.eia.doe.gov/cneaf/electricity/st_profiles/arkansas.html.

** 2005-2025 growth rates calculated from AEO2007 projections for Southwest Power Pool and Southeastern Electric Reliability Council.

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

	1990-2005[a]	2005-2010[b]	2010-2015 [b]	2015-2020 [b]	2020-2025 [b]
Residential					
natural gas	-1.0%	0.45%	0.17%	-0.10%	-0.21%
petroleum	-1.5%	1.1%	1.5%	1.4%	1.2%
wood	-1.6%	2.9%	-0.92%	0.16%	-0.05%
coal	-100%	-4.4%	-1.0%	-1.0%	-1.2%
Commercial					
natural gas	1.5%	1.9%	2.0%	1.2%	1.4%
petroleum	3.3%	-0.07%	1.5%	0.59%	0.72%
wood	5.7%	0.00%	0.00%	0.00%	0.00%
coal	-100%	0.00%	0.00%	0.00%	0.00%
Industrial					
natural gas	-2.4%	4.6%	-0.30%	0.90%	0.47%
petroleum	6.0%	0.54%	0.60%	0.21%	0.77%
wood	0.44%	2.2%	1.5%	1.3%	1.4%
coal	3.1%	0.74%	-0.31%	-0.02%	0.14%

[a] Compound annual growth rates calculated from EIA SED historical consumption by sector and fuel type for Arkansas. 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 Arkansas' projected population.

Results

Figures B1, B2, and B3 show historical and projected emissions for the RCI sectors in Arkansas 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 29% in 2005, and is projected to be 30% in 2025. The commercial sector's share of total RCI emissions from direct fuel use and electricity was 19% in 1990, increased to 21% in 2005, and is projected to increase to 25% by 2025. The industrial sector's share of total RCI emissions from direct fuel use and electricity was 51% in 1990, decreased to 50% in 2005, and is projected to decrease to 46% in 2025. Emissions associated with the generation of electricity to meet RCI demand accounts for about 81% of the emissions for the residential sector, 77% 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 16% and 20% of total emissions, respectively. For the industrial sector, emissions associated with the combustion of coal, natural gas, and petroleum account for about 4%, 29%, and 20% respectively, on average, over the 1990 to 2025 period.

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 about 9.3 MMtCO$_2$e, and are estimated to increase to about 16.5 MMtCO$_2$e by 2025. Emissions associated with the generation of electricity to meet residential energy consumption demand accounted for about 73% of total residential emissions in 1990, and are estimated to increase to 86% of total residential emissions by 2025. In 1990, natural gas consumption accounted for about 23% of total residential emissions, and is estimated to account for about 11% of total residential emissions by 2025. Residential-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 0.5 MMtCO$_2$e combined, and accounted for about 5% of total residential emissions. Emissions from these fuels decreased to 0.4 MMtCO$_2$e in 2005. Emissions associated with the consumption of these three fuels in 2025 are estimated to be 0.5 MMtCO$_2$e, accounting for 3% 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 petroleum are expected to increase at average annual rates of about 1.7% and 1.3% respectively. Emissions associated with the use of natural gas and wood are expected to increase slightly by about 0.08% and 0.5%, respectively. Total GHG emissions for this sector increase by an average of about 1.5% annually over the 20-year period.

Figure B1. Residential Sector GHG Emissions from Fuel Consumption
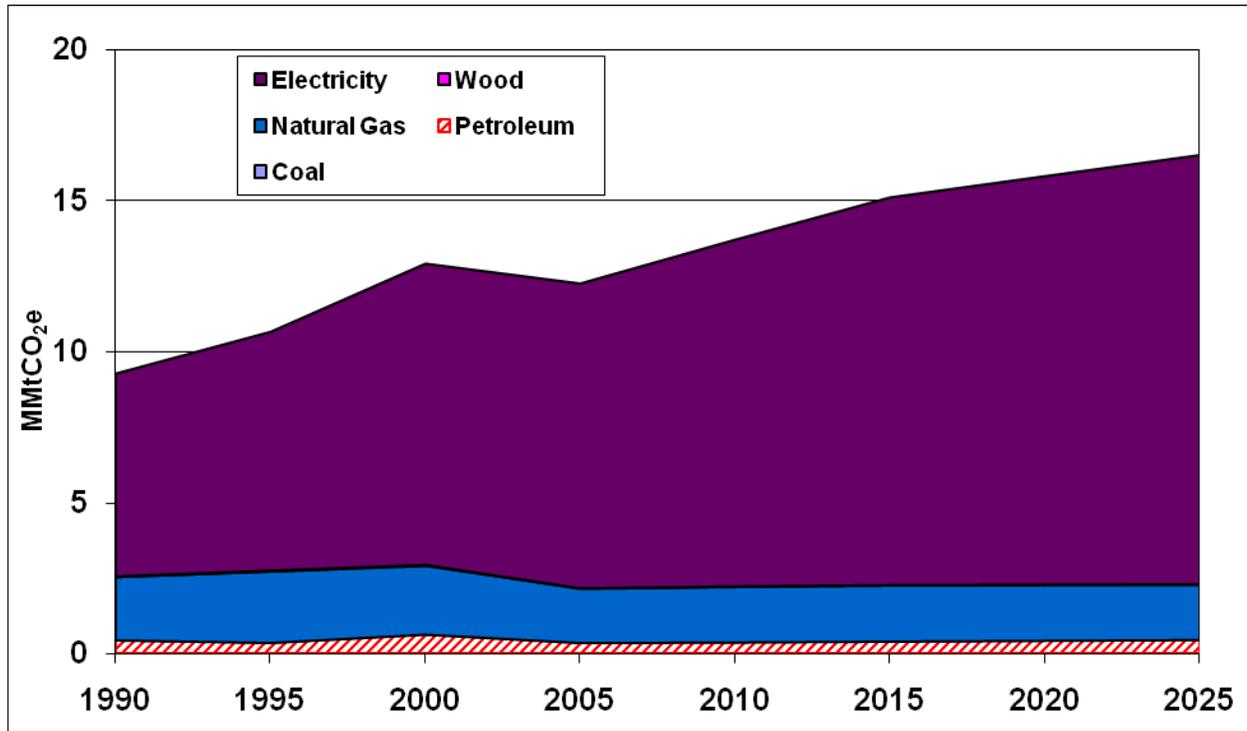
Source: Calculations based on approach described in text.
Note: Emissions associated with coal and wood combustion are too small to be seen on this graph.

Table B3a. Residential Sector Emissions Inventory and Reference Case Projections (MMtCO$_2$e)

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.43	0.35	0.63	0.35	0.37	0.40	0.42	0.45
Natural Gas	2.10	2.37	2.29	1.80	1.84	1.85	1.84	1.82
Wood	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Electricity Consumption	6.73	7.92	9.99	10.11	11.50	12.86	13.54	14.24
Total	9.28	10.67	12.93	12.27	13.72	15.12	15.83	16.53

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	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Petroleum	4.7%	3.3%	4.8%	2.8%	2.7%	2.6%	2.7%	2.7%
Natural Gas	22.6%	22.2%	17.7%	14.6%	13.4%	12.2%	11.6%	11.0%
Wood	0.2%	0.3%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%
Electricity Consumption	72.5%	74.2%	77.3%	82.4%	83.8%	85.0%	85.6%	86.1%

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 6 MMtCO$_2$e, and are estimated to increase to about 14 MMtCO$_2$e by 2025. Emissions associated with the generation of electricity to meet commercial energy consumption demand accounted for about 73% of total commercial emissions in 1990, and are estimated to increase to 79% 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 17% of total commercial emissions by 2025. Commercial sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 0.3 MMtCO$_2$e combined, and accounted for about 4% of total commercial emissions. By 2025, emissions associated with the consumption of these three fuels are estimated to be 0.5 MMtCO$_2$e and to account for 4% of total commercial sector emissions.

For the 20-year period from 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 2.4%, 1.6%, and 0.7% respectively. Emissions associated with the use of coal and wood are not expected to change relative to 2005. Total GHG emissions for this sector increase by an average of about 2.2% annually over the 20-year period.

Figure B2. Commercial Sector GHG Emissions from Fuel Consumption
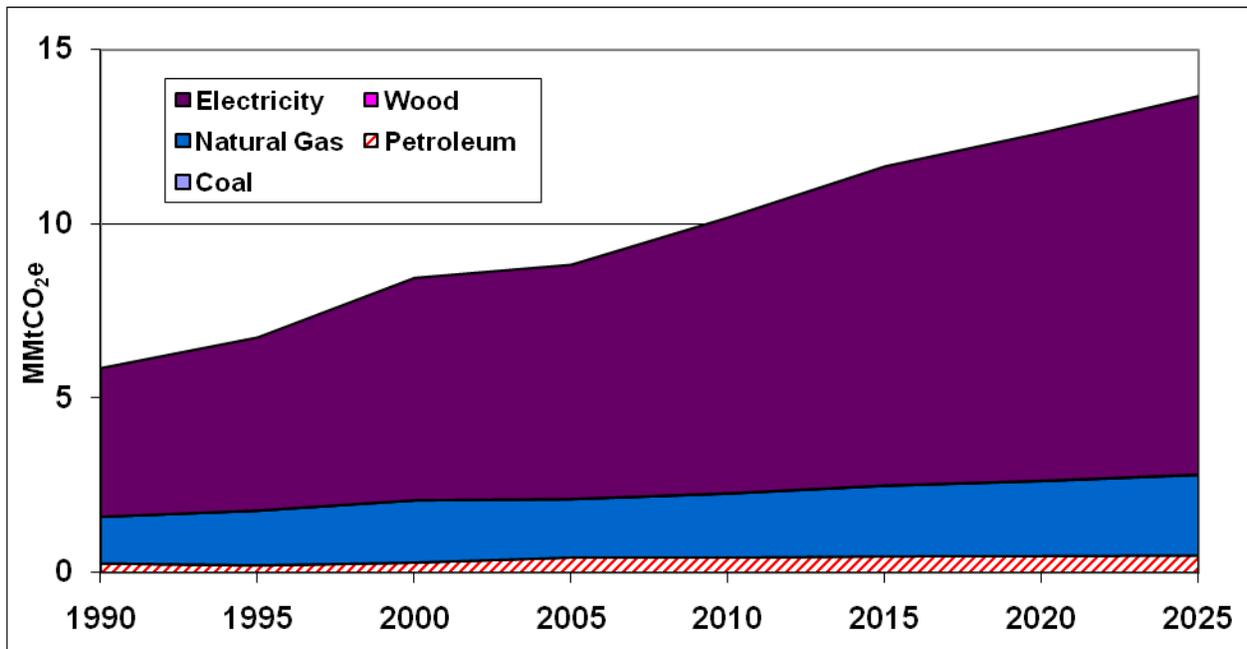
Source: Calculations based on approach described in text.
Note: Emissions associated with coal and wood combustion are too small to be seen on this graph.

**Table B4a. Commercial Sector Emissions Inventory and
Reference Case Projections (MMtCO$_2$e)**

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.26	0.20	0.28	0.43	0.43	0.46	0.47	0.49
Natural Gas	1.35	1.58	1.80	1.68	1.85	2.04	2.16	2.32
Wood	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
Electricity Consumption	4.26	4.95	6.36	6.70	7.89	9.13	9.96	10.84
Total	5.86	6.74	8.44	8.82	10.17	11.64	12.60	13.65

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	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Petroleum	4.4%	3.0%	3.3%	4.8%	4.2%	3.9%	3.7%	3.6%
Natural Gas	23.0%	23.4%	21.3%	19.1%	18.2%	17.5%	17.2%	17.0%
Wood	0.04%	0.07%	0.03%	0.06%	0.06%	0.05%	0.05%	0.04%
Electricity Consumption	72.6%	73.5%	75.4%	76.0%	77.6%	78.5%	79.0%	79.4%

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 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 about 16 MMtCO$_2$e and are estimated to increase to about 25 MMtCO$_2$e by 2025. Emissions associated with the generation of electricity to meet industrial energy consumption demand accounted for about 40% of total industrial emissions in 1990, and are estimated increase to about 49% of total industrial emissions by 2025. In 1990, natural gas consumption accounted for about 42% of total industrial emissions, and is estimated to decrease to about 25% of total industrial emissions by 2025. Petroleum consumption accounted for about 14% of total industrial emissions in 1990, and is estimated to increase to about 23% of total industrial emissions by 2025. In 1990, coal consumption accounted for about 3.4% of total industrial emissions, and is estimated to be about 3.5% of total industrial emissions in 2025. Emissions associated with wood consumption by the industrial sector are about 1% of total emissions in from 1990 to 2025.

For the 20-year period 2005 to 2025, industrial-sector GHG emissions associated with the use of electricity, natural gas, and wood are expected to increase at average annual rates of about 0.8%, 1.4%, and 1.6% respectively. Emissions associated with the use of petroleum and coal are expected to increase annually by about 0.5% and 0.1%, respectively. Total GHG emissions for the industrial sector increase by an average of about 0.9% annually over the 20-year period.

Figure B3. Industrial Sector GHG Emissions from Fuel Consumption
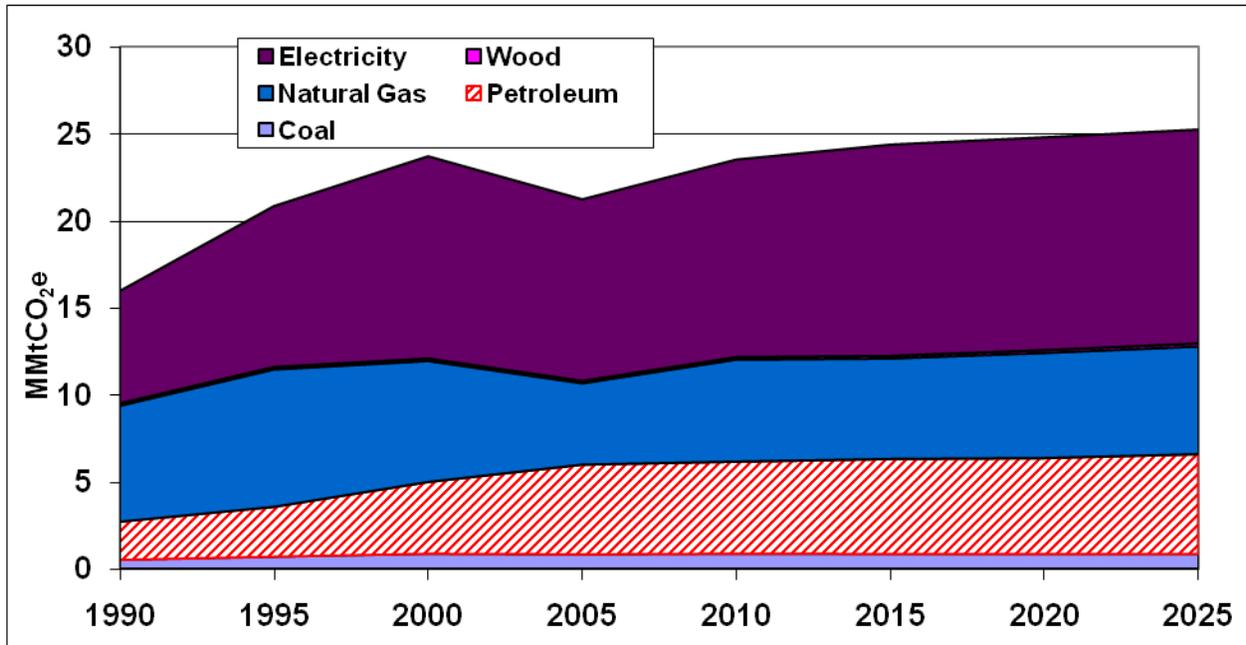
Source: Calculations based on approach described in text.
Note: Emissions associated with wood combustion are too small to be seen on this graph.

**Table B5a. Industrial Sector Emissions Inventory and
Reference Case Projections (MMtCO$_2$e)**

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	0.55	0.73	0.90	0.87	0.90	0.89	0.89	0.90
Petroleum	2.21	2.87	4.12	5.15	5.29	5.45	5.51	5.72
Natural Gas	6.68	7.89	6.95	4.69	5.87	5.78	6.04	6.19
Wood	0.12	0.14	0.14	0.13	0.14	0.15	0.16	0.17
Electricity Consumption	6.45	9.23	11.60	10.42	11.34	12.12	12.22	12.28
Total	16.00	20.87	23.73	21.26	23.54	24.40	24.82	25.26

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	3.4%	3.5%	3.8%	4.1%	3.8%	3.6%	3.6%	3.5%
Petroleum	13.8%	13.8%	17.4%	24.2%	22.5%	22.3%	22.2%	22.7%
Natural Gas	41.7%	37.8%	29.3%	22.1%	24.9%	23.7%	24.3%	24.5%
Wood	0.7%	0.7%	0.6%	0.6%	0.6%	0.6%	0.7%	0.7%
Electricity Consumption	40.3%	44.2%	48.9%	49.0%	48.2%	49.7%	49.2%	48.6%

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 South 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 Arkansas 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

The transportation sector is one the largest sources of greenhouse gas (GHG) emissions in Arkansas. This sector includes light- and heavy-duty (on-road) vehicles, aircraft, rail engines, and marine engines. Carbon dioxide (CO_2) accounts for about 98% of transportation GHG emissions in 2005. 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.[33,34] For on-road 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 (2005) from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data* (SED) added.[35] The default SIT data was also used to estimate VMT for the years 1990-1992. VMT data from the Arkansas Highway and Transportation Department were used for 1993 to 2005[36]. Default data in the SIT from the Federal Highway Administration (FHWA)[37] were used to allocate the VMT by vehicle type in the State.

On-road Vehicles

SIT default VMT data were used for 1990 through 1992 for calculating CH_4 and N_2O emissions. The Arkansas Highway and Transportation Department provided VMT data for the years 1993 through 2005[38]. These VMT data were distributed by vehicle type in the same proportion as the default VMT data in the SIT. The default EIA SED on-road fuel consumption data were used to calculate the CO_2 emissions from on-road 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 Arkansas decreased between 1990 and 1996. Ethanol consumption remained at or near zero for the years

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[33] 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.

[34] 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.

[35] Energy Information Administration, State Energy Consumption, Price, and Expenditure Estimates (SED), http://www.eia.doe.gov/emeu/states/_seds.html.

[36] Arkansas Highway and Transportation Department. Daily VMT Estimates 1993-2005. Provided by Mike Selig and Linda Hargrove on 2/1/08.

[37] Highway Statistics, Federal Highway Administration, http://www.fhwa.dot.gov/policy/ohpi/hss/index.htm.

[38] Arkansas Highway and Transportation Department. Daily VMT Estimates 1993-2005. Provided by Mike Selig and Linda Hargrove on 2/1/08.

1997-2005. Ethanol consumption ranged from a maximum value of about 0.35% of the gasoline consumption on a Btu basis in 1990, down to 0% in 1997 and thereafter. For the reference case projections, ethanol consumption was assumed to remain at the 2005 level (0% of gasoline consumption on Btu basis).

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

Vehicle Type and Pollutants	Methods
On-road 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 (2006-2025)** Gasoline and diesel fuel projected using linear regression of state VMT calculated using historical default SIT VMT data (1990-1992) and Arkansas state VMT data (1993-2005) and adjusted for fuel efficiency improvement projections from EPA . Other on-road fuels projected using West South Central Region fuel consumption projections from EIA AEO2007 adjusted using state-to-regional ratio of population growth.
On-road gasoline and diesel vehicles – CH_4 and N_2O	**Inventory (1990-2005)** State VMT calculated using default SIT data (1990-1992) and Arkansas state data (1993-2005). VMT allocated by vehicle type using default data in SIT. **Reference Case Projections (2006-2025)** 1990-2005 state total VMT forecasted through 2025 by linear regression 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. Commercial marine based on allocation of national fuel consumption. **Reference Case Projections (2006-2025)** Aircraft projected using aircraft operations projections from Federal Aviation Administration (FAA). No growth assumed for rail diesel. Marine gasoline projected based on linear regression of historical data.

On-road vehicle gasoline and diesel emissions were projected through 2025 based on statewide VMT growth rates developed from linear regression of the historical default SIT 1990-1992 VMT data and the 1993-2005 VMT data provided by the Arkansas Highway and Transportation Department. The resulting total annual VMT data were then allocated by vehicle type based on national VMT forecasts by vehicle type reported in EIA's *Annual Energy Outlook 2007* (AEO2007).[39] The AEO2007 data were incorporated because they indicate significantly different VMT growth rates for certain vehicle types (e.g., 24% growth between 2005 and 2025 in light-duty gasoline vehicle VMT versus 55% growth in heavy-duty diesel truck VMT over this period). The AEO2007 vehicle type-based national growth rates were applied to the 2005 Arkansas estimates of VMT by vehicle type. The resulting vehicle-type VMT estimates and compound annual average growth rates are displayed in Tables C-2 and C-3, respectively. These VMT growth rates were used to forecast the CH_4 and N_2O emissions from on-road 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. On-road 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 on-road fuel consumption growth rates are shown in Table C4. Growth rates for projecting CO_2 emissions from natural gas vehicles, lubricants, and other fuel consumption were calculated by allocating the AEO2007 consumption of these fuels in the West South Central region and allocating this to Arkansas based on the ratio of the State's projected population to the region's projected population.

Table C2. Arkansas Vehicle Miles Traveled Estimates (millions)

Vehicle Type	2005	2010	2015	2020	2025
Heavy Duty Diesel Vehicle	2,090	2,501	2,855	3,193	3,549
Heavy Duty Gasoline Vehicle	308	324	346	374	410
Light Duty Diesel Truck	316	402	515	680	946
Light Duty Diesel Vehicle	95	121	155	204	284
Light Duty Gasoline Truck	10,506	11,531	12,487	13,421	14,297
Light Duty Gasoline Vehicle	17,815	19,554	21,174	22,758	24,243
Motorcycle	107	117	127	136	145
Total	31,237	34,549	37,657	40,766	43,874

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[39] 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/archive/aeo07/index.html.

Table C3. Arkansas Vehicle Miles Traveled Compound Annual Growth Rates

Vehicle Type	2005-2010	2010-2015	2015-2020	2020-2025
Heavy Duty Diesel Vehicle	3.66%	2.68%	2.26%	2.14%
Heavy Duty Gasoline Vehicle	0.97%	1.32%	1.60%	1.86%
Light Duty Diesel Truck	4.91%	5.10%	5.72%	6.82%
Light Duty Diesel Vehicle	4.91%	5.10%	5.72%	6.82%
Light Duty Gasoline Truck	1.88%	1.60%	1.45%	1.27%
Light Duty Gasoline Vehicle	1.88%	1.60%	1.45%	1.27%
Motorcycle	1.88%	1.60%	1.45%	1.27%

Table C4. Arkansas On-road Fuel Consumption Compound Annual Growth Rates

Fuel Growth Factors	2005-2010	2010-2015	2015-2020	2020-2025
On-road gasoline	1.39%	1.57%	1.38%	1.29%
On-road diesel	3.49%	2.88%	2.50%	2.55%

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 for 2006 through 2025 from the Federal Aviation Administration's (FAA) Terminal Area Forecast System[40] and national aircraft fuel efficiency forecasts. To estimate changes in jet fuel consumption, itinerant 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 itinerant general aviation aircraft operations in Arkansas, which was obtained from the FAA source noted above. The resulting compound annual average growth rates are displayed in Table C5.

Table C5. Arkansas Aviation Fuels Compound Annual Growth Rates

Fuel	2005-2010	2010-2015	2015-2020	2020-2025
Aviation Gasoline	1.05%	0.78%	0.69%	0.76%
Jet Fuel	-1.14%	0.25%	0.32%	0.51%

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[40] Terminal Area Forecast, Federal Aviation Administration, http://www.apo.data.faa.gov/main/taf.asp.

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 Arkansas 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 Arkansas marine vessel fuel consumption. Arkansas fuel consumption estimates were developed by allocating 1990-2005 national diesel and residual oil vessel bunkering fuel consumption estimates obtained from EIA.[41] Marine vessel fuel consumption was allocated to Arkansas using the marine vessel activity allocation methods/data compiled to support the development of EPA's National Emissions Inventory (NEI).[42] 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 Arkansas 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."[43]

Non-road Engines

It should be noted that fuel consumption data from EIA includes non-road gasoline and diesel fuel consumption in the commercial and industrial sectors. Emissions from these non-road engines 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

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[41] 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).

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

[43] Table 4.1 "Waterborne Commerce by States" from "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 AR percentage of national waterborne tonnage.

Results

As shown in Figure C1 and in Table C7, on-road gasoline consumption accounts for the largest share of transportation GHG emissions throughout the historical and forecast periods. Emissions from on-road gasoline vehicles increased by about 15% from 1990 to 2005, and accounted for 57% of total transportation emissions in 2005. GHG emissions from on-road diesel fuel consumption increased by 61% from 1990 to 2005, and by 2005 accounted for 28% of GHG emissions from the transportation sector. Emissions from boats and ships increased by 97% from 1990 to 2005. These account for 8% of transportation emissions in 2005. Emissions from all other categories combined (aviation, locomotives, natural gas and liquefied petroleum gas (LPG), and oxidation of lubricants) contributed to about 7% of total transportation emissions in 2005.

GHG emissions from on-road gasoline consumption are projected to increase by about 32%, and emissions from on-road diesel consumption are expected to increase by 78% between 2005 and 2025. Aviation emissions are projected to remain relatively constant between 2005 and 2025, while marine emissions are projected to increase by 15% between the same period. By 2025, the share of transportation emissions from on-road gasoline decreases to 53% while the share of transportation emissions from on-road diesel increases to 35%. Overall, the transportation sector GHG emissions in Arkansas are expected to increase to 31 MMtCO$_2$e by 2025, a 41% increase over 2005 emission levels.

Figure C1. Transportation Gross GHG Emissions by Fuel, 1990-2025
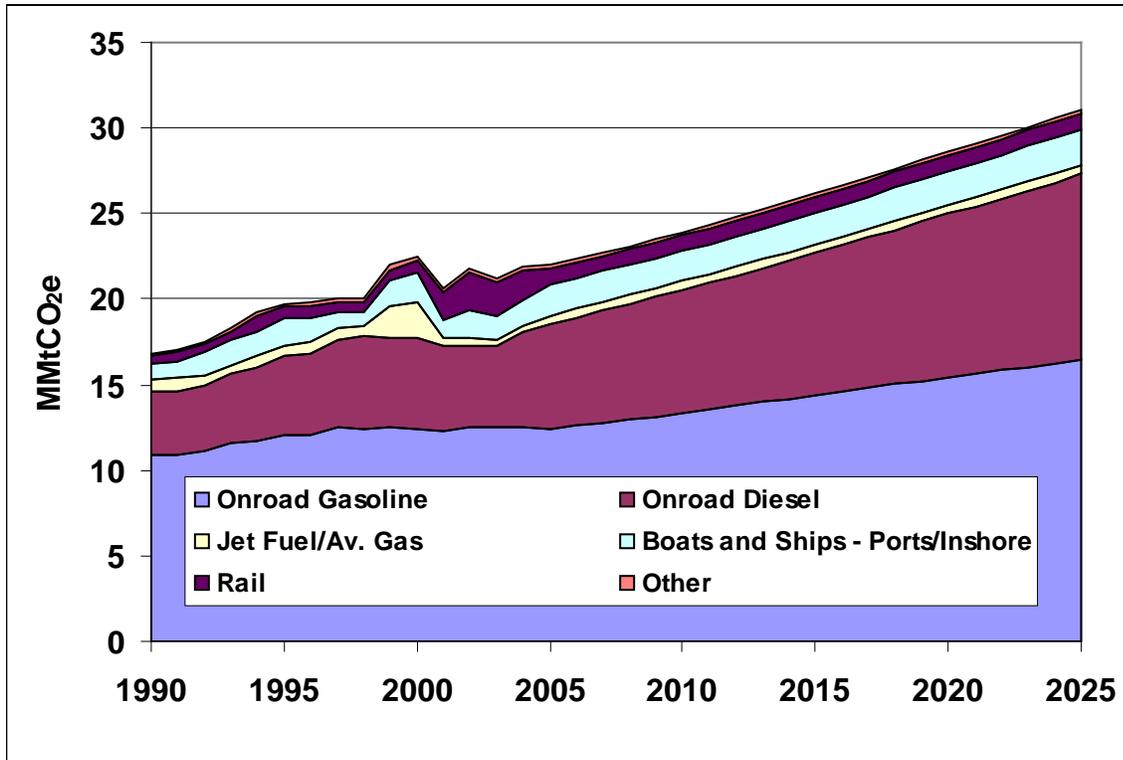
Source: Calculations based on approach described in text.

Table C7. Gross GHG Emissions from Transportation (MMtCO$_2$e)

Source	1990	1995	2000	2005	2010	2015	2020	2025
On-road Gasoline	10.86	12.10	12.41	12.44	13.34	14.42	15.44	16.46
On-road Diesel	3.78	4.63	5.37	6.08	7.22	8.29	9.55	10.84
Jet Fuel/Aviation Gas	0.72	0.53	2.01	0.53	0.50	0.51	0.52	0.53
Boats and Ships - Ports/Inshore	0.93	1.63	1.79	1.84	1.73	1.86	1.98	2.11
Rail	0.37	0.64	0.66	0.92	0.92	0.92	0.92	0.92
Other	0.20	0.19	0.21	0.18	0.18	0.19	0.21	0.22
Total	*16.85*	*19.72*	*22.44*	*21.99*	*23.90*	*26.19*	*28.63*	*31.08*

Key Uncertainties

Uncertainties in On-road Fuel Consumption

A major uncertainty in this analysis is the conversion of the projected VMT to fuel consumption. These are based on first allocating the Arkansas total VMT values by vehicle type using national vehicle type growth projections from AEO2007 modeling, which may not reflect Arkansas conditions. The conversion of the VMT data to fuel consumption also includes national assumptions regarding fuel economy by vehicle type. If the Arkansas vehicle fleet turns over at a significantly different than the nation as a whole, these fuel economy values may not reflect conditions in Arkansas.

Energy Independence and Security Act of 2007

The reference case projections documented here do not include the new 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 CO$_2$ emissions from onroad vehicles. Reductions attributable to the new CAFE standards are shown in Table 3 at the front of this report.

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; and

- The proportion of freight tonnage at ports in Arkansas to the total national freight tonnage reflects the proportion of national marine fuel that is consumed in Arkansas

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 Arkansas, 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;
    – 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; and

- Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) from consumption of substitutes for ozone-depleting substances (ODS) used in cooling and refrigeration equipment.

Other industrial processes that are sources of GHG emissions but are not found in Arkansas 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.

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) guidance document for this sector.[44] 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

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[44] 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.

Table D1. Approach to Estimating Historical Emissions

Source Category	Time Period	Required Data for SIT	Data Source
Cement Manufacture	1990 – 2005	Metric tons (Mt) of clinker produced and masonry cement produced each year.	Historical production for Arkansas from USGS Minerals Yearbook, Cement Statistics and Information (http://minerals.usgs.gov/minerals/pubs/commodity/cement/index.html#myb).
Lime Manufacture	1990-2005	Mt of high-calcium and dolomitic lime produced each year.	Production data for high-calcium lime for 1990-2005 from Arkansas Department of Environmental Quality (ADEQ).
Limestone and Dolomite Consumption	1994 – 2004	Mt of limestone and dolomite consumed.	Historical consumption (sales) for Arkansas 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; data for 2004 were used for 2005 production.
Soda Ash Consumption	1990 – 2005	Mt 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 (2000-2005) and state (2000-2005) population from US Census Bureau (http://www.census.gov/popest/states/NST-ann-est.html). --US (1990-2000) population from US Census Bureau (http://www.census.gov/popest/archives/1990s/). -- State (1990-2000) population from US Census Bureau (http://www.census.gov/popest/archives/2000s/vintage_2001/CO-EST2001-12/CO-EST2001-12-05.html).
Ammonia Production and Urea Application	1990-2004	Mt of ammonia produced and urea consumed	SIT default activity data for ammonia production and urea application for 1990-2004; activity data is based on national USGS data. Data for 2004 were used for 2005 as a surrogate to fill in the missing production data.
Iron and Steel Production	1990-2007	Mt of crude steel produced by production method.	ADEQ provided steel production data from the Electric Arc Furnace (EAF) production method for 1990-2007. Default SIT emission factor for EAF production method is used for steel production from scrap metal. The emission factor for EAF steel production from crude steel is from U.S. EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005* (http://www.epa.gov/climatechange/emissions/downloads06/07CR.pdf).
Nitric Acid	1990-2005	Mt of nitric acid produced	ADEQ provided production data for the years 1990-2005.
ODS Substitutes - Castings	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://www.epa.gov/climatechange/emissions/downloads06/07CR.pdf). References for US Census Bureau national and state population figures are cited under the data sources for soda ash above.

Source Category	Time Period	Required Data for SIT	Data Source
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 soda ash above.

Mt = metric tons; ODS = ozone depleting substance; T&D = transmission and distribution

the availability of data. To the extent possible, information provided by Arkansas state and local sources was used in this analysis.

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). A no growth assumption was assumed when the historical periods indicated divergent activity trends (i.e., growth in certain periods and decline in other 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

Source Category	Projection Assumptions	Data Source	Annual Growth Rates (%)			
			2005 to 2010	2010 to 2015	2015 to 2020	2020 to 2025
Cement Manufacture	Annual growth rate computed from Cement & Concrete Product Manufacturing employment forecast for State.	2004-2014 employment projections from Arkansas Labor Market Information (http://www.discoverarkansas.net/publication.asp?PUBLICATIONID=1108&PAGEID=4&SUBID=)	1.5	1.5	1.5	1.5
Lime Manufacture	Annual growth rate computed from Arkansas Lime Company production forecasts.	Arkansas lime production forecasts (2006-2025) provided by ADEQ.	11.6	0.0	0.0	0
Limestone and Dolomite Consumption	Annual growth rate computed from Other Nonmetallic Mineral Product Manufacturing employment forecast for State.	2004-2014 employment projections from Arkansas Labor Market Information (http://www.discoverarkansas.net/publication.asp?PUBLICATIONID=1108&PAGEID=4&SUBID=)	0.3	0.3	0.3	0.3
Soda Ash Consumption	Smallest historical annual decline in state consumption from each of three periods analyzed (1990-2005)	Annual change in Arkansas soda ash consumption: 1990-2005 = -0.4% 1995-2005 = -0.6% 2000-2005 = -0.9%	-0.4	-0.4	-0.4	-0.4

Source Category	Projection Assumptions	Data Source	Annual Growth Rates (%)			
			2005 to 2010	2010 to 2015	2015 to 2020	2020 to 2025
Ammonia & Urea Production	No growth assumption based on analysis of state historical trends	Annual change in Arkansas ammonia consumption: 1990-2004 = -3.6% 1995-2004 = -0.8% 2000-2004 = +0.3%	0.0	0.0	0.0	0.0
Iron and Steel Production	Annual growth rate computed from steel production forecasts from AR steel companies.	Arkansas steel production 2025 forecast provided by ADEQ.	2.8	2.8	2.8	2.8
Nitric Acid Production	No growth assumption based on analysis of state historical trends	Annual change in Arkansas ammonia consumption: 1990-2005 = +0.8% 1995-2005 = -0.6% 2000-2005 = -0.1%	0.0	0.0	0.0	0.0
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 D-1 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 D-10 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

ODS = ozone-depleting substance; T&D = transmission and distribution

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 Arkansas GHG emissions were about 2.2 million metric tons of CO_2 equivalence (MMtCO$_2$e) in 1990, 4.0 MMtCO$_2$e in 2005, and are projected to increase to about 7.5 MMtCO$_2$e in 2025. Emissions from the overall industrial processes category are expected to grow by about 3.1% annually from 2005 through 2025, as shown in Figures D1 and D2, with emissions growth primarily associated with increasing use of ODS substitutes.

Figure D1. GHG Emissions from Industrial Processes, 1990-2025
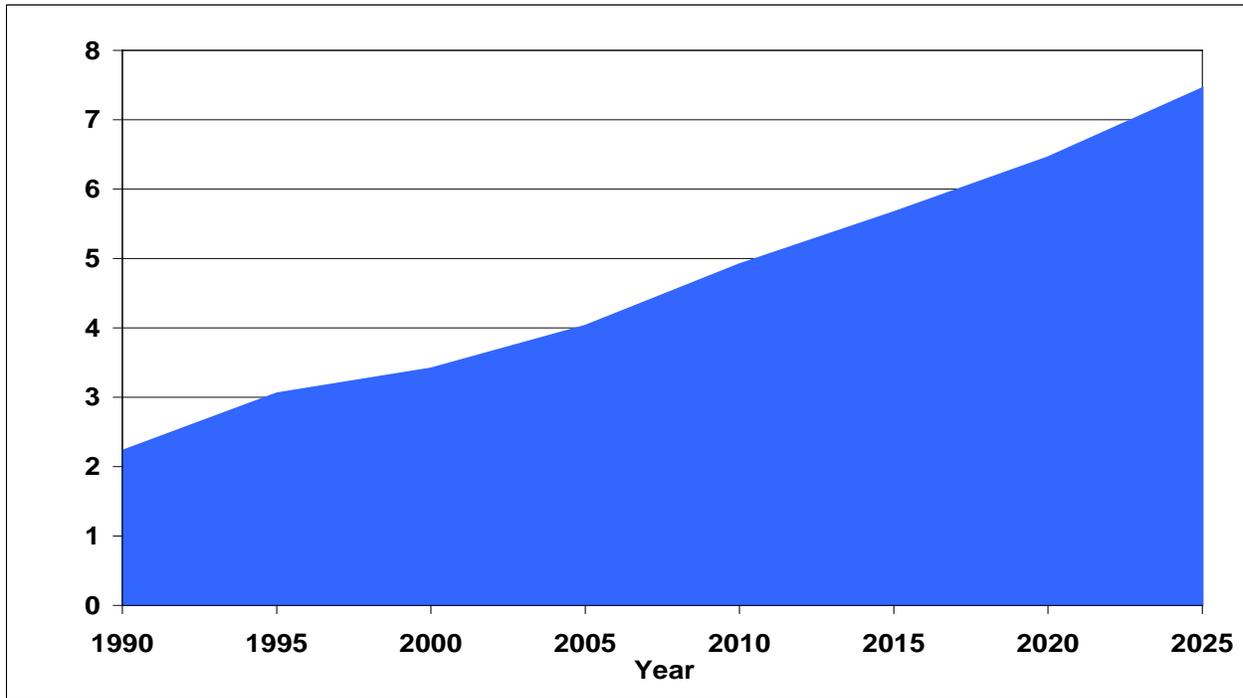
Source: Calculations based on approach described in text.

Figure D2. GHG Emissions from Industrial Processes, 1990-2025, by Source
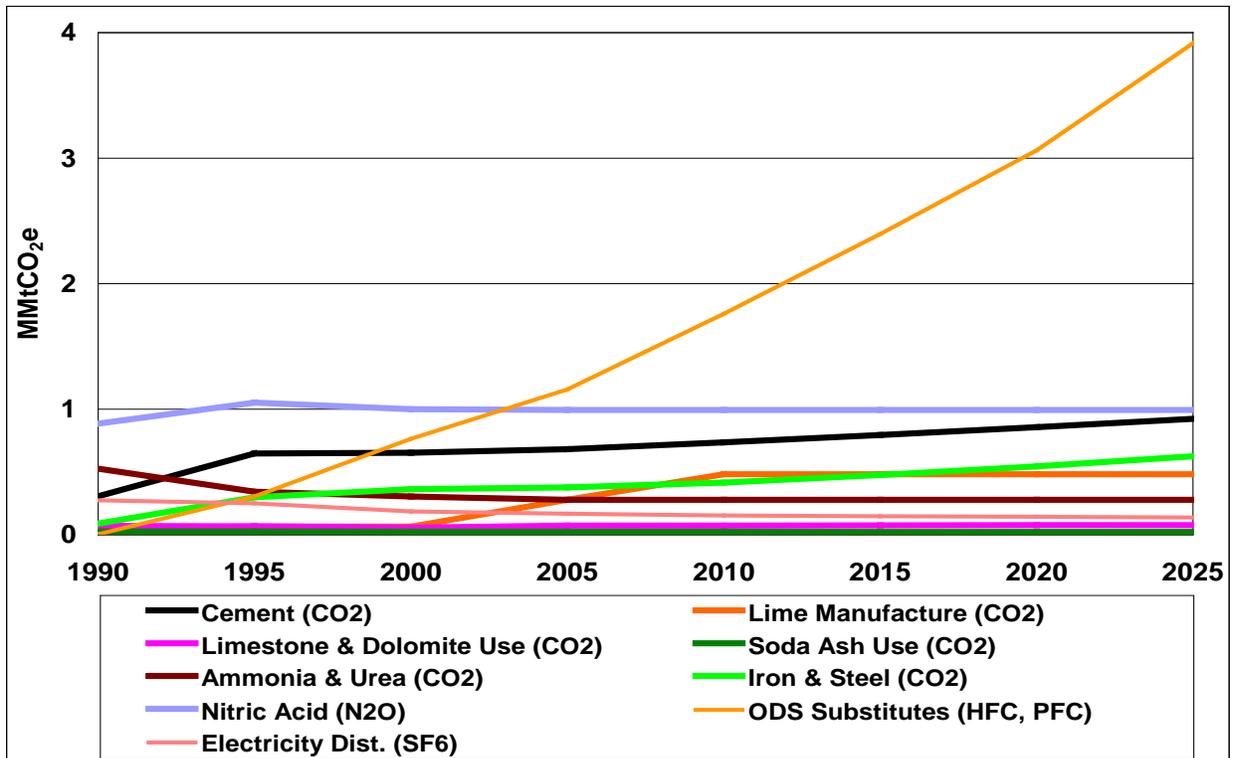
Source: Calculations based on approach described in text.

Table D3. Historical and Projected Emissions for the Industrial Processes Sector (MMtCO$_2$e)

	1990	1995	2000	2005	2010	2015	2020	2025
Cement (CO$_2$)	0.31	0.65	0.65	0.68	0.74	0.79	0.86	0.92
Lime Manufacture (CO$_2$)	0.05	0.07	0.07	0.28	0.48	0.48	0.48	0.48
Limestone & Dolomite Use (CO$_2$)	0.07	0.07	0.06	0.07	0.07	0.07	0.08	0.08
Soda Ash Use (CO$_2$)	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02
Ammonia & Urea (CO$_2$)	0.53	0.34	0.30	0.28	0.28	0.28	0.28	0.28
Iron & Steel (CO$_2$)	0.09	0.30	0.36	0.38	0.42	0.48	0.55	0.62
Nitric Acid (N$_2$O)	0.88	1.05	1.00	0.99	0.99	0.99	0.99	0.99
ODS Substitutes (HFC, PFC)	0.00	0.30	0.76	1.16	1.76	2.40	3.06	3.91
Electricity Dist. (SF$_6$)	0.27	0.25	0.18	0.17	0.15	0.15	0.14	0.14
Total	**2.23**	**3.06**	**3.41**	**4.03**	**4.92**	**5.67**	**6.46**	**7.45**

Cement Manufacture

The cement production process is one that releases relatively high amounts of CO$_2$ in the industrial non-fuel combustion sector. 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 (Mt) of CO$_2$ emitted per Mt of clinker produced) and cement kiln dust (0.020 MtCO$_2$ emitted per Mt 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 percent. Lime accounts for approximately 60 percent of the added substances. About 0.0224 MtCO$_2$ is emitted for every Mt of masonry cement produced, relative to the CO$_2$ emitted during the production of a Mt 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 0.31 MMtCO$_2$e in 1990, 0.68 MMtCO$_2$e in 2005, and are projected to increase to about 0.92 MMtCO$_2$e by 2025. Historical clinker and masonry cement production data for Arkansas obtained from the United States Geological Survey (USGS) (see Table D1) and the default emission factors in SIT were used to calculate CO$_2$ emissions for 1990-2005. Emissions are projected to increase at a rate of 1.5 percent per year based on Cement and Concrete Product Manufacturing sector employment projections available from the State of Arkansas (note that these projections are available to 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).

Arkansas Lime Company is the only lime manufacturer in the state. Its high-calcium quicklime and hydrated lime production data were provided by the Arkansas Department of Environmental Quality (ADEQ). Emissions associated with lime manufacture were estimated for 1990 through 2005 using the amount of lime produced and an emission factor of 0.75 $MtCO_2$ per ton high-calcium lime produced. Arkansas Lime Company has also provided projections of lime production to 2025. Based on these forecasts, emissions are assumed to grow annually at 11.6 percent between 2005 and 2010, and stay constant between 2010 and 2025. Carbon dioxide emissions from lime production are relatively low in 1990 (about 0.05 $MMtCO_2e$), it increases to 0.28 $MMtCO_2e$ by 2005, and is projected to increase further to 0.48 $MMtCO_2e$ by 2025.

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.[45]

Historical limestone and dolomite consumption (sales) data for Arkansas 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 on limestone and dolomite consumption for 1990-1993 were not available for Arkansas; therefore, 1994 production data were used as a surrogate to estimate emissions for 1990-1993. Limestone and dolomite consumption for 2005 is also not available, so 2004 production data were used as a surrogate for 2005 data. Emissions are projected to increase at a rate of 0.3 percent per year based on Other Nonmetallic Mineral Product Manufacturing sector employment projections available from the State of Arkansas (note that these projections are available to 2014—in lieu of other information, the same rate of increase was used throughout the forecast period to 2025). Relative to total industrial non-combustion process emissions, CO_2 emissions from limestone and dolomite consumption are low (about 0.07

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[45] 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).

MMtCO$_2$e in 1990, and remaining near this level through 2005), and therefore, appear at the bottom of the graph (see pink line at the 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 dark pink line in Figure D2) based on the state's population and national per capita soda ash consumption from the US EPA national GHG inventory. An annual -0.4 percent decrease was assumed for the forecast period based on the negative consumption trends observed over the historical periods analyzed. Relative to total industrial non-combustion process emissions, CO$_2$ emissions from soda ash consumption are low (about 0.03 MMtCO$_2$e in 1990, and 0.02 MMtCO$_2$e in 2005), and therefore, appear at the bottom of the graph (see dark green line at the bottom of Figure D2).

Ammonia and Urea Production

Ammonia (NH$_3$) and urea ((NH$_2$)$_2$CO) 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 CO$_2$ 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.

SIT default production data, along with default emission factors for ammonia and urea, were used to calculate CO$_2$ emissions in Arkansas. In 1990, ammonia production/urea consumption constituted a significant portion of the total Arkansas GHG emissions in the Industrial Processes sector. However, by 2005, this is no longer the case. Emissions from ammonia and urea decreased over the period of 1990-2005, with 0.53 MMtCO$_2$e in 1990, and 0.28 MMtCO$_2$e in 2005. Projections from 2006-2025 are assumed to stay constant at 2005 levels due to conflicting historical trends.

Iron and Steel Production

Arkansas has four iron and steel production facilities: Nucor-Yamato Steel Company, Nucor Corporation, Quanex Corporation (MacSteel), and Arkansas Steel Associates, LLC. 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 production of metallurgical coke from coking coal produces CO$_2$ emissions as well.

The EPA SIT methodology was used to estimate Arkansas' CO$_2$ emissions from steel production (see Table D1). The basic activity data needed were 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 ADEQ for

the years 1990 to 2007, and projected 2025 production. Nucor Corporation did not have production data available for 1990 and 1991. It is assumed that 10 percent of steel production from the Nucor-Yamato and Nucor Corporation steel plants are from crude steel and 90 percent from scrap metal.[46] The default SIT emission factor of 0.08 $MtCO_2$ per Mt production was used for EAF steel production from scrap metal, and 0.004 $MtCO_2$ per Mt production was used for EAF steel production from crude steel.[47] As shown in Figure D2 (see lime-green line) and Table D3, emissions from iron and steel increased from 0.09 $MMtCO_2e$ in 1990 to 0.38 $MMtCO_2e$ in 2005. The annual growth rate estimated from the forecasted 2025 steel production (2.75% per year) was used to project emissions from 2008 to 2025.

Nitric Acid Production

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.[48]

The El Dorado Chemical Company is the only producer of nitric acid in Arkansas. ADEQ provided production data for the years 1990-2005. The SIT was used to estimate N_2O emissions from nitric acid production. However, the default SIT emission factor of 0.008 MtN_2O per Mt of nitric acid produced was not used. This is because the default emission factor is based on a weighted-average calculated over the different types of emissions control technologies employed by nitric acid plants nationwide.[49] The Selective Catalytic Reduction (SCR) control technology was used by El Dorado Chemical, so the emission factor of 0.095 MtN2O per Mt nitric acid produced was used instead.[50] Relative to total industrial non-combustion process emissions, estimated emissions associated with nitric acid production are significant (about 0.88 $MMtCO_2e$ in 1990 and 0.99 $MMtCO_2e$ in 2005), and therefore, appear near the middle of Figure D2. Projections from 2006-2025 are assumed to stay constant at 2005 levels due to conflicting historical trends.

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[46] Crude steel and scrap metal allocation from personal communications with Nucor Steel plants.

[47] EAF emission factor of 0.004 MtCO2/Mt production from US EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005* (http://www.epa.gov/climatechange/emissions/downloads06/07CR.pdf).

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

[49] According to Chapter 6 of the EIIP guidance document, the nitric 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.

[50] US EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005* (http://www.epa.gov/climatechange/emissions/downloads06/07CR.pdf).

Substitutes for Ozone-Depleting Substances (ODS)

HFCs and PFCs are used as substitutes for ODS, most notably CFCs (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*.[51] 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 0.00 MMtCO$_2$e in 1990 to about 1.16 MMtCO$_2$e in 2005, and are expected to increase at an average rate of 6.3% per year from 2005 to 2025 (to 3.91 MMtCO$_2$e by 2025) due to increased substitutions of these gases for ODS (see the light-orange 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 nineties (see light brown 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.[52]

As shown in Figure D2 and Table D3, SF_6 emissions from electric power T&D are about 0.27 MMtCO$_2$e in 1990 and 0.17 MMtCO$_2$e in 2005. Emissions in 2025 are projected at 0.14MMtCO$_2$e. Emissions in Arkansas 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 Arkansas to the US electricity consumption (sales) estimates available from the Energy Information Administration's (EIA) Electric Power Annual and provided in 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 Arkansas. 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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[51] 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.

[52] 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.

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 Arkansas manufacturers in these industries, and the specific nature of the production processes used in Arkansas.

- 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. For example, 1994 activity data for limestone and dolomite consumption were used as a surrogate to estimate emissions for 1990 through 1993. 2005 values are also missing for ammonia and urea production. Replacing these values would make future estimates more accurate.

- 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 Industries

Overview

The inventory for this subsector of the Energy Supply sector includes methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) emissions associated with the production, processing, transmission, and distribution of fossil fuels in Arkansas.[53] In 2005, emissions from the subsector accounted for an estimated 2.82 million metric tons (MMt) of CO_2 equivalent (CO_2e) of total gross greenhouse gas (GHG) emissions in Arkansas, and are estimated to increase to about 3.04 MMtCO$_2$e by 2025.

Emissions and Reference Case Projections

Oil and Gas Production
In 2005, Arkansas' crude oil production totaled 17,000 barrels (bbls) per day, accounting for only 0.3% of US production.[54] Proved crude oil reserves are 40 million bbls, which is similarly about 0.2% of US totals. The peak year of oil production in Arkansas was 1986 (43,000 bbls per day). Production has steadily declined for more than two decades since.[55] Arkansas has two operating petroleum refineries located in the Gulf Coastal Plain in the southern portion of the state, with a crude oil distillation capacity of 76,800 bbls per day.[56]

Arkansas is also responsible for about 1% of US natural gas production. The productive Arkoma Basin region is located in the western part of the state, and there are a number of gas wells located in the Gulf Coastal Plain to the south. In 2005, Arkansas consumed 214 billion cubic feet (Bcf) of natural gas while it produced 191 Bcf. [57]

The majority of Arkansas oil and gas emissions comes from transportation of natural gas through the state's transmission pipelines. Due to its location near larger natural gas producing states, including Texas and Louisiana, Arkansas is home to thousands of miles of natural gas transmission and distribution pipeline which transports the gas to consumption markets in the Midwest and Northeast.

Oil and Gas Industry Emissions
Emissions can occur at several stages of production, processing, transmission, and distribution of oil and gas. Based on the information provided in the Emission Inventory Improvement Program

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[53] 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..
[54] US Department of Energy (DOE), Energy Information Administration, "Crude Oil Production", accessed from http://tonto.eia.doe.gov/dnav/pet/pet_crd_crpdn_adc_mbblpd_a.htm, January 2008.
[55] US DOE Energy Information Administration, "Crude Oil Proved Reserves, Reserves Changes, and Production," accessed from http://tonto.eia.doe.gov/dnav/pet/pet_crd_pres_dcu_SAR_a.htm, January 2008.
[56] "State Energy Profiles: Arkansas", US DOE Energy Information Administration website, January 2008, accessed from http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=AR.
[57] State Energy Profiles: Arkansas", US DOE Energy Information Administration website, January 2008, accessed from http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=AR.

(EIIP) guidance[58] 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 leaks, compressor fugitives, vents, and pneumatic devices. Distribution pipelines are extensive networks of generally small diameter, low-pressure pipelines that distribute gas within cities or towns. Sources of CH_4 emissions from distribution pipelines are leaks, meters, regulators, and mishaps. Carbon dioxide, CH_4, and N_2O emissions occur as the result of the combustion of natural gas by internal combustion engines used to operate compressor stations.

With 3,500 active gas-producing wells in the state, 5 operational gas processing plants, and nearly 27,000 miles of gas pipelines, there are significant uncertainties associated with estimates of Arkansas' GHG emissions from this sector. This is compounded by the fact that there are no regulatory requirements to track GHG emissions. Therefore, estimates based on emissions measurements in Arkansas are not possible at this time.

The EPA's State Greenhouse Gas Inventory Tool (SIT) facilitates the development of a rough estimate of state-level GHG emissions. GHG emission estimates are calculated by multiplying emissions-related activity levels (e.g., miles of pipeline, number of compressor stations) by aggregate industry-average emission factors. Key information sources for the activity data are the US Department of Energy's Energy Information Administration (EIA)[59] and the US Department of Transportation's Office of Pipeline Safety (OPS).[60] The Arkansas Oil and Gas Commission (AOGC) and Arkansas Public Service Commission (APSC) provided additional activity data and adjustments to OPS distribution pipeline information. Emissions were estimated using the SIT, with reference to methods/data sources outlined in the EIIP guidance document for natural gas and oil systems.[61] Emissions of CO_2, CH_4, and N_2O associated with pipeline natural gas combustion were estimated using SIT emission factors[62] and Arkansas 1990-2005 natural gas data from EIA for the "consumed as pipeline fuel" category.[63]

Unfortunately 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/gathering pipelines since 2001 and state-level data for their distribution pipelines since 2004. Before these dates, a number of Arkansas pipeline records report data as multi-state totals. As noted above, the APSC was able to provide natural gas distribution pipeline data that avoided these issues. To estimate a complete

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

[59] "Natural Gas Navigator," US DOE Energy Information Administration website, January 2008, accessed from http://www.eia.doe.gov.

[60] 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.

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

[62] 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.

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

time-series of natural gas transmission/gathering pipeline data, CCS compiled surrogate data to back-cast the 2001 transmission/gathering pipeline mileage for each year back to 1990.[64] The AOGC also provided information on the number of associated wells, which are oil wells that also produce natural gas. The AOGC estimates approximately 200 such wells in operation for each year throughout the historical analysis period.

Coal Production Emissions
The US Environmental Protection Agency (US EPA) reports nominal coal mining-related GHG emissions in Arkansas throughout the historical analysis period.[65] These estimates were incorporated directly into this inventory.

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

Emission Forecasts
Table E1 provides an overview of data sources and approaches used to develop projected fossil fuel sector emission estimates for Arkansas. 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 analysis period, and the other using the historical 1990-2005 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 Arkansas-specific trends (e.g., AEO forecasts of natural gas production are for the Midcontinent Region, which includes 7 states in addition to Arkansas), the AEO forecast growth rates were only used when they were in-line with the Arkansas historical growth rates. Therefore, some oil and gas production sector projections are based on state-level historical activity/emissions trends. In cases where each of 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 production, processing, and pipeline technologies that could result in GHG emissions reductions are generally not accounted for in the projections analysis.

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[64] Note that CCS estimated an additional 964 transmission pipeline miles in 2002 to account for an operator that appeared to be missing from the OPS database (Mississippi River Transmission Corporation).
[65] US Environmental Protection Agency, "Inventory Of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005, USEPA #430-R-07-002, April 2007

Table E1. Approach to Estimating Historical/Projected Emissions from Fossil Fuel Systems

Activity	Approach to Estimating Historical Emissions		Surrogate Data Used to Backcast Activity to 1990	Forecasting Approach
Activity	*Required SIT Data*	*Data Source*	*Activity to 1990*	*Projection Assumption*
Natural Gas Production	Number of gas/associated wells	Gas wells - EIA[66] Associated wells - AOGC[67]		Used AEO 2007[68] Midcontinent region natural gas production forecast because annualized growth rate over forecast period (0.24%) is in-line with the long-term historical annual growth rate.
Natural Gas Processing	Number of gas processing plants	*Oil and Gas Journal*[69]		Annual growth rate (1.50%) based on smallest annualized rate of growth in number of natural gas processing plants from each of 3 periods analyzed (1990-2005).
	Flaring of Entrained Gas	EIA[70]		No change because no clear historical trend (growth in 1 period; decreases in other 2 historical periods analyzed).
Natural Gas Transmission	Miles of gathering pipeline	Office of Pipeline Safety[71]	AR natural gas production as reported by EIA[72] Average of volume of natural gas transported into AR and transported out of AR, from EIA[73]	Used AEO 2007 West South Central region natural gas pipeline use projections since annualized growth over forecast period (0.47%) is in-line with long-term historical AR transmission emissions growth.
	Miles of transmission pipeline			
	Number of gas transmission compressor stations	EIIP[74]		
	Number of gas storage compressor stations	EIIP[75]		

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[66] US DOE, Energy Information Administration, "Arkansas Natural Gas Number of Gas and Gas Condensate Wells," accessed from http://tonto.eia.doe.gov/dnav/ng/hist/na1170_sar_8a.htm, January 2008.

[67] Personal communication, "RE: Greenhouse Gas Inventory Contacts," from Lawrence Bengal, Arkansas Oil and Gas Commission, to Andy Bollman, CCS, February 1, 2008.

[68] 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.

[69] PennWell Corporation, "Worldwide Gas Processing," *Oil and Gas Journal* (1990-2005 June/July issues).

[70] US DOE, Energy Information Administration, "Arkansas Natural Gas Vented and Flared," accessed from http://tonto.eia.doe.gov/dnav/ng/hist/na1130_sar_2a.htm , January 2008.

[71] 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.

[72] US DOE, Energy Information Administration, "Arkansas Dry Natural Gas Production," accessed from http://tonto.eia.doe.gov/dnav/ng/hist/na1160_sar_2a.htm, January 2008.

[73] 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_SAR_a.htm, January 2008.

[74] Number of gas transmission compressor stations = miles of transmission pipeline x 0.006 – EIIP, Volume VIII: Chapter 5, March 2005.

[75] Number of gas storage compressor stations = miles of transmission pipeline x 0.0015 EIIP. Volume VIII: Chapter 5, March 2005.

Table E1. Approach to Estimating Historical/Projected Emissions from Fossil Fuel Systems (continued)

Activity	Approach to Estimating Historical Emissions		Surrogate Data Used to Backcast Activity to 1990	Forecasting Approach
Activity	*Required SIT Data*	*Data Source*		*Projection Assumption*
Natural Gas Distribution	Miles of distribution pipeline by pipeline material type	Office of Pipeline Safety[76] and APSC[77]		Used annual rate of decline (-0.26%) reflecting smallest annualized decrease in distribution emissions from each of 3 periods analyzed (1990-2005).
	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[78]		Used AEO 2007 projected regional pipeline fuel consumption growth rates since they are in-line with historical AR trends.
Oil Production	Annual production	EIA[79]		Used annual rate of decline (-2.37%) representing smallest annualized decrease in oil production from each of 3 periods analyzed (2000-2005).
Oil Refining	Annual volume refined	EIA[80]		Used AEO 2007 PAD III region refining capacity projections since annual growth over forecast period (0.76%) is in-line with long-term historical AR refining activity growth.
Oil Transport	Annual volume transported	Unavailable (per SIT, assumed oil refined = oil transported)		(same as oil refining)

[76] 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.

[77] Personal communication, "RE: Inquiry," from John Bethel, Arkansas Public Service Commission, to Andy Bollman, CCS, February 6, 2008.

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

[79] US DOE, Energy Information Administration, "Arkansas Crude Oil Production," accessed from http://tonto.eia.doe.gov/dnav/pet/hist/mcrfpar1a.htm, January 2008.

[80] Refining is assumed to be equal to the total input of crude oil into PADD III times the ratio of Arkansas' refining capacity to PADD III's total refining capacity. No data for 1996 and 1998, so linear interpolation used to estimate values in these years. Data are from US DOE, Energy Information Administration, "Petroleum Navigator." PADD capacity data accessed from http://tonto.eia.doe.gov/dnav/pet/hist/moclep32A.htm. PADD crude input data accessed from http://tonto.eia.doe.gov/dnav/pet/hist/mgirip32A.htm. State capacity data accessed from http://tonto.eia.doe.gov/dnav/pet/hist/8_na_8do_sar_4a.htm, January 2008.

Table E1. Approach to Estimating Historical/Projected Emissions from Fossil Fuel Systems (continued)

Coal Mining	Methane emissions in million cubic feet	US EPA[81]		Used AEO 2007 Western Interior coal production projections since annualized growth over forecast period (0.61%) is in-line with recent historical AR coal mining emissions trend.

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

Results

Table E2 displays the estimated emissions from the fossil fuel industry in Arkansas for select years over the period 1990 to 2025. Emissions from this sector grew by 4% from 1990 to 2005 and are projected to increase by an additional 8% between 2005 and 2025. Natural gas transmission is the major contributor to both historical emissions and emissions growth.

Table E2. Historical and Projected Emissions for the Fossil Fuel Industry (MMtCO$_2$e)

Sector	1990	1995	2000	2005	2010	2015	2020	2025
Fossil Fuel Industry Total	**2.72**	**3.21**	**2.88**	**2.82**	**2.97**	**3.18**	**3.11**	**3.04**
Natural Gas Industry	2.58	3.10	2.79	2.73	2.89	3.10	3.04	2.98
Production	*0.30*	*0.41*	*0.41*	*0.36*	*0.37*	*0.36*	*0.37*	*0.38*
Processing	*0.10*	*0.08*	*0.10*	*0.13*	*0.14*	*0.15*	*0.16*	*0.18*
Transmission	*1.26*	*1.47*	*1.31*	*1.31*	*1.40*	*1.57*	*1.50*	*1.44*
Distribution	*0.45*	*0.46*	*0.47*	*0.44*	*0.43*	*0.42*	*0.42*	*0.41*
Flaring	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*
Pipeline Fuel	*0.46*	*0.66*	*0.47*	*0.48*	*0.53*	*0.59*	*0.58*	*0.56*
Oil Industry	0.13	0.12	0.09	0.10	0.09	0.08	0.07	0.06
Production	*0.13*	*0.11*	*0.09*	*0.09*	*0.08*	*0.07*	*0.07*	*0.06*
Refining	*0.002*	*0.003*	*0.003*	*0.003*	*0.003*	*0.003*	*0.003*	*0.004*
Coal Mining	0.003	0.002	0.001	0.000	0.000	0.000	0.000	0.000

Source: Based on approach described in text.

Figure E1 displays process-level emission trends from the fossil fuel industry, on an MMtCO$_2$e basis.

Figure E1. Fossil Fuel Industry Emission Trends (MMtCO$_2$e)
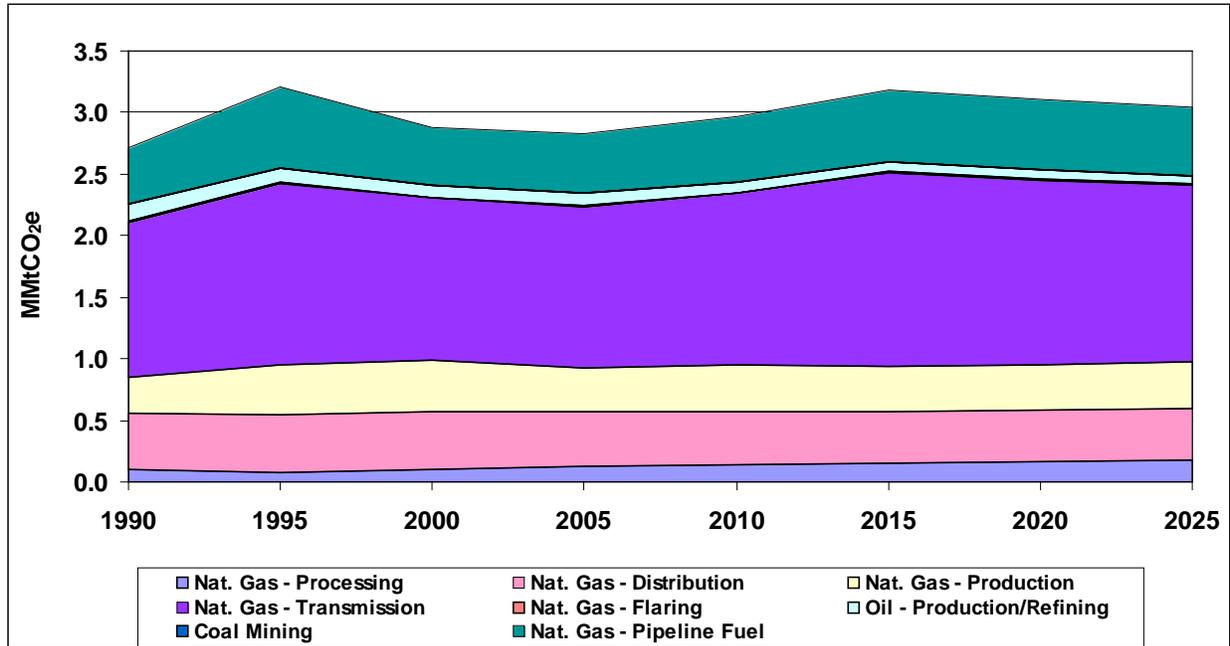
Source: Based on approach described in text.

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, natural gas gathering and transmission pipeline emissions in earlier years were estimated by assuming that changes in each emissions producing activity were related to changes in activity levels for surrogates for the emissions activity.[82]

- 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 oil and gas production, processing, and pipeline technologies.

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[82] For example, gathering pipeline emissions were back-cast to pre-2001 years by applying the ratio of Arkansas natural gas production in each pre-2001 year to Arkansas natural gas production in 2001.

Appendix F. Agriculture

Overview

The emissions discussed in this appendix refer to non-energy methane (CH_4) and nitrous oxide (N_2O) emissions from enteric fermentation, manure management, rice cultivation, agricultural soils, and agricultural burning. Emissions and sinks of carbon in agricultural soils 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).

There are two livestock sources of greenhouse gas (GHG) emissions: enteric fermentation and manure management. Methane 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. Methane 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. Under aerobic conditions, N_2O emissions are dominant. Emissions estimates from manure management are based on manure that is stored and treated on livestock 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 in the agricultural soils emissions.

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, nitrogen fixation, and histosols (high organic soils, such as wetlands or peatlands) cultivation. 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 is transported off-site before entering the nitrification/denitrification cycle. Methane and N_2O emissions also result when crop residues are burned and during rice cultivation. Rice fields must remain flooded, which means that decomposition occurs in a low-oxygen environment, resulting in anaerobic decomposition. This decomposition results in methane and N_2O emissions, though total emissions can vary depending on water management practices.

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. Finally, the practice of adding limestone and dolomite to agricultural soils (for neutralizing acidic soil conditions) results in CO_2 emissions.

Emissions and Reference Case Projections

Methane and Nitrous Oxide

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.[83] 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.[84]

Data on crop production and livestock in Arkansas from 1990 to 2005 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.[85] The default SIT manure management system assumptions for each livestock category were used for this inventory. See Tables F1 and F2 for more information on the estimated manure management emissions in the state, broken down by animal type.

Table F1. CH₄ Emissions from Manure Management in Arkansas (MMtCO₂e)

Animal Type	1990	2005	2015	2025
All Poultry	0.526	0.113	0.125	0.136
All Cows	0.093	0.078	0.072	0.073
All Swine	0.255	0.115	0.115	0.115
Other	0.007	0.011	0.012	0.014
Total	**0.881**	**0.317**	**0.324**	**0.338**

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[83] 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.

[84] 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/).

[85] USDA, NASS (http://www.nass.usda.gov/Statistics_by_State/Arkansas/index.asp).

Table F2. N$_2$O Emissions from Manure Management in Arkansas (MMtCO$_2$e)

Animal Type	1990	2005	2015	2025
All Poultry	0.779	0.980	1.098	1.200
All Cows	0.015	0.008	0.007	0.006
All Swine	0.005	0.002	0.002	0.002
Other	0.000	0.000	0.000	0.000
Total	**0.799**	**0.990**	**1.107**	**1.208**

SIT data on fertilizer usage came from the Arkansas Feed & Fertilizer Division of the Arkansas Agriculture State Plant Board, which provided the amount of fertilizer sold in the state[86]. These numbers were then used to approximate the amount of nitrogen applied to the soil for the years 1990-2005.

Crop production data from USDA NASS were provided through 2005; therefore, N$_2$O emissions from crop residues and crops that use nitrogen (i.e., nitrogen fixation) and N$_2$O and CH$_4$ emissions from agricultural residue burning were calculated through 2005. Emissions for the other agricultural crop production categories (i.e., synthetic and organic fertilizers) were also 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).

There is some agricultural residue burning conducted in Arkansas. Emissions are estimated to be relatively small, approximately 0.11 MMtCO$_2$e in 2005. The default SIT method was used to calculate emissions. 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 and burned, the resultant dry matter, and the carbon/nitrogen content of the dry matter.

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).[87] Swine populations were projected to remain constant between 2005-2025. Projections for all other livestock categories were estimated based on linear forecasts of the historical 1990-2005 populations. Livestock population growth rates are shown in Table F3. Emissions from aquaculture, such as fish farms, were not included in this analysis.[88]

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[86] From Jamey Johnson, Feed & Fertilizer Division, Arkansas State Plant Board. *Total Fertilizer Summary* chart out of the "Arkansas Distribution of Fertilizer Sales by County," 1990-2006.

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

[88] Catfish sales were 91,620,000 pounds in 2007, or 41,558 tons of catfish (NASS, http://www.nass.usda.gov/Statistics_by_State/Arkansas/Publications/Livestock_Releases/Catfish/2008/fishjan08.pdf). A DOE publication cited the GHG emissions from catfish farms as being 2.0 kg CO2e/kg of fish product (http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/p17.pdf). This would result in emissions of 83,000 metric tons of CO2e from catfish farms in 2007. However, there is significant uncertainty in this estimate. If the 83,000 Mt CO2e estimate is accurate, then catfish farms account for less than 1 percent of all agricultural

**Table F3. Growth Rates Applied for the Enteric Fermentation
And Manure Management Categories**

Livestock Category	2005-2025 Annual Growth
Dairy Cattle	-8.24%
Beef Cattle	0.62%
Swine	0.00%
Sheep	1.80%
Goats	0.25%
Horses	1.29%
Turkeys	-0.81%
Layers	-0.16%
Broilers	1.39%

Projections for agricultural burning and agricultural soils were based on linear extrapolation of the 1990-2005 historical data. Table F4 shows the 2005-2025 annual growth rates estimated for each category. The historical default data for liming of soils are available from 1990 through 2004. Therefore, projections for this category begin with the year 2005, rather than 2006.

Note that emissions from agricultural soils estimated using the SIT were multiplied by a national adjustment factor to reconcile differences between methodologies used in the National Inventory of Greenhouse Gas Emissions and the SIT.

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emissions. Given the uncertainty involved and relatively low emissions totals, it was decided not to include catfish farms in the total agricultural emissions estimate.

Table F4. Growth Rates Applied for the Agricultural Soils and Burning

Agricultural Category	2005-2025 Growth Rate
Agricultural Burning	2.00%
Liming of Agricultural Soils	1.36%
Agricultural Soils – Direct Emissions	
Fertilizers	-1.05%
Crop Residues	-0.57%
Nitrogen-Fixing Crops	-1.57%
Livestock	-1.09%
Agricultural Soils – Indirect Emissions	
Fertilizers	-0.99%
Livestock	-2.36%
Leaching/Runoff	-1.42%

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 limestone and dolomite applications from the United States Geological Survey (USGS).[90] Currently, these are the best available data at the state-level for this category.

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 Arkansas, Table F5 shows a summary of the latest estimates available from the USDA, which are for 1997.[91] The data show that changes in agricultural practices are estimated to result in net reduction of 1.8 million metric tons (MMt) of CO_2 equivalent (CO_2e) per year in Arkansas; this reduction comes largely from manure applications and the cultivation of other cropland.

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[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] US Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001. Global Change Program Office, Office of the Chief Economist, US Department of Agriculture. Technical Bulletin No. 1907, 164 pp. March 2004. http://www.usda.gov/oce/global_change/gg_inventory.htm; the data are in appendix B table B-11. The table contains two separate IPCC categories: "carbon stock fluxes in mineral soils" and "cultivation of organic soils." The latter is shown in the second to last column of Table F3. The sum of the first nine columns is equivalent to the mineral soils category.

**Table F5. GHG Emissions from Soil Carbon Changes Due to Cultivation Practices
(MMtCO$_2$e)**

Changes in Cropland			Changes in Hayland				Other			Total[4]
Plowout of grassland to annual cropland[1]	Cropland manage-ment	Other cropland[2]	Cropland converted to hayland[3]	Hayland manage-ment	Cropland converted to grazing land[3]	Grazing land manage-ment	CRP	Manure application	Cultivation of organic soils	Net soil carbon emissions
0.81	(0.22)	(0.81)	(0.11)	0.04	(0.37)	(0.11)	(0.15)	(0.88)	0.00	(1.80)

Based on USDA 1997 estimates, http://www.usda.gov/oce/global_change/gg_inventory.htm located in Appendix B, Table B-11. Parentheses indicate net sequestration.
[1] Losses from annual cropping systems due to plow-out of pastures, rangeland, hayland, set-aside lands, and perennial/horticultural cropland (annual cropping systems on mineral soils, e.g., corn, soybean, cotton, and wheat).
[2] Perennial/horticultural cropland and rice cultivation.
[3] Gains in soil carbon sequestration due to land conversions from annual cropland into hay or grazing land.
[4] Total does not include change in soil organic carbon storage on federal lands, including those that were previously under private ownership, and does not include carbon storage due to sewage sludge applications.

Since data are not yet available from USDA to make a determination of whether the emissions are increasing or decreasing in the subsequent years, emissions of -1.8 MMtCO$_2$e per year are assumed to remain constant throughout all historical and projected analysis years. The inventory and forecast does not consider above ground carbon sequestration in agriculture because it is not considered to be sequestered. Above-ground carbon re-enters the natural carbon cycle and is lost to the atmosphere through respiration or decomposition either directly or indirectly (e.g. used as energy as animal feed or by humans) over relatively short periods of time (months to years). Carbon sequestration in agriculture is below ground in the form of soil carbon (i.e. the result of the photosynthesis process), where carbon can be stored over long periods of time (potentially indefinitely). The EPA sites http://www.epa.gov/sequestration/ccyle.html and http://www.epa.gov/sequestration/local_scale.html have some useful information. For additional information on the potential for sequestration in Agriculture is in the EPA's *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture (see* http://www.epa.gov/sequestration/pdf/greenhousegas2005.pdf).

Results

Figure F1 and Table F6 show gross GHG emissions associated with the agricultural sector from 1990 through 2025. Table F6 also shows the net emissions associated with the agricultural sector after the sequestration from soil carbon changes due to cultivation practices is accounted for. In 1990, enteric fermentation accounted for about 19% (2.02 MMtCO$_2$e) of gross agricultural emissions. Enteric fermentation emissions increased slightly to 2.08 MMtCO$_2$e between 1990 and 2005 due to the increase in beef cattle populations over this period. Due to this increase in the beef cattle population, enteric fermentation emissions are estimated to rise to 2.30 MMtCO$_2$e by 2025. There is a projected increase in the beef cattle population, and enteric fermentation emissions are estimated to increase to 2.30 MMtCO$_2$e in 2025.

The manure management category accounted for 16% (1.68 MMtCO$_2$e) of gross agricultural emissions in 1990 and decreased significantly by 2005, accounting for 11% (1.31 MMtCO$_2$e) of

Arkansas' gross agricultural emissions. Manure management is projected to increase slightly by 2025, to account for 13% (1.55 MMtCO$_2$e) of gross agricultural emissions at that time.

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 decrease from 1990 to 2025, with 1990 emissions accounting for 45% (4.76 MMtCO$_2$e) of gross agricultural emissions and 2025 emissions estimated to be about 35% (4.15 MMtCO$_2$e) of gross agricultural emissions.

Rice cultivation is another significant contributor of GHG emissions in Arkansas. Emissions from rice cultivation made up 20% (2.14 MMtCO$_2$e) of gross agricultural emissions in 1990. This number is projected to increase to 31% (3.70 MMtCO$_2$e) of agricultural emissions in 2025. Growth of emissions from rice cultivation between 1990 and 2025 was greater than the total growth predicted for all the remaining agricultural sectors.

Figure F1. Gross GHG Emissions from Agriculture, 1990-2025
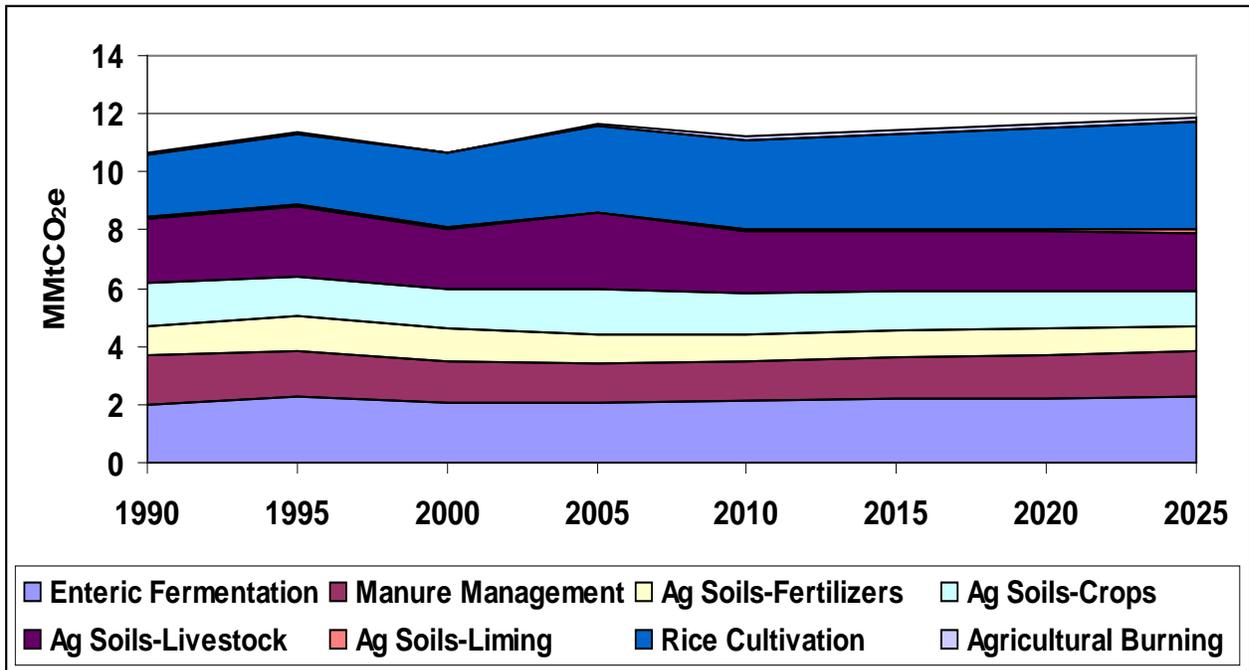
Source: Calculations based on approach described in text.
Notes: Ag Soils – Crops category includes: incorporation of crop residues and nitrogen fixing crops (no cultivation of histosols estimated); emissions for agricultural residue burning are too small to be seen in this chart.

Table F6. GHG Emissions from Agriculture in Arkansas (MMtCO$_2$e)

Source	1990	1995	2000	2005	2010	2015	2020	2025
Enteric Fermentation	2.02	2.24	2.05	2.08	2.10	2.17	2.24	2.30
Manure Management	1.68	1.61	1.45	1.31	1.37	1.43	1.49	1.55
Ag Soils-Fertilizers	0.97	1.18	1.16	1.02	0.96	0.92	0.87	0.83
Ag Soils-Crops	1.52	1.36	1.29	1.57	1.41	1.36	1.31	1.25
Ag Soils-Livestock	2.22	2.43	2.09	2.58	2.12	2.08	2.03	1.98
Ag Soils-Liming	0.05	0.07	0.08	0.07	0.07	0.07	0.08	0.09
Rice Cultivation	2.14	2.39	2.52	2.92	3.06	3.27	3.49	3.70
Agricultural Burning	0.05	0.05	0.06	0.11	0.11	0.13	0.14	0.16
Total Gross Emissions	**10.65**	**11.35**	**10.69**	**11.66**	**11.20**	**11.42**	**11.64**	**11.86**
Soil Carbon (Cultivation Practices)	-1.80	-1.80	-1.80	-1.80	-1.80	-1.80	-1.80	-1.80
Total Net Emissions	**8.85**	**9.55**	**8.89**	**9.86**	**9.40**	**9.62**	**9.84**	**10.06**

Source: Calculations based on approach described in text.

Soil carbon changes due to cultivation practices are a net sink of carbon in the state of Arkansas. Since data are not yet available from USDA to determine if emissions are increasing or decreasing, emissions of -1.80 MMtCO$_2$e per year are assumed to remain constant throughout the inventory and forecast period. This net sequestration is shown in Table F5. Since soil carbon changes due to cultivation practices are not a source of emissions in Arkansas, they are not shown in figure F1, which shows only gross (rather than net) emissions in the state.

The only standard IPCC source category missing from this report is N$_2$O emissions from the cultivation of histosols; there were no activity data available for Arkansas.

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 1997. When newer data are released by the USDA, these should be reviewed to represent current conditions as well as to assess trends. In particular, given the potential for some CRP acreage to retire and possibly return to active cultivation prior to 2025, the emissions could be appreciably affected.

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.

There is also uncertainty in the nitrogen applied to soils through fertilizers. The information provided by the state of Arkansas is measured in tons of fertilizer sold. We assumed that the amount of fertilizer sold is equal to the amount of fertilizer applied, and that we could correctly estimate the amount of nitrogen in each fertilizer type. Both of these estimates add a level of uncertainty to the calculations of the amount of nitrogen applied to soils.

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.

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)[92];

- Solid waste combustion – CH_4, carbon dioxide (CO_2), and nitrous oxide (N_2O) emissions from the combustion of solid waste in incinerators or waste to energy plants; and

- Wastewater management – CH_4 and N_2O from municipal wastewater and CH_4 from industrial wastewater (WW) 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. Arkansas Department of Environmental Quality (ADEQ) provided the quantity of municipal solid waste (MSW) landfilled in the State from 2002-2005.[93] ADEQ was also contacted to provide information regarding landfill emissions controls; however ADEQ does not have the necessary data.[94] CCS did not apply the SIT default 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.

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 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 LFGTE projects compiled by the EPA, and a database maintained by the Energy Information Administration (EIA) for the voluntary reporting of greenhouse gases.[95] The amount of landfill gas flared in Arkansas may be underestimated if Arkansas flaring and LFGTE controls have been underreported to the EPA and EIA.

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[92] 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.

[93] MSW landfill data from ADEQ Recycling Branch. Accessed 19 September, 2008 from http://www.adeq.state.ar.us/solwaste/branch_recycling/default.htm.

[94] ADEQ, communicated to CCS from Bryan Leamons, Solid Waste Division via email, Feb 2008.

[95] 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).

ADEQ provided a growth rate for MSW landfills, while the industrial landfills growth rate was based on historical (1996-2005) emissions. The annual growth rates are 4.7% for MSW landfills and 2.4% for industrial landfills. The years 1996 through 2005 were used to calculate the industrial landfill growth rate since these are the years when the SIT starts including flaring and LFGTE in the default data.

Solid Waste Combustion

ADEQ sources indicate that there is no combustion of MSW and no medical waste incineration in Arkansas.[96]

Likewise, open burning (e.g. residential burn barrels) was assumed to not contribute emissions after 1999 – the year it became illegal in the State of Arkansas.[97] Prior to 1999, the quantity of waste burned at residential sites in Arkansas was obtained from the 2002 National Emissions Inventory.[98] Emissions from open burning were calculated using SIT emission factors and waste characteristics. If unregulated open burning is occurring in a significant way, then the post-1999 emissions for this sector may be a slight underestimate. However, this is not expected to be the case.

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 1.3% 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
Arkansas 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.

For industrial wastewater emissions, SIT provides default assumptions and emission factors for three industrial sectors: Fruits & Vegetables, Red Meat & Poultry, and Pulp & Paper. ADEQ provided 2005 industrial wastewater flow data for all fruits & vegetables, poultry, and pulp & paper. Historical flows for poultry and fruits and vegetables were estimated using 1992-2002

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[96] ADEQ, communicated to CCS from Thomas Rheaume, Air Division via email, Feb 2008.
[97] See http://www.co.benton.ar.us/Environment/openburning.html, accessed Feb 2008.
[98] EPA, ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/nonpoint/2002nei_final_nonpoint_documentation0206version.pdf.

growth rates for broilers sold and fruits and vegetables harvested calculated from USDA data.[99]
No data for growing the pulp and paper estimates were identified, so wastewater emissions from
this sector were held constant for all analysis years. The SIT default activity data were used to
estimate emissions for red meat production. SIT emission factors were used to calculate
emissions. Emissions were projected to 2025 based on the 1990-2005 annual growth rate (1.3%).

Results

Figure G1 and Table G2 show the emission estimates for the waste management sector. Overall,
the sector accounts for 2.40 MMtCO$_2$e in 2005, and emissions are estimated to be 5.17
MMtCO$_2$e/yr in 2025.

Figure G1. Arkansas GHG Emissions from Waste Management, 1990-2025
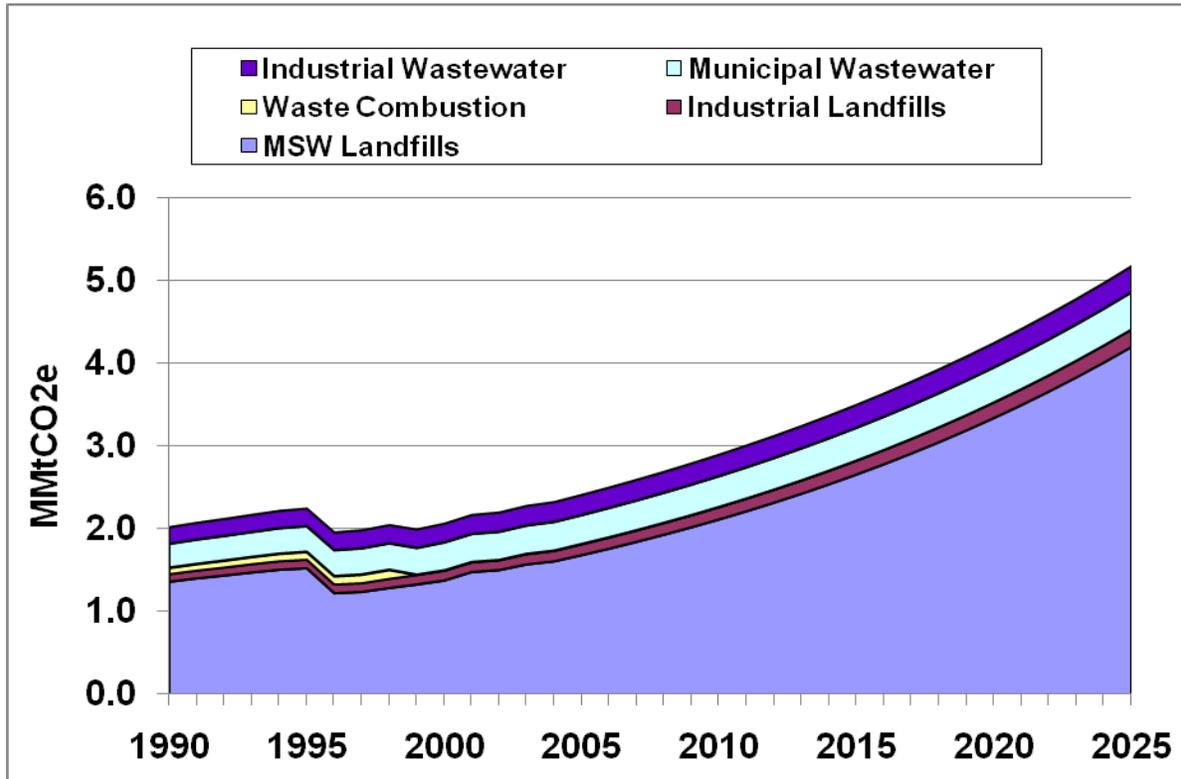
Source: Based on approach described in text.

Table G2. Arkansas GHG Emissions from Waste Management (MMtCO$_2$e)

Source	1990	1995	2000	2005	2010	2015	2020	2025
MSW Landfills	1.36	1.52	1.37	1.68	2.11	2.65	3.33	4.19
Industrial Landfills	0.09	0.11	0.12	0.13	0.15	0.17	0.19	0.22
Waste Combustion	0.07	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Municipal Wastewater	0.29	0.31	0.34	0.35	0.37	0.40	0.42	0.45
Industrial Wastewater	0.20	0.21	0.22	0.24	0.26	0.27	0.29	0.31
Total	**2.01**	**2.24**	**2.05**	**2.40**	**2.89**	**3.49**	**4.24**	**5.17**

Source: Based on approach described in text.

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[99] USDA, http://www.nass.usda.gov/census/census02/volume1/ar/st05_1_001_001.pdf, accessed Feb 2008.

The largest contributor to waste management emissions is the solid waste sector, in particular, municipal landfills. In 2005, municipal landfills accounted for 70% of total waste management emissions. By 2025, the contribution from these sites is expected to increase to about 81%. Industrial landfills accounted for about 6% of waste management emissions in 2005, and 4% in 2025.

In 2005, about 15% of the waste management sector emissions were contributed by municipal wastewater treatment systems and 10% were contributed by industrial wastewater. 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 sector is expected to contribute about 9% and industrial wastewater 6% to the waste management sector total.

Emissions from waste combustion did not contribute to waste management emissions after 1999.

Key Uncertainties

Municipal solid waste emissions for 1990-2001 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 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. ADEQ was contacted to provide more complete landfill and emissions controls data; however they do not have that data.[100] 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. Data on solid waste imports from other states or exports was not available from ADEQ.

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 AR, this could be an over- or underestimate.

ADEQ indicated that there is no waste combustion or waste-to-energy conversion in Arkansas. Although open residential burning is illegal, there is likely some occurring, particularly in rural areas. The Agriculture, Forestry, and Waste Technical Working Group was asked to provide estimates of illegal open burning, but no estimations were provided. To the extent that unreported waste burning is occurring in Arkansas, the emissions reported in this inventory and forecast may be underestimated.

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 Arkansas population on

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[100] ADEQ, communicated to CCS from Bryan Leamons, Solid Waste Division via email, Feb 2008.

septic; fraction of BOD which is anaerobically decomposed). The SIT defaults were derived from national data.

For industrial wastewater, key uncertainties are associated with the use of SIT emission factors and wastewater chemical oxygen demand estimates for each industry.

This inventory in its current state does not quantify current actions taken by the State of Arkansas that may lower future emissions. These include Recycling Legislation (Act 94, HB1055) and the Solid Waste Management and Recycling Fund (Act 1325, SB575).

Appendix H. Forestry and Land Use

Overview

Forestland emissions refer to the net carbon dioxide (CO_2) flux[101] from forested lands in Arkansas, which account for about 56% of the state's land area.[102] The dominant forest types in Arkansas are Oak-hickory which makes up about 39% of forested lands. Other common forest types are Loblolly-shortleaf pine at 28%, Oak-pine at 17%, and at Oak-gum-cypress at 15% of forested land. All other forest types make up less than 2% 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 forest fires 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 burning.

- *Urban Forestry and Land Use:* this covers carbon sequestration in urban trees, flux associated with carbon storage from landscape waste and food scraps into 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 Arkansas 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.[103] Additional forest carbon information is in the form of specific carbon conversion factors.[104]

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[101] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.

[102] Total forested acreage is 18.8 million acres in 1997. Acreage by forest type available from the USFS at: http://www.fs.fed.us/ne/global/pubs/books/epa/states/AR.htm. The total land area in Arkansas is 33.3 million acres (http://www.50states.com/arkansas.htm).

[103] 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. Additional background on the FORCARB2 system is provided in a number of publications.[105]

Carbon dioxide flux is estimated using 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 and 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 designations of 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.[106]

Carbon pool data for three FIA cycles to estimate flux for two different periods are available for Arkansas. The carbon pool data for three points in time are shown in Table H1 below. Note that prior to 1995, the Southern FIA Program took periodic forest inventory surveys for Arkansas (approximately on a 10-year schedule). Beginning in 1999, Arkansas transitioned from periodic to annual inventories as modifications to the FIA program were applied. The annual inventory

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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.

[104] 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.

[105] 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.

[106] 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.

measures 20% of the plots in Arkansas each year and delivers a complete inventory report every 5 years.

The underlying FIA data, as shown in Table H1, display a net increase in forested area: an increase of 1.1 million acres between 1988 and 1995, and an increase in forested area of 40,000 acres between 1995 and 2005. Most of the forested lands in Arkansas are considered timberland, meaning they are unreserved productive forestland producing (or capable of producing) crops of industrial wood. The timberland area is shown to have increased by 1.1 million acres between 1988 and 1995, while it only increased 88,000 acres between 1995 and 2005. This increase in timberland area resulted in the tremendous increase in carbon (81 million metric tons) from forested areas between 1988 and 1995, and a smaller increase in carbon (28 million metric tons) from 1995 to 2005.

Table H1. USFS Forest Carbon Pool Data for Arkansas

Forest Pool	1988 (MMtC)	1995 (MMtC)	2005 (MMtC)
Live Tree – Above Ground	358	402	422
Live Tree – Below Ground	70.7	79.4	83.2
Understory	21.7	22.7	23.0
Standing Dead	16.8	17.9	17.7
Down Dead	28.7	32.6	34.2
Forest Floor	55.9	60.0	62.9
Soil Carbon	302	321	320
Totals	**854**	**935**	**963**
Forest Area	**1988 (10^3 acres)**	**1995 (10^3 acres)**	**2005 (10^3 acres)**
All Forests	17,687	18,790	18,830
Timberland	17,247	18,392	18,480

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 Arkansas FIA data using the Carbon Calculation Tool (CCT)[107]. 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.

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[107] 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)	1995 (MMtC)	2005 (MMtC)
Live Tree – Above Ground	370	398	426
Live Tree – Below Ground	73.1	78.7	84.1
Understory	21.9	22.6	23.1
Standing Dead	17.1	17.8	17.6
Down Dead	29.8	32.3	34.7
Forest Floor	57.0	59.6	63.6
Soil Carbon	307	319	320
Totals	876	929	969
Forest Area	1990 (10^3 acres)	1995 (10^3 acres)	2005 (10^3 acres)
All Forests	17,990	18,702	18,839
Timberland	17,561	18,301	18,499

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). HWP include durable wood products (e.g., lumber and furniture) and other wood products (e.g., paper). Carbon remains stored in the durable wood products pool; wood products that become waste are 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 (WOODCARB2 also accounts for wood harvested for energy production).[108] State-level information for Arkansas was provided to CCS by USFS[109].

As shown in Table H3, about 4.7 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 fluctuates between -43 MMtCO$_2$e/yr (between 1988 and 1995) and -18 MMtCO$_2$e/yr (between 1995 and 2005).[110] This fluctuation is due to lower forest carbon sequestration both in the non-soil pools as well as the soil organic carbon pool in the second period. Note that from 1988-1995 soil carbon was considered a net sink, and from 1995-2005, it is a net source. These types of changes often relate to conversions in forested land to developed use. Given the changes noted above in timberland, it appears that much of the higher levels of sequestration seen in the earlier period relate to a significant land use change into forested use (possibly from agricultural land use).

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[108] 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.

[109] Obtained from the Harvested Wood Product model developed by Ken Skog, USFS

[110] 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 Arkansas

Forest Pool	1988-1995 Flux (MMtCO$_2$)	1995-2005 Flux (MMtCO$_2$)
Forest Carbon Pools (non-soil)	-29.5	-13.5
Soil Organic Carbon	-8.92	0.36
Harvested Wood Products	-4.69	-4.69
Totals	**-43.2**	**-17.8**
Totals (excluding soil carbon)	**-34.2**	**-18.2**

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), 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 1988-1995 carbon flux to represent yearly forest carbon flux prior to 1995. Current flux estimates (1995-2005) are from the 1995 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 in forested area.

Forest Fires and Prescribed Burns

Biomass burned in forest fires emits CO_2, methane (CH_4), and N_2O, in addition to many other gases and pollutants. Since CO_2 emissions are captured under the total carbon flux calculations above, CCS used the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) to estimate CH_4 and N_2O emissions. CCS used state data from the Arkansas Forestry Commission on the acres burned by wildfirs.[111] Forest fire acres burned data for each year (1990-2005) were entered in SIT under the "other temperate forests" category to calculate historical emissions. Projected emissions for 2005-2025 were held constant at 2005 levels. The emission estimates are presented at the end of this section. No data were identified for prescribed burn acreage.

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[111] Wildfire acres burned data obtained from Arkansas Forestry Commission
(http://www.forestry.state.ar.us/protect/firestats.html) under Fires by Month, downloaded December 2007.

Urban Forestry and Land Use

GHG emissions from urban forestry and land use for 1990 through 2005 were estimated using the EPA SIT software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[112] 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.[113] Table H4 displays the emissions and reference case projections for Arkansas.

Table H4. Urban Forestry Emissions and Reference Case Projections (MMtCO$_2$e)

Urban Forestry and Land Use Subsector	1990	2000	2005	2010	2020	2025
Urban Trees	-0.37	-0.46	-0.50	-0.50	-0.50	-0.50
Landfilled Yard Trimmings and Food Scraps	-2.16	-0.50	-0.52	-0.52	-0.52	-0.52
N$_2$O from Settlement Soils	0.10	0.13	0.11	0.11	0.11	0.11
Total	**-2.43**	**-0.83**	**-0.91**	**-0.91**	**-0.91**	**-0.91**

*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 1,897 square kilometers [km^2] to 2,587 km^2 between 1990 and 2005) was multiplied by the state estimate of the percent of urban area with tree cover (25% for Arkansas) 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.[114] 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.

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[112] GHG emissions were calculated using SIT, with reference to EIIP, Volume VIII: Chapter 8.

[113] 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/).

[114] 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

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.

Table H5. Forestry and Land Use Flux and Reference Case Projections (MMtCO$_2$e)

Subsector	1990	2000	2005	2010	2020	2025
Forested Landscape (excluding soil carbon)	-34.2	-18.2	-18.2	-18.2	-18.2	-18.2
Forest Fires and Prescribed Burns	0.17	0.18	0.18	0.18	0.18	0.18
Urban Forestry and Land Use	-2.43	-0.83	-0.91	-0.91	-0.91	-0.91
Sector Total	**-36.5**	**-18.8**	**-18.9**	**-18.9**	**-18.9**	**-18.9**

Source: Based on approach described in text.

Key Uncertainties

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 Arkansas 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 surveys 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 and land use emission estimates rely on national default data and could be improved with state-specific information.

Appendix I. Greenhouse Gases and Global Warming Potential Values: Excerpts from the Inventory of U.S. Greenhouse Emissions and Sinks: 1990-2000

Original Reference: Material for this Appendix is taken from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2000*, US Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-02-003, April 2002 www.epa.gov/globalwarming/ publications/emissions. Michael Gillenwater directed the preparation of this appendix.

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 2000. 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.

The Intergovernmental Panel on Climate Change (IPCC) has recently updated the specific global warming potentials for most greenhouse gases in their 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[115] were developed prior to the publication of the TAR. 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 two 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: 1990-2000*.

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

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[115] 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	0.700	0.270	0	40
Atmospheric concentration (1998)	365	1.745	0.314	4.2	80
Rate of concentration change[b]	1.5[c]	0.007[c]	0.0008	0.24	1.0
Atmospheric Lifetime	50-200[d]	12[e]	114[e]	3,200	>50,000

Source: IPCC (2001)

[a] Concentrations in parts per trillion (ppt) and rate of concentration change in ppt/year.

[b] Rate is calculated over the period 1990 to 1999.

[c] Rate has fluctuated between 0.9 and 2.8 ppm per year for CO_2 and between 0 and 0.013 ppm per year for CH4 over the period 1990 to 1999.

[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 367 ppmv in 1999, a 31 percent increase (IPCC 2001). The IPCC notes that "[t]his concentration has not been exceeded during the past 420,000 years, and likely not during the past 20 million years. The rate of increase over the past century is unprecedented, at least during the past 20,000 years." The IPCC definitively states that "the present atmospheric CO_2 increase is caused by anthropogenic emissions of CO_2" (IPCC 2001). 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 150 percent since pre-industrial times, 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 2001).

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 the use of synthetic and manure fertilizers; 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 16 percent since 1750, from a pre industrial value of about 270 ppb to 314 ppb in 1998, 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.

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
Global Warming Potentials (GWPs) are intended as a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas. It is defined as the cumulative radiative forcing—both direct and indirect effects—integrated over a period of time from the emission of a unit mass of gas relative to some reference gas (IPCC 1996). Carbon dioxide (CO_2) was chosen as this reference gas. Direct effects occur when the gas itself is a greenhouse gas. 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 relationship between gigagrams (Gg) of a gas and Tg CO_2 Eq. can be expressed as follows:

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

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 policy makers to compare the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of roughly ±35 percent, though some GWPs have larger uncertainty than others, especially those in which lifetimes have not yet been ascertained. In the following decision, the parties to the UNFCCC have agreed to use consistent GWPs from the IPCC Second Assessment Report (SAR), based upon a 100 year time horizon, although other time horizon values are available (see Table I2).

> *In addition to communicating emissions in units of mass, Parties may choose also to use global warming potentials (GWPs) to reflect their inventories and projections in carbon dioxide-equivalent terms, using information provided by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report. Any use of GWPs should be based on the effects of the greenhouse gases over a 100-year time horizon. In addition, Parties may also use other time horizons. (FCCC/CP/1996/15/Add.1)*

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.

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

Gas	Atmospheric Lifetime	100-year GWP[a]	20-year GWP	500-year GWP
Carbon dioxide (CO_2)	50-200	1	1	1
Methane (CH_4)[b]	12±3	21	56	6.5
Nitrous oxide (N_2O)	120	310	280	170
HFC-23	264	11,700	9,100	9,800
HFC-125	32.6	2,800	4,600	920
HFC-134a	14.6	1,300	3,400	420
HFC-143a	48.3	3,800	5,000	1,400
HFC-152a	1.5	140	460	42
HFC-227ea	36.5	2,900	4,300	950
HFC-236fa	209	6,300	5,100	4,700
HFC-4310mee	17.1	1,300	3,000	400
CF_4	50,000	6,500	4,400	10,000
C_2F_6	10,000	9,200	6,200	14,000
C_4F_{10}	2,600	7,000	4,800	10,100
C_6F_{14}	3,200	7,400	5,000	10,700
SF_6	3,200	23,900	16,300	34,900

Source: IPCC (1996)

[a] GWPs used here are calculated over 100 year time horizon

[b] The methane GWP 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.

Table I3 presents direct and net (i.e., direct and indirect) GWPs for ozone-depleting substances (ODSs). Ozone-depleting substances directly absorb infrared radiation and contribute to positive radiative forcing; however, their effect as ozone-depleters also leads to a negative radiative

forcing because ozone itself is a potent greenhouse gas. There is considerable uncertainty regarding this indirect effect; therefore, a range of net GWPs is provided for ozone depleting substances.

Table I3. Net 100-year Global Warming Potentials for Select Ozone Depleting Substances*

Gas	Direct	Net$_{min}$	Net$_{max}$
CFC-11	4,600	(600)	3,600
CFC-12	10,600	7,300	9,900
CFC-113	6,000	2,200	5,200
HCFC-22	1,700	1,400	1,700
HCFC-123	120	20	100
HCFC-124	620	480	590
HCFC-141b	700	(5)	570
HCFC-142b	2,400	1,900	2,300
$CHCl_3$	140	(560)	0
CCl_4	1,800	(3,900)	660
CH_3Br	5	(2,600)	(500)
Halon-1211	1,300	(24,000)	(3,600)
Halon-1301	6,900	(76,000)	(9,300)

Source: IPCC (2001)

* Because these compounds have been shown to deplete stratospheric ozone, they are typically referred to as ozone depleting substances (ODSs). However, they are also potent greenhouse gases. Recognizing the harmful effects of these compounds on the ozone layer, in 1987 many governments signed the *Montreal Protocol on Substances that Deplete the Ozone Layer* to limit the production and importation of a number of CFCs and other halogenated compounds. The United States furthered its commitment to phase-out ODSs by signing and ratifying the Copenhagen Amendments to the *Montreal Protocol* in 1992. Under these amendments, the United States committed to ending the production and importation of halons by 1994, and CFCs by 1996. The IPCC Guidelines and the UNFCCC do not include reporting instructions for estimating emissions of ODSs because their use is being phased-out under the *Montreal Protocol*. The effects of these compounds on radiative forcing are not addressed here.

The IPCC recently published its Third Assessment Report (TAR), providing the most current and comprehensive scientific assessment of climate change (IPCC 2001). Within that report, the GWPs of several gases were revised relative to the IPCC's Second Assessment Report (SAR) (IPCC 1996), and new GWPs have been calculated for an expanded set of gases. Since the SAR, the IPCC has applied an improved calculation of CO_2 radiative forcing and an improved CO_2 response function (presented in WMO 1999). The GWPs are drawn from WMO (1999) and the SAR, 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. Because the revised radiative forcing of CO_2 is about 12 percent lower than that in the SAR, the GWPs of the other gases relative to CO_2 tend to be larger, taking into account revisions in lifetimes. However, there were some instances in which other variables, such as the radiative efficiency or the chemical lifetime, were altered that resulted in further increases or decreases in particular GWP values. In addition, the values for radiative forcing and lifetimes have been calculated for a variety of halocarbons, which were not presented in the SAR. The changes are described in the TAR as follows:

New categories of gases include fluorinated organic molecules, many of which are ethers that are proposed as halocarbon substitutes. Some of the GWPs have larger uncertainties than that of others, particularly for those gases where detailed laboratory data on lifetimes are not yet available. The direct GWPs have been calculated relative to CO_2 using an improved calculation

of the CO₂ radiative forcing, the SAR response function for a CO₂ pulse, and new values for the radiative forcing and lifetimes for a number of halocarbons.

References

FCCC (1996) Framework Convention on Climate Change; FCCC/CP/1996/15/Add.1; 29 October 1996; Report of the Conference of the Parties at its second session. Revised Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention, p18. Geneva 1996.

IPCC (2001) *Climate Change 2001: A Scientific Basis*, Intergovernmental Panel on Climate Change; J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, C.A. Johnson, and K. Maskell, eds.; Cambridge University Press. Cambridge, U.K.

IPCC (2000) *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.* IPCC National Greenhouse Gas Inventories Programme Technical Support Unit, Kanagawa, Japan. Available online at <http://www.ipcc-nggip.iges.or.jp/gp/report.htm>.

IPCC (1999) *Aviation and the Global Atmosphere*. Intergovernmental Panel on Climate Change; Penner, J.E., et al., eds.; Cambridge University Press. Cambridge, U.K.

IPCC (1996) *Climate Change 1995: The Science of Climate Change*. Intergovernmental Panel on Climate Change; J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell, eds.; Cambridge University Press. Cambridge, U.K.

IPCC/UNEP/OECD/IEA (1997) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.* Paris: Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency.

Jacobson, M.Z. (2001) Strong Radiative Heating Due to the Mixing State of Black Carbon in Atmospheric Aerosols. Nature. In press.

UNEP/WMO (2000) *Information Unit on Climate Change*. Framework Convention on Climate Change (Available on the internet at <http://www.unfccc.de>.)

WMO (1999) Scientific Assessment of Ozone Depletion, Global Ozone Research and Monitoring Project-Report No. 44, World Meteorological Organization, Geneva, Switzerland.