Final Kentucky Greenhouse Gas Inventory and Reference Case Projections 1990-2030

Center for Climate Strategies
June 2010

Principal Authors: Randy Strait, Maureen Mullen, Bill Dougherty, Rachel Anderson, Andy Bollman, Viola Glenn, Juan Maldonado, Steve Roe, Jackson Schreiber, Brad Strode, Katie Pasko

[This page intentionally left blank.]

Executive Summary

The Center for Climate Strategies (CCS) prepared this report for the Kentucky Energy and Environment Cabinet (KEEC). The report presents an assessment of the State's greenhouse gas (GHG) emissions and anthropogenic sinks (carbon storage) from 1990 to 2030. The preliminary draft inventory and forecast served as a starting point to assist the State, as well as the Kentucky Climate Action Plan Council (KCAPC) and Technical Work Groups (TWGs), with an initial comprehensive understanding of Kentucky's current and possible future GHG emissions, and thereby informed the identification and analysis of policy options for mitigating GHG emissions.[1] The KCAPC 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 KCAPC.

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

Kentucky's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the period from 1990 to 2030. Historical GHG emission estimates (1990 through 2007)[2] were developed using a set of generally accepted principles and guidelines for State GHG emissions, relying to the extent possible on Kentucky-specific data and inputs when it was possible to do so. The reference case projections (2008-2030) are based on a compilation of various projections of electricity generation, fuel use, and other GHG-emitting activities for Kentucky, 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 U.S. 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 Kentucky accounted for approximately 183 million metric tons (MMt) of gross[4] CO_2e emissions (consumption basis) in 2005, an amount equal to about

[1] "Draft Kentucky Greenhouse Gas Inventory and Reference Case Projections, 1990-2030," prepared by the Center for Climate Strategies for the Kentucky Energy and Environment Cabinet, January 2010.

[2] The last year of available historical data varies by sector; ranging from 2004 to 2008.

[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.

2.6% of total U.S. gross GHG emissions (based on 2005 U.S. data).[5] Kentucky's gross GHG emissions are rising at a faster rate than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). Kentucky's gross GHG emissions increased by about 34% from 1990 to 2005, while national emissions rose by 16% from 1990 to 2005. The growth in Kentucky's emissions from 1990 to 2005 is primarily associated with the electricity consumption and transportation sectors.

Estimates of carbon sinks within Kentucky's forests and soils, including urban forests, land use changes, and agricultural soil cultivation practices, have also been included in this report. The current estimates indicate that about 7.6 Million Metric Tons of Carbon Dioxide Equivalent ($MMtCO_2e$) emissions were stored in Kentucky biomass in 2005. This leads to net emissions of about 176 $MMtCO_2e$ in Kentucky in 2005, an amount equal to 2.8% of total U.S. 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, Kentucky residents emitted about 37 metric tons (t) of gross CO_2e in 1990, much higher than the 1990 national per capita emissions of 25 tCO_2e. Unlike the national per capita emissions which remained nearly constant from 1990 to 2005, the Kentucky per capita emissions increased by 19% from 1990 to 2005. The electricity supply sector shows the greatest difference between per capita emissions in Kentucky and the US, at 22 tCO_2e per capita in Kentucky for this sector compared with 8 tCO_2e per capita nationally. This is because the electricity consumed in Kentucky relies on a high amount of coal in the generation fuel mix relative to the US as a whole; about 90% for Kentucky versus 50% for the US in 2005. The use of coal has led to low electricity rates in Kentucky compared to the rest of the country, which has allowed energy-intensive industries to flourish in the state, as acknowledged in Kentucky's Energy Plan.[7] Like the nation as a whole, Kentucky's economic growth exceeded emissions growth throughout the 1990-2005 period (leading to declining estimates of GHG emissions per unit of state product). From 1990 to 2005, emissions per unit of gross product dropped by 11% in Kentucky and by about 26% nationally.[8]

The principal sources of Kentucky's GHG emissions are electricity consumption; transportation; and residential, commercial, and industrial (RCI) fuel use accounting for 50%, 20%, and 17% of Kentucky's gross GHG emissions in 2005, respectively.

---

[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] Historical Kentucky population statistics are compiled by Kentucky State Data Center from US Census Bureau data, are available at http://ksdc.louisville.edu/kpr/popest/est.htm.. Kentucky population projections through 2050 are available from the same source at http://ksdc.louisville.edu/kpr/pro/projections.htm.

[7] *Intelligent Energy Choices for Kentucky's Future: Kentucky's 7-Point Strategy for Energy Independence,* Governor Steven L. Beshear, November 2008.

[8] 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 *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).

As illustrated in Figure ES-2 and shown numerically in Table ES-1, under the reference case projections, Kentucky's gross GHG emissions continue to grow, and are projected to climb to about 248 $MMtCO_2e$ by 2030, reaching 81% 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 Kentucky, followed by emissions associated with transportation, and then by emissions associated with the increasing use of HFCs as substitutes for ozone-depleting chlorofluorocarbons (CFCs)[9].

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

GHG Reductions from Recent Actions

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 development of the inventory and forecast, sufficient information was identified (e.g., implementation schedules) to estimate GHG emission reductions associated with implementing the Corporate Average Fuel Economy (CAFE) requirements in Kentucky. Further reductions in transportation emissions will be achieved through the Obama plan for adopting the California vehicle CO_2 emission standards nationwide. The GHG emission reductions projected to be achieved by these recent federal actions are summarized in Table ES-2. This table shows a total reduction of about 6.2 $MMtCO_2e$ in 2030 from the business-as-usual reference case emissions, or a 2.5% reduction from the business-as-usual emissions in 2030 for all sectors combined. GHG emission reductions projected to be achieved by additional recent federal and state actions will be analyzed and quantified, where possible, through the KCAPC process.

[9] 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 residential, commercial, and industrial (RCI) direct fuel use and transport sectors as well as in the industrial sector; they are included here, however, within the industrial processes emissions.

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

Million Metric Tons CO_2e	1990	2000	2005	2010	2015	2020	2025	2030	Explanatory Notes for Projections
Energy Use (CO_2, CH_4, N_2O)	**121.6**	**149.5**	**165.9**	**173.8**	**187.4**	**199.2**	**212.4**	**225.8**	
Electricity Use (Consumption)	**59.2**	**78.5**	**90.9**	**101.1**	**110.3**	**118.0**	**126.2**	**134.3**	
Electricity Production (in state)	68.5	89.1	98.4	105.4	115.0	123.0	131.5	140.0	
Coal	*68.3*	*88.7*	*93.6*	*101.2*	*110.3*	*118.0*	*126.3*	*134.4*	*See electric sector assumptions*
Natural Gas	*0.016*	*0.31*	*1.64*	*1.89*	*2.07*	*2.23*	*2.28*	*2.39*	*in Appendix A.*
Oil	*0.090*	*0.13*	*3.12*	*2.32*	*2.53*	*2.70*	*2.87*	*3.07*	
Biomass (CH_4 and N_2O)	*0.000*	*0.000*	*0.002*	*0.003*	*0.003*	*0.003*	*0.003*	*0.004*	
MSW/Landfill Gas	*0.000*	*0.000*	*0.036*	*0.057*	*0.062*	*0.066*	*0.071*	*0.076*	
Other Wastes	*0.000*	*0.000*	*0.008*	*0.007*	*0.008*	*0.009*	*0.009*	*0.010*	
Net Imported/Exported Electricity	-9.27	-10.58	-7.51	-4.30	-4.69	-5.01	-5.36	-5.70	Negative values represent net exported electricity
Residential/Commercial/ Industrial (RCI) Fuel Use	**26.7**	**30.4**	**31.2**	**28.3**	**29.1**	**28.8**	**28.5**	**27.7**	
Coal	8.54	5.77	5.88	5.28	5.61	5.56	5.40	5.04	Based on USDOE regional projections
Natural Gas	8.72	11.3	11.2	10.8	10.8	10.8	10.8	10.6	Based on USDOE regional projections
Oil	9.34	13.3	14.0	12.2	12.5	12.4	12.2	11.9	Based on USDOE regional projections
Wood (CH_4 and N_2O)	0.11	0.06	0.10	0.10	0.10	0.11	0.11	0.11	Based on USDOE regional projections
Transportation	**27.2**	**33.2**	**37.3**	**36.8**	**40.9**	**45.5**	**50.8**	**56.9**	
Onroad Gasoline	16.4	19.0	19.2	20.3	22.2	24.2	26.3	28.5	Based on VMT projections from KYTC
Onroad Diesel	5.77	8.90	9.59	10.8	12.7	15.1	18.2	22.0	Based on VMT projections from KYTC
Marine Vessels	1.17	1.35	3.63	1.43	1.50	1.57	1.64	1.70	Based on historical growth
Rail, Natural Gas, LPG, other	1.49	1.28	1.48	2.12	2.13	2.13	2.13	2.13	Based on USDOE regional projections
Jet Fuel and Aviation Gasoline	2.32	2.68	3.35	2.21	2.39	2.48	2.56	2.62	Based on FAA projected operations and AEO2009 efficiency gains
Fossil Fuel Industry	**8.51**	**7.33**	**6.50**	**7.46**	**7.05**	**6.91**	**6.91**	**6.90**	
Natural Gas Industry	4.00	3.59	3.43	3.95	4.06	4.17	4.30	4.47	
Oil Industry	0.077	0.058	0.047	0.052	0.057	0.062	0.069	0.076	
Coal Mining (CH_4)	4.43	3.68	3.03	3.46	2.93	2.67	2.53	2.35	Used AEO Central Appalachia coal production projections
Industrial Processes	**4.75**	**5.65**	**6.52**	**7.75**	**8.50**	**9.35**	**10.70**	**12.55**	
Cement Manufacture (CO_2)	0.37	0.35	0.54	0.53	0.59	0.64	0.69	0.73	Based on Portland Cement Association's Cement Outlook 2008.
Lime Manufacture (CO_2)	0.46	0.48	0.72	0.77	0.83	0.88	0.94	1.01	Based on analysis of historical growth
Limestone and Dolomite Use (CO_2)	0.31	0.28	0.32	1.08	1.08	1.08	1.08	1.08	No growth assumed due to conflicting historical data
Soda Ash (CO_2)	0.040	0.038	0.036	0.034	0.033	0.031	0.029	0.029	Based on employment

Million Metric Tons CO_2e		1990	2000	2005	2010	2015	2020	2025	2030	Explanatory Notes for Projections
										projections from Workforce KY
	Iron & Steel (CO_2)	2.43	2.57	2.62	2.70	2.70	2.70	2.70	2.70	No growth assumed
	Ammonia and Urea (CO_2)	0.011	0.010	0.007	0.008	0.008	0.008	0.008	0.008	Based on analysis of historical growth
	ODS Substitutes (HFC, PFC)	0.005	1.02	1.48	1.90	2.56	3.32	4.59	6.35	Based on national projections (USEPA)
	Electric Power T&D (SF_6)	0.60	0.34	0.34	0.31	0.29	0.28	0.27	0.26	Based on national projections (USEPA)
	Aluminum Production (PFC)	0.53	0.57	0.46	0.42	0.41	0.40	0.40	0.39	Based on national projections (USEPA)
Waste Management		**2.18**	**2.13**	**2.16**	**2.33**	**1.75**	**1.87**	**1.98**	**2.10**	
	Waste Combustion	0.11	0.17	0.20	0.21	0.21	0.21	0.21	0.21	Used growth rate calculated for 1995-2002 emissions growth
	Landfills	1.71	1.56	1.54	1.68	1.09	1.18	1.27	1.37	Based on historical KY landfill emplacement; Used landfill disposal projections from waste management profile to estimate future emissions
	Wastewater Management	0.36	0.40	0.41	0.44	0.46	0.48	0.50	0.52	Used growth rate calculated for 1990-2005 emissions growth
Agriculture		**7.89**	**6.96**	**7.88**	**7.05**	**6.81**	**6.65**	**6.56**	**6.59**	
	Enteric Fermentation	3.25	2.91	3.12	3.14	3.06	3.02	3.04	3.16	Based on projected livestock population
	Manure Management	0.48	0.48	0.53	0.45	0.42	0.40	0.40	0.41	Based on projected livestock population
	Agricultural Soils	3.67	3.31	4.08	3.35	3.26	3.17	3.07	2.98	Used historical growth rate
	Agricultural Burning	0.014	0.017	0.018	0.019	0.020	0.021	0.022	0.023	Used historical growth rate
	Agricultural Liming	0.48	0.24	0.13	0.088	0.057	0.037	0.024	0.016	Based on historical agricultural liming estimate
Forest Wildfires (N_20 and CH_4)		**0.29**	**1.72**	**0.66**	**0.68**	**0.68**	**0.68**	**0.68**	**0.68**	Based on average of historical emissions
Total Gross Emissions (Consumption Basis, Excludes Sinks)		**136.7**	**165.9**	**183.1**	**191.6**	**205.1**	**217.7**	**232.3**	**247.7**	
	increase relative to 1990		*21%*	*34%*	*40%*	*50%*	*59%*	*70%*	*81%*	
Emissions Sinks		**-9.94**	**-7.77**	**-7.57**	**-7.57**	**-7.57**	**-7.57**	**-7.57**	**-7.57**	
	Forested Landscape	-4.71	-4.71	-4.71	-4.71	-4.71	-4.71	-4.71	-4.71	Held at 2005 levels
	Urban Forestry and Land Use	-4.09	-1.92	-1.73	-1.73	-1.73	-1.73	-1.73	-1.73	Extrapolated based on historical data
	Agricultural Soils (cultivation practices)	-1.14	-1.14	-1.14	-1.14	-1.14	-1.14	-1.14	-1.14	Held at 1997 levels based on most recent data available
Net Emissions (Includes Sinks)		**126.8**	**158.2**	**175.5**	**184.0**	**197.6**	**210.1**	**224.8**	**240.2**	
	increase relative to 1990		*25%*	*38%*	*45%*	*56%*	*66%*	*77%*	*89%*	

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

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

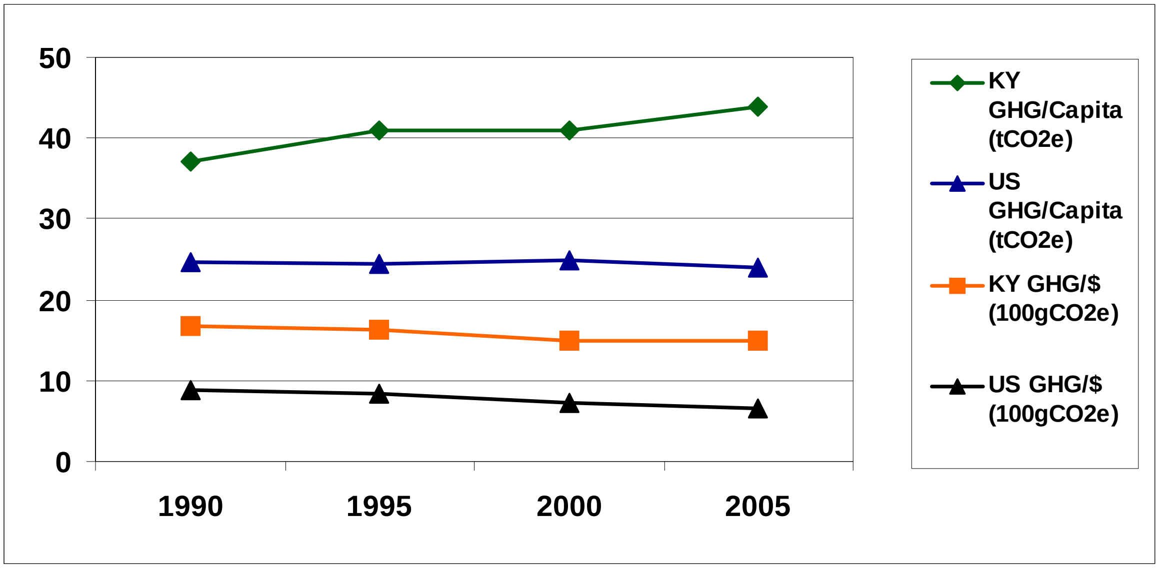
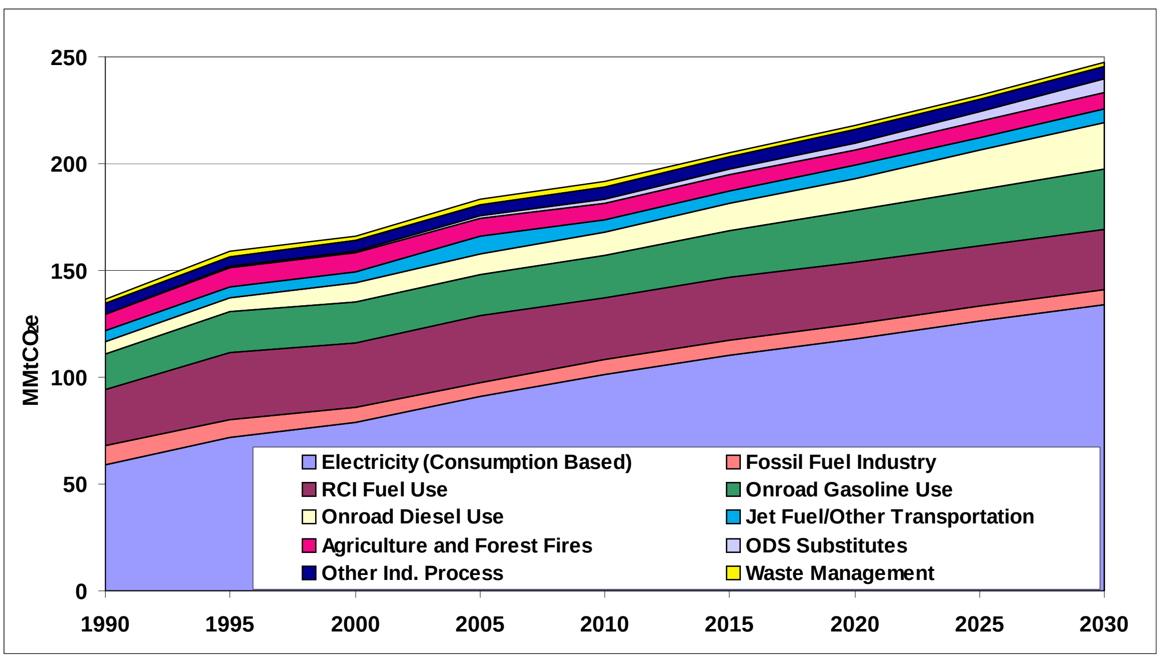
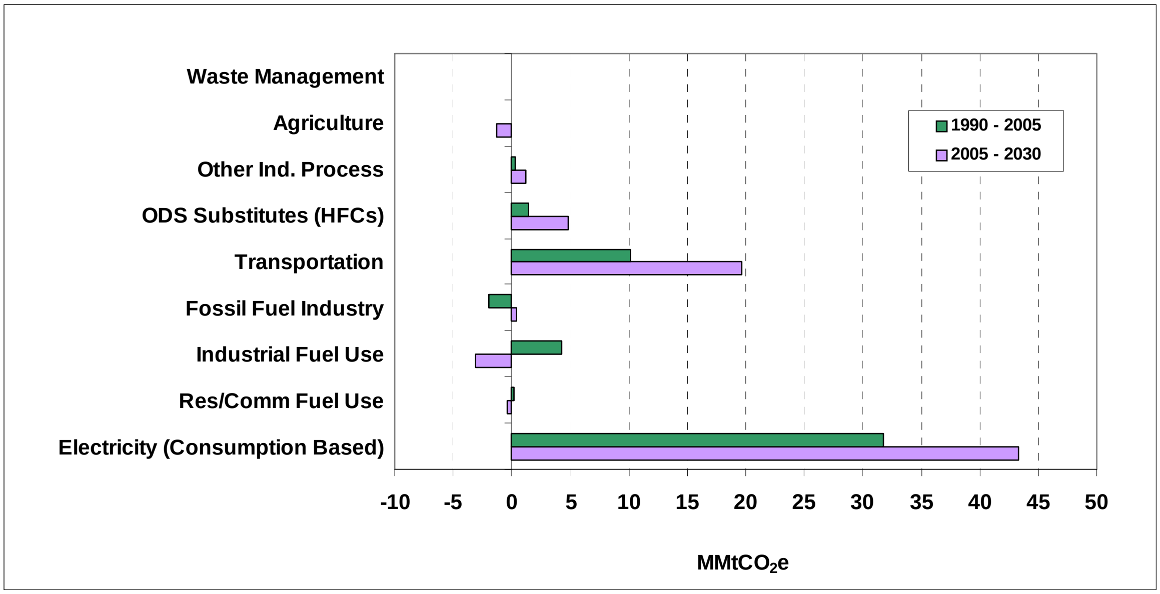


Figure ES-2. Kentucky Gross GHG Emissions by Sector, 1990-2030: Historical and Projected



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

Figure ES-3. Sector Contributions to Gross Emissions Growth in Kentucky, 1990-2030: 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 Kentucky (Consumption-Basis, Gross Emissions)

Sector / Recent Action	GHG Reductions (MMtCO$_2$e)		GHG Emissions (MMtCO2e) Business as Usual	GHG Emissions (MMtCO2e) With Recent Actions
	2020	2030	2030	2030
Transportation and Land Use (TLU)				
Federal Corporate Average Fuel Economy (CAFE) Requirements plus California CO_2 Vehicle Standards	4.02	6.23	56.9	50.7
Total (All Sectors)			**247.7**	**241.5**

Table of Contents

Executive Summary iii
Acknowledgements xv
Summary of Preliminary Findings 1
  Introduction 1
Kentucky Greenhouse Gas Emissions: Sources and Trends 3
  Historical Emissions 6
    Overview 6
    A Closer Look at the Three Major Sources: Electricity Consumption, Transportation, and RCI Fuel Use 8
  Reference Case Projections (Business as Usual) 10
  Reference Case Projections with Recent Actions 12
  Key Uncertainties and Next Steps 14
  Approach 14
    General Methodology 14
    General Principles and Guidelines 15
Appendix A. Electricity Supply and Use A-1
Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion B-1
Appendix C. Transportation Energy Use C-1
Appendix D. Industrial Processes D-1
Appendix E. Fossil Fuel Industries E-1
Appendix F. Agriculture F-1
Appendix G. Waste Management G-1
Appendix H. Forestry & Land Use H-1
Appendix I. Greenhouse Gases and Global Warming Potential Values: Excerpts from the Inventory of US Greenhouse Emissions and Sinks: 1990-2000 ..... I-1

Acronyms and Key Terms

AEO2009 – EIA's Annual Energy Outlook 2009

bbls – Barrels

BC – Black Carbon*

Bcf – Billion Cubic Feet

BOD – Biochemical Oxygen Demand

Btu – British Thermal Unit

C – Carbon*

$CaCO_3$ – Calcium Carbonate

CAFE - Corporate Average Fuel Economy

CAR - Climate Action Reserve

CCS – Center for Climate Strategies

CFCs – Chlorofluorocarbons*

CH_4 – Methane*

CO – Carbon Monoxide*

CO_2 – Carbon Dioxide*

CO_2e – Carbon Dioxide equivalent*

CRP – Federal Conservation Reserve Program

DOE – Department of Energy

DOT – Department of Transportation

EC – Elemental Carbon*

EIA – US DOE Energy Information Administration

EIIP – Emission Inventory Improvement Program

EISA - Energy Independence and Security Act

FAA – Federal Aviation Administration

FERC – Federal Energy Regulatory Commission

FHWA – Federal Highway Administration

FIA – Forest Inventory Analysis

Gg – Gigagrams

GHG – Greenhouse Gas*

GWh – Gigawatt-hour

GWP – Global Warming Potential*

H_2O – Water Vapor*

HBFCs – Hydrobromofluorocarbons*

HCFCs – Hydrochlorofluorocarbons*

HFCs – Hydrofluorocarbons*

Histosols - high organic content soils

HWP – Harvested Wood Products

IPCC – Intergovernmental Panel on Climate Change*

KCAPC – Kentucky Climate Action Plan Council

KEEC – Kentucky Energy and Environment Cabinet

km^2 – Square Kilometers

K-nitrogen - Kjeldahl nitrogen

kWh – Kilowatt-hour

KYDEP – Kentucky Department of Environmental Protection

KYTC - Kentucky Transportation Cabinet

LandGEM- Landfill Gas Emissions Model, version 3.02

lb – Pound

LF – Landfill

LFG – Landfill Gas

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

LMOP - US EPA Landfill Methane Outreach Program

LPG – Liquefied Petroleum Gas

Mg – Megagrams

MMBtu – Million British thermal units

MMt – Million Metric tons

$MMtCO_2e$ – Million Metric tons Carbon Dioxide equivalent

MSW – Municipal Solid Waste

Mt – Metric ton (equivalent to 1.102 short tons)

MWh – Megawatt-hour

N – Nitrogen*

$(NH_2)_2CO$ - Urea

NH_3 - Ammonia

N_2O – Nitrous Oxide*

NASS – National Agriculture Statistical Service

NEI – National Emissions Inventory

NEMS – National Energy Modeling System

NF – National Forest

NMVOCs – Nonmethane Volatile Organic Compound*

NO_2 – Nitrogen Dioxide*

NO_x – Nitrogen Oxides*

O_3 – Ozone*

ODS – Ozone-Depleting Substance*

OM – Organic Matter*

OH – Hydroxyl radical*

OPS – Office of Pipeline Safety

PFCs – Perfluorocarbons*

PM – Particulate Matter*

ppb – parts per billion

ppm – parts per million

ppmv – parts per million by volume

PSC – Public Service Commission

RCI – Residential, Commercial, and Industrial

SAR – Second Assessment Report*

SED – State Energy Data

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*

t – metric ton

T&D – Transmission and Distribution

TAR – Third Assessment Report*

TLU – Transportation and Land Use

TWGs – Technical Work Groups

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

VOCs – Volatile Organic Compound*

VS – Volatile Solids

yr – Year

* – See Appendix I for more information

Acknowledgements

We appreciate all of the time and assistance provided by contacts in Kentucky, as well as at federal agencies. Thanks go to in particular the staff at several Kentucky State Agencies for their inputs, in particular the Kentucky Transportation Cabinet, and to Talina Mathews of the Kentucky Energy and Environment Cabinet (KEEC) who provided key guidance for this analytical effort. Thanks also to Michael Gillenwater for directing preparation of Appendix I.

Summary of Findings

Introduction

The Center for Climate Strategies (CCS) prepared this report for the Kentucky Energy and Environment Cabinet (KEEC). The report presents an assessment of the State's greenhouse gas (GHG) emissions and anthropogenic sinks (carbon storage) from 1990 to 2030. The preliminary draft inventory and forecast served as a starting point to assist the State, as well as the Kentucky Climate Action Plan Council (KCAPC) and Technical Work Groups (TWGs), with an initial comprehensive understanding of Kentucky's current and possible future GHG emissions, and thereby informed the identification and analysis of policy options for mitigating GHG emissions.[10] The KCAPC 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 KCAPC.

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

Kentucky's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the period from 1990 to 2030. Historical GHG emission estimates (1990 through 2007)[11] 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 Kentucky-specific data and inputs. The initial reference case projections (2008-2030) are based on a compilation of various projections of electricity generation, fuel use, and other GHG-emitting activities for Kentucky, along with a set of simple, transparent assumptions described in the appendices of this report.

The inventory and projections cover the six gases included in the U.S. 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.[12]

---

[10] "Draft Kentucky Greenhouse Gas Inventory and Reference Case Projections, 1990-2030," prepared by the Center for Climate Strategies for the Kentucky Energy and Environment Cabinet, January 2010.

[11] The last year of available historical data varies by sector; ranging from 2004 to 2008.

[12] 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.

It is important to note that the emissions estimates reflect the *GHG emissions associated with the electricity sources used to meet Kentucky's demands,* corresponding to a consumption-based approach to emissions accounting (see "Approach" section below). Another way to look at electricity emissions is to consider the *GHG emissions produced by electricity generation facilities in the State.* This report covers both methods of accounting for emissions, but for consistency, all total results are reported as *consumption-based.*

Kentucky Greenhouse Gas Emissions: Sources and Trends

Table 1 provides a summary of GHG emissions estimated for Kentucky by sector for the years 1990, 2000, 2005, 2010, 2015, 2020, 2025, and 2030. Details on the methods and data sources used to construct these estimates are provided in the appendices to this report**.** In the sections below, we discuss GHG emission sources (positive, or *gross*, emissions) and sinks (negative emissions) separately in order to identify trends, projections, and uncertainties clearly for each.

This next section of the report provides a summary of the historical emissions (1990 through 2007) followed by a summary of the reference-case projection-year emissions (2008 through 2030) 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. Kentucky Historical and Reference Case GHG Emissions, by Sector[a]

Million Metric Tons CO_2e	1990	2000	2005	2010	2015	2020	2025	2030	Explanatory Notes for Projections
Energy Use (CO_2, CH_4, N_2O)	**121.6**	**149.5**	**165.9**	**173.8**	**187.4**	**199.2**	**212.4**	**225.8**	
Electricity Use (Consumption)	**59.2**	**78.5**	**90.9**	**101.1**	**110.3**	**118.0**	**126.2**	**134.3**	
Electricity Production (in state)	68.5	89.1	98.4	105.4	115.0	123.0	131.5	140.0	
Coal	*68.3*	*88.7*	*93.6*	*101.2*	*110.3*	*118.0*	*126.3*	*134.4*	*See electric sector assumptions*
Natural Gas	*0.016*	*0.31*	*1.64*	*1.89*	*2.07*	*2.23*	*2.28*	*2.39*	*in Appendix A.*
Oil	*0.090*	*0.13*	*3.12*	*2.32*	*2.53*	*2.70*	*2.87*	*3.07*	
Biomass (CH_4 and N_2O)	*0.000*	*0.000*	*0.002*	*0.003*	*0.003*	*0.003*	*0.003*	*0.004*	
MSW/Landfill Gas	*0.000*	*0.000*	*0.036*	*0.057*	*0.062*	*0.066*	*0.071*	*0.076*	
Other Wastes	*0.000*	*0.000*	*0.008*	*0.007*	*0.008*	*0.009*	*0.009*	*0.010*	
Net Imported/Exported Electricity	-9.27	-10.58	-7.51	-4.30	-4.69	-5.01	-5.36	-5.70	Negative values represent net exported electricity
Residential/Commercial/ Industrial (RCI) Fuel Use	**26.7**	**30.4**	**31.2**	**28.3**	**29.1**	**28.8**	**28.5**	**27.7**	
Coal	8.54	5.77	5.88	5.28	5.61	5.56	5.40	5.04	Based on USDOE regional projections
Natural Gas	8.72	11.3	11.2	10.8	10.8	10.8	10.8	10.6	Based on USDOE regional projections
Oil	9.34	13.3	14.0	12.2	12.5	12.4	12.2	11.9	Based on USDOE regional projections
Wood (CH_4 and N_2O)	0.11	0.06	0.10	0.10	0.10	0.11	0.11	0.11	Based on USDOE regional projections
Transportation	**27.2**	**33.2**	**37.3**	**36.8**	**40.9**	**45.5**	**50.8**	**56.9**	
Onroad Gasoline	16.4	19.0	19.2	20.3	22.2	24.2	26.3	28.5	Based on VMT projections from KYTC
Onroad Diesel	5.77	8.90	9.59	10.8	12.7	15.1	18.2	22.0	Based on VMT projections from KYTC
Marine Vessels	1.17	1.35	3.63	1.43	1.50	1.57	1.64	1.70	Based on historical growth
Rail, Natural Gas, LPG, other	1.49	1.28	1.48	2.12	2.13	2.13	2.13	2.13	Based on USDOE regional projections
Jet Fuel and Aviation Gasoline	2.32	2.68	3.35	2.21	2.39	2.48	2.56	2.62	Based on FAA projected operations and AEO2009 efficiency gains
Fossil Fuel Industry	**8.51**	**7.33**	**6.50**	**7.46**	**7.05**	**6.91**	**6.91**	**6.90**	
Natural Gas Industry	4.00	3.59	3.43	3.95	4.06	4.17	4.30	4.47	
Oil Industry	0.077	0.058	0.047	0.052	0.057	0.062	0.069	0.076	
Coal Mining (CH_4)	4.43	3.68	3.03	3.46	2.93	2.67	2.53	2.35	Used AEO Central Appalachia coal production projections
Industrial Processes	**4.75**	**5.65**	**6.52**	**7.75**	**8.50**	**9.35**	**10.70**	**12.55**	
Cement Manufacture (CO_2)	0.37	0.35	0.54	0.53	0.59	0.64	0.69	0.73	Based on Portland Cement Association's Cement Outlook 2008.
Lime Manufacture (CO_2)	0.46	0.48	0.72	0.77	0.83	0.88	0.94	1.01	Based on analysis of historical growth
Limestone and Dolomite Use (CO_2)	0.31	0.28	0.32	1.08	1.08	1.08	1.08	1.08	No growth assumed due to conflicting historical data
Soda Ash (CO_2)	0.040	0.038	0.036	0.034	0.033	0.031	0.029	0.029	Based on employment

Million Metric Tons CO_2e	1990	2000	2005	2010	2015	2020	2025	2030	Explanatory Notes for Projections
									projections from Workforce KY
Iron & Steel (CO_2)	2.43	2.57	2.62	2.70	2.70	2.70	2.70	2.70	No growth assumed
Ammonia and Urea (CO_2)	0.011	0.010	0.007	0.008	0.008	0.008	0.008	0.008	Based on analysis of historical growth
ODS Substitutes (HFC, PFC)	0.005	1.02	1.48	1.90	2.56	3.32	4.59	6.35	Based on national projections (USEPA)
Electric Power T&D (SF_6)	0.60	0.34	0.34	0.31	0.29	0.28	0.27	0.26	Based on national projections (USEPA)
Aluminum Production (PFC)	0.53	0.57	0.46	0.42	0.41	0.40	0.40	0.39	Based on national projections (USEPA)
Waste Management	**2.18**	**2.13**	**2.16**	**2.33**	**1.75**	**1.87**	**1.98**	**2.10**	
Waste Combustion	0.11	0.17	0.20	0.21	0.21	0.21	0.21	0.21	Used growth rate calculated for 1995-2002 emissions growth
Landfills	1.71	1.56	1.54	1.68	1.09	1.18	1.27	1.37	Based on historical KY landfill emplacement; Used landfill disposal projections from waste management profile to estimate future emissions
Wastewater Management	0.36	0.40	0.41	0.44	0.46	0.48	0.50	0.52	Used growth rate calculated for 1990-2005 emissions growth
Agriculture	**7.89**	**6.96**	**7.88**	**7.05**	**6.81**	**6.65**	**6.56**	**6.59**	
Enteric Fermentation	3.25	2.91	3.12	3.14	3.06	3.02	3.04	3.16	Based on projected livestock population
Manure Management	0.48	0.48	0.53	0.45	0.42	0.40	0.40	0.41	Based on projected livestock population
Agricultural Soils	3.67	3.31	4.08	3.35	3.26	3.17	3.07	2.98	Used historical growth rate
Agricultural Burning	0.014	0.017	0.018	0.019	0.020	0.021	0.022	0.023	Used historical growth rate
Agricultural Liming	0.48	0.24	0.13	0.088	0.057	0.037	0.024	0.016	Based on historical agricultural liming estimate
Forest Wildfires (N_20 and CH_4)	**0.29**	**1.72**	**0.66**	**0.68**	**0.68**	**0.68**	**0.68**	**0.68**	Based on average of historical emissions
Total Gross Emissions (Consumption Basis, Excludes Sinks)	**136.7**	**165.9**	**183.1**	**191.6**	**205.1**	**217.7**	**232.3**	**247.7**	
increase relative to 1990		*21%*	*34%*	*40%*	*50%*	*59%*	*70%*	*81%*	
Emissions Sinks	**-9.94**	**-7.77**	**-7.57**	**-7.57**	**-7.57**	**-7.57**	**-7.57**	**-7.57**	
Forested Landscape	-4.71	-4.71	-4.71	-4.71	-4.71	-4.71	-4.71	-4.71	Held at 2005 levels
Urban Forestry and Land Use	-4.09	-1.92	-1.73	-1.73	-1.73	-1.73	-1.73	-1.73	Extrapolated based on historical data
Agricultural Soils (cultivation practices)	-1.14	-1.14	-1.14	-1.14	-1.14	-1.14	-1.14	-1.14	Held at 1997 levels based on most recent data available
Net Emissions (Includes Sinks)	**126.8**	**158.2**	**175.5**	**184.0**	**197.6**	**210.1**	**224.8**	**240.2**	
increase relative to 1990		*25%*	*38%*	*45%*	*56%*	*66%*	*77%*	*89%*	

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

Historical Emissions

Overview

In 2005, activities in Kentucky accounted for approximately 183 million metric tons (MMt) of *gross*[13] CO_2e emissions (consumption basis) in 2005, an amount equal to about 2.6% of total U.S. gross GHG emissions (based on 2005 U.S. data).[14] Kentucky's gross GHG emissions are rising at a faster rate than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). Kentucky's gross GHG emissions increased by about 34% from 1990 to 2005, while national emissions rose by 16% from 1990 to 2005. The growth in Kentucky's emissions from 1990 to 2005 is primarily associated with the electricity consumption and transportation sectors.

Figure 1 illustrates the State's emissions per capita and per unit of economic output.[15] On a per capita basis, Kentucky residents emitted about 37 metric tons (t) of gross CO_2e in 1990, much higher than the 1990 national per capita emissions of 25 tCO_2e. Unlike the national per capita emissions which remained nearly constant from 1990 to 2005, the Kentucky per capita emissions increased by 19% from 1990 to 2005. The electricity supply sector shows the greatest difference between per capita emissions in Kentucky and the US, at 22 tCO_2e per capita in Kentucky for this sector compared with 8 tCO_2e per capita nationally. This is because the electricity consumed in Kentucky relies on a high amount of coal in the generation fuel mix relative to the US as a whole; about 90% for Kentucky versus 50% for the US in 2005. The use of coal has led to low electricity rates in Kentucky compared to the rest of the country, which has allowed energy-intensive industries to flourish in the state, as acknowledged in Kentucky's Energy Plan.[16] Like the nation as a whole, Kentucky's economic growth exceeded emissions growth throughout the 1990-2005 period (leading to declining estimates of GHG emissions per unit of state product). From 1990 to 2005, emissions per unit of gross product dropped by 11% in Kentucky and by about 26% nationally.[17]

[13] Excluding GHG emissions removed due to forestry and other land uses and excluding GHG emissions associated with exported electricity.

[14] 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).

[15] Historical Kentucky population statistics are compiled by Kentucky State Data Center from US Census Bureau data, are available at http://ksdc.louisville.edu/kpr/popest/est.htm.. Kentucky population projections through 2050 are available from the same source at http://ksdc.louisville.edu/kpr/pro/projections.htm.

[16] *Intelligent Energy Choices for Kentucky's Future: Kentucky's 7-Point Strategy for Energy Independence,* Governor Steven L. Beshear, November 2008.

[17] 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 *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).

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

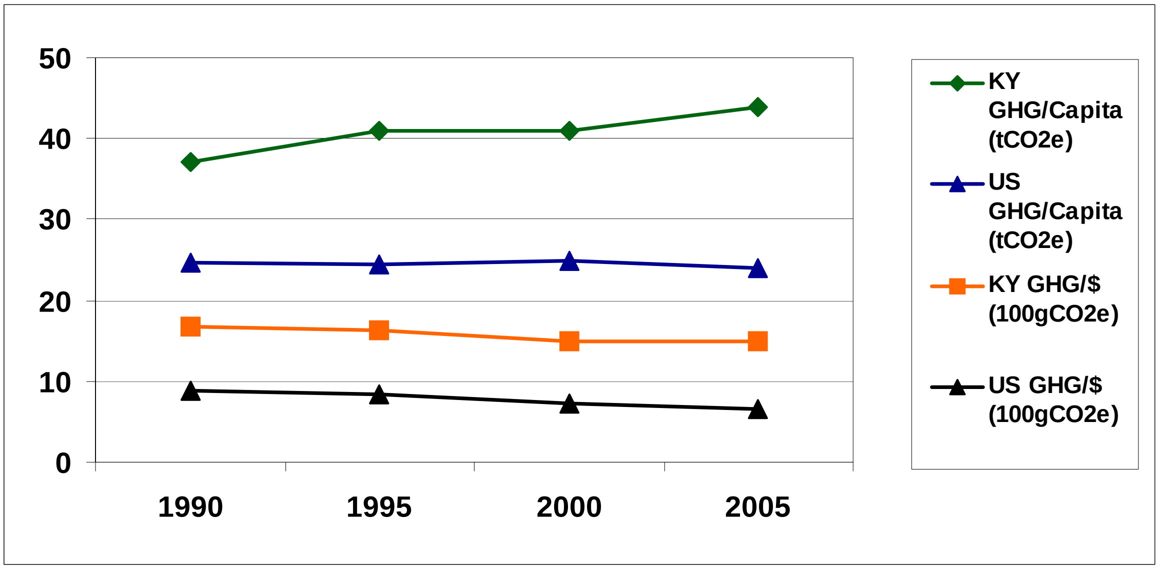


Figure 2 compares the contribution of gross GHG emissions by sector estimated for Kentucky to emissions for the U.S. for year 2005. Principal sources of Kentucky's GHG emissions are electricity consumption; transportation; and residential, commercial, and industrial (RCI) fuel use accounting for 50%, 20%, and 17% of Kentucky's gross GHG emissions in 2005, respectively.

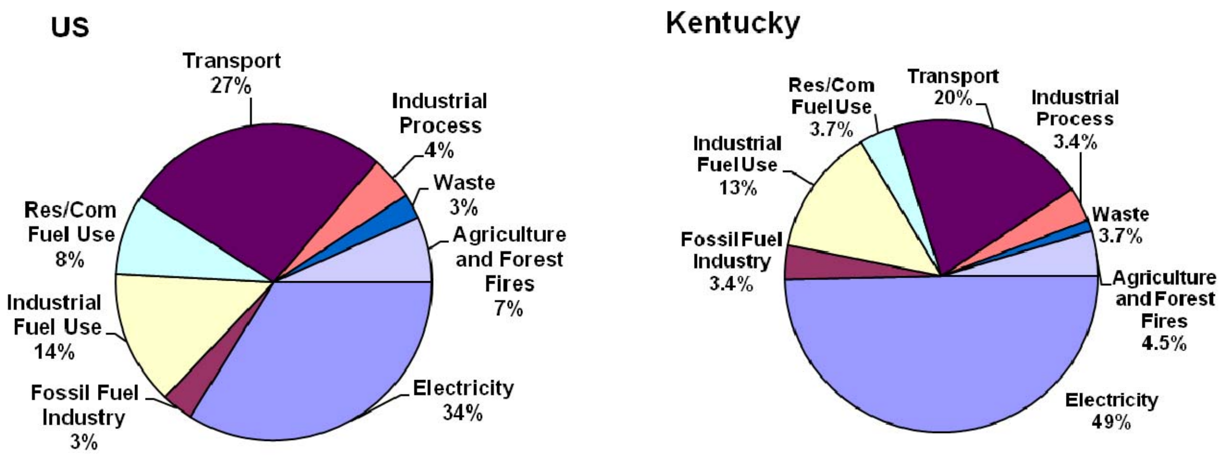
The next largest contributor of gross GHG emissions in 2005 is the agriculture and forest fires sector, accounting for about 4.7% of the 2005 gross GHG emissions in Kentucky. The agriculture sector includes emissions from enteric fermentation, manure management, agricultural soils, and agricultural burning. Forest fires include forest wildfires and prescribed burning.

The fossil fuel industries and industrial processes each account for about 3.6% of Kentucky's gross GHG emissions in 2005. The fossil fuel industry sector includes GHG emissions associated with natural gas production, processing, T&D, and pipeline fuel use, as well as with oil production and refining and coal mining. Industrial process emissions are dominated by the use of HFCs as substitutes for ozone-depleting chlorofluorocarbons (CFCs), which are rising rapidly through the historical and projection periods.[18] Other industrial process emissions result from CO_2 released during iron and steel, cement, and lime, and manufacturing; ammonia production; and soda ash, limestone, dolomite, and urea use. In addition, SF_6 is released during the use of electric power transmission and distribution (T&D) equipment, while aluminum production is responsible for the release of PFCs.

[18] 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.

The waste management sector accounts for about 1.2% of Kentucky's gross GHG emissions in 2005. The waste management sector is dominated by CH_4 emissions from landfills, but also includes emissions from waste combustion and wastewater management.

Figure 2. Gross GHG Emissions by Sector, 2005, Kentucky and US



Notes: Res/Com = residential and commercial fuel use sectors; emissions for the residential, commercial, and industrial fuel use sectors are associated with the direct use of fuels (natural gas, petroleum, coal, and wood) to provide space heating, water heating, process heating, cooking, and other energy end-uses. The commercial sector accounts for emissions associated with the direct use of fuels by, for example, hospitals, schools, government buildings (local, county, and state), and other commercial establishments. The industrial processes sector accounts for emissions associated with manufacturing and excludes emissions included in the industrial fuel use sector. The transportation sector accounts for emissions associated with fuel consumption by all on-road and non-highway vehicles. Non-highway vehicles include jet aircraft, gasoline-fueled piston aircraft, railway locomotives, boats, and ships. Emissions from non-highway agricultural and construction equipment are included in the industrial sector. Electricity = electricity generation sector emissions on a consumption basis (including emissions associated with electricity imported from outside of Kentucky and excluding emissions associated with electricity exported from Kentucky to other states).

Estimates of carbon sinks in Kentucky include urban forests, land use changes, and agricultural soil cultivation practices. Note that forest wildfires and prescribed burning are sources of GHG emissions are were included with the agriculture sector in Figure 2. Forestry activities and agricultural soil cultivation practices in Kentucky are estimated to be net sinks of GHG emissions in all years. The current estimates indicate that about 7.6 $MMtCO_2e$ were stored in Kentucky biomass in 2005. This leads to *net* emissions of 176 $MMtCO_2e$ in Kentucky in 2005, an amount equal to 2.8% of total US net GHG emissions.

A Closer Look at the Three Major Sources: Electricity Consumption, Transportation, and RCI Fuel Use

Electricity Consumption Sector

Electricity generation in Kentucky is dominated by steam units, which are primarily fueled by coal. Throughout the historical and forecasted periods, Kentucky power plant generation exceeds the electricity consumed in the state. The remaining electricity generated in Kentucky is assumed to be exported to neighboring regions. As shown in Figure 2, electricity consumption accounted for about 50% of Kentucky's gross GHG emissions in 2005 (about 91 $MMtCO_2e$), which was higher than the national average share of emissions from electricity consumption (34%).[19] The GHG emissions associated with Kentucky's electricity consumption sector increased by about 32 $MMtCO_2e$ between 1990 and 2005, accounting for 69% of the state's growth in gross GHG emissions in this time period.

In 2005, emissions associated with Kentucky's electricity consumption (91 $MMtCO_2e$) were about 7.5 $MMtCO_2e$ lower than those associated with electricity production (98 $MMtCO_2e$). The higher level for production-based emissions reflects GHG emissions associated with net exports of electricity to other states to neighboring regions.[20] Projections of electricity sales for 2008 through 2030 indicate that Kentucky will remain a net exporter of electricity. Emissions from net electricity exports are projected to increase over the 2008-2030 period, from 4.1 $MMtCO_2e$ in 2008 to 5.7 $MMtCO_2e$ in 2030. Overall, the reference case projection indicates that production-based emissions (associated with electricity generated in-state) will increase by about 42 $MMtCO_2e$ from 2005 levels, and consumption-based emissions (associated with electricity consumed in-state) will increase by about 43 $MMtCO_2e$ from 2005 to 2030.

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

Transportation Sector

As shown in Figure 2, the transportation sector accounted for about 20% of Kentucky's gross GHG emissions in 2005 (about 37 $MMtCO_2e$), which was lower than the national average share of emissions from transportation fuel consumption (27%). The GHG emissions associated with Kentucky's transportation sector increased by 10 $MMtCO_2e$ between 1990 and 2005, accounting for about 22% of the State's net growth in gross GHG emissions in this time period.

From 1990 through 2005, Kentucky's GHG emissions from transportation fuel use have risen steadily at an average rate of about 2.1% annually. In 2005, onroad gasoline vehicles accounted for about 52% of transportation GHG emissions. Onroad diesel vehicles accounted for another 26% of transportation emissions, and marine vessels for roughly 10%. Air travel, rail, and other sources (natural gas- and liquefied petroleum gas- (LPG) fueled-vehicles used in transport applications) accounted for the remaining 13% of transportation emissions. GHG emissions from onroad gasoline use grew 17% between 1990 and 2005. Meanwhile, GHG emissions from onroad diesel use rose 66% during that period, suggesting rapid growth in freight movement within or across the State. Emissions associated with marine fuel use increased by about 211% from 1990 to 2005, while emissions associated with aviation fuel consumption increased by 45% in the same period.

During the period from 2005 to 2030, emissions from transportation fuels are projected to rise at a rate of 1.7% per year. This leads to an increase of 20 $MMtCO_2e$ in transportation emissions

[19] 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 even less.

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

from 2005 to 2030. The largest percentage increase in emissions over this time period is seen in onroad diesel fuel consumption, which is projected to increase by 129% from 2005 to 2030.

Residential, Commercial, and Industrial Fuel Use Sectors

Activities in the RCI[21] 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 17% (about 31 $MMtCO_2e$) of Kentucky's gross GHG emissions, below the RCI sector contribution for the nation (22%).

In 2005, the residential sector's share of total RCI emissions from direct fuel use was 13% (3.9 $MMtCO_2e$), the commercial sector accounted for 10% (3.1 $MMtCO_2e$), and the industrial sector's share of total RCI emissions from direct fuel use was 78% (24 $MMtCO_2e$). Overall, emissions for the RCI sectors (excluding those associated with electricity consumption) are expected to decrease by 11% between 2005 and 2030 to 28 $MMtCO_2e$. Emissions from the residential sector are projected to increase slightly by 0.8% from 2005 to 2030. In contrast, emissions from the commercial and industrial sectors are expected to decrease by 12% and 13%, respectively, from 2005 to 2030.

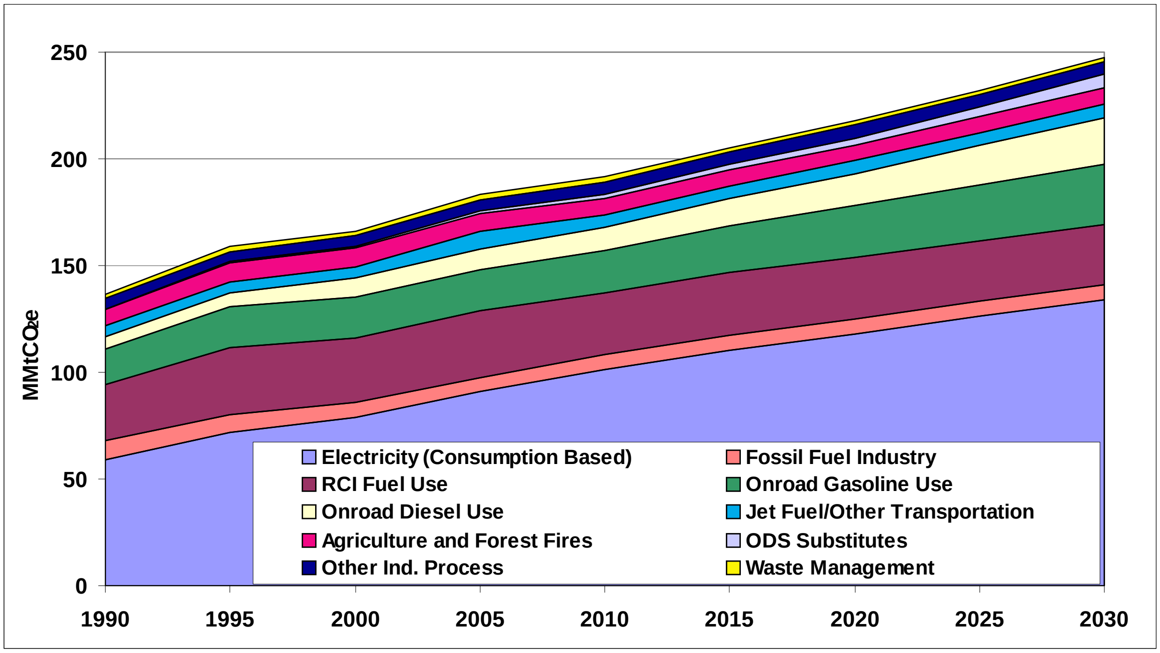
Reference Case Projections (Business as Usual)

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 2030. As illustrated in Figure 3 and shown numerically in Table 1, under the reference case projections, Kentucky gross GHG emissions continue to grow steadily, climbing to about 248 $MMtCO_2e$ by 2030, 81% above 1990 levels. This equates to an annual growth rate of 1.2% per year from 2005 to 2030. Relative to 2005, the share of emissions associated with electricity consumption, transportation, and industrial processes increase to 54%, 23%, and 5%, respectively, in 2030. The share of emissions from the RCI fuel use, fossil fuel industries, waste management, and agriculture sectors all decrease by 2030, relative to 2005, to 11%, 3%, 0.8%, and 3%, respectively.

The electricity consumption sector is projected to be the largest contributor to future emissions growth, followed by emissions from transportation, ODS substitutes (HFCs), other industrial products, and the fossil fuel industry, as shown in Figure 4. Table 2 summarizes the growth rates that drive the growth in the Kentucky reference case projections as well as the sources of these data.

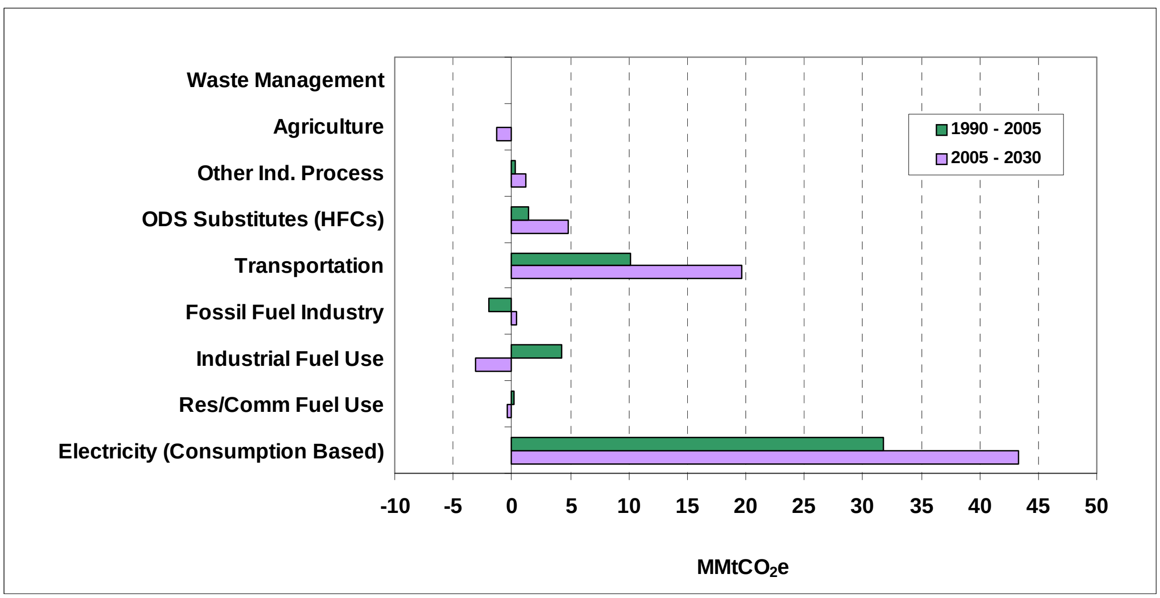
[21] The industrial sector includes emissions associated with agricultural energy use and fuel used by the fossil fuel production industry.

Figure 3. Kentucky Gross GHG Emissions by Sector, 1990-2030: 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 Kentucky, 1990-2030: Historical and 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 2. Key Annual Growth Rates for Kentucky, Historical and Projected

	1990-2008	2008-2030	Sources
Population	0.82%	0.72%	Historical Kentucky population statistics are compiled by Kentucky State Data Center from US Census Bureau data, are available at http://ksdc.louisville.edu/kpr/popest/est.htm. Kentucky population projections through 2050 are available from the same source at http://ksdc.louisville.edu/kpr/pro/projections.htm
Electricity Sales	2.4%	1.5%	For 1990-2008, annual growth rate in total electricity sales for all sectors combined in Kentucky calculated from EIA State Electricity Profiles (Table 8) available from http://www.eia.doe.gov/cneaf/electricity/page/sales_revenue.xls
Vehicle Miles Traveled	1.9%	2.2%	Based on historical VMT and projected VMT growth rates provided by Kentucky Transportation Cabinet

KCAPC Revisions

The following identifies the revisions that the Kentucky Climate Action Plan Council made to the inventory and reference case projections, thus explaining the differences between this report and the initial assessment completed in January 2010:

Electric Supply: There were several major changes from the initial version of the ES GHG I&F. First, the electricity sales forecast was changed from reliance on the AEO2009 to that of the most recent Kentucky utility forecasts provided to the Kentucky Public Service Commission (PSC). On average, this resulted in an increase in the electricity sales growth rate from about 0.5%/year to about 1.5%/year over the 2007 to 2030 period. Second, the amount of on-site electricity use was changed from reliance on the low levels assumed in AEO2009 to higher levels more consistent with Kentucky experience and industry standards. On average, this resulted in an increase in parasitic load from about 0.5% of total electricity production to 7% for coal stations and 2% for natural gas-fired and oil-fired power stations. Third, there were several typos in the original report denoting "imports"; these have since been corrected to "exports". Finally, the uncertainty section was revised to address the issue of KY-specific versus regional assumptions.

RCI Fuel Use: The changes discussed above for the electricity supply sector affecting the changes in the electricity sales forecast also have an impact on how the electricity emissions are allocated among the RCI sectors. This is reflected in Appendix B. In addition, a figure was added showing the breakout of RCI emissions by RCI sector and fuel type.

Transportation: KCAPC did not recommend any changes to the reference case transportation projections at this time. However, the KCAPC did recommend reviewing alternative VMT projections. In response to this request, Appendix C of this report presents the Kentucky transportation emissions under an alternative VMT growth scenario in which VMT growth follows projected population growth. Transportation emissions in this front section of the I&F report are unchanged from those reported in the draft I&F report.

Waste Sector:

- The landfill emissions were revised based on waste emplacement, flaring, and landfill-gas-to-energy data from Solid Waste Division.

- There is no controlled waste combustion in state, so default emissions for that category were removed.
- No industrial wastewater data available for key industries such as bourbon production so industrial wastewater emissions numbers remained unchanged.

Reference Case Projections with Recent Actions

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 development of the inventory and forecast, sufficient information was identified (e.g., implementation schedules) to estimate GHG emission reductions associated with implementing the Corporate Average Fuel Economy (CAFE) requirements in Kentucky. Further reductions in transportation emissions will be achieved through the Obama plan for adopting the California vehicle CO_2 emission standards nationwide.

The GHG emission reductions projected to be achieved by this recent federal action are summarized in Table 3. This table shows a total reduction of about 6.2 $MMtCO_2e$ in 2030 from the business-as-usual reference case emissions, or a 2.5% reduction from the business-as-usual emissions in 2030 for all sectors combined.

It is anticipated that the KCAPC process will result in identifying additional federal and Kentucky-specific recent actions that will be quantified throughout the KCAPC process.

The following provides a brief summary of the component of the EISA that was analyzed as a recent federal action.

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.

Table 3. Emission Reduction Estimates Associated with the Effect of Recent Actions in Kentucky (Consumption-Basis, Gross Emissions)

Sector / Recent Action	GHG Reductions ($MMtCO_2e$)		GHG Emissions ($MMtCO_2e$) Business as Usual	GHG Emissions ($MMtCO_2e$) With Recent Actions
	2020	2030	2030	2030
Transportation and Land Use (TLU)				
Federal Corporate Average Fuel Economy (CAFE) Requirements plus California CO_2 Vehicle Standards	4.02	6.23	56.9	50.7
Total (All Sectors)			**247.7**	**241.5**

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 Kentucky's future GHG emissions (See Table 2 and Figure 4). These growth rates are driven by uncertain economic, demographic and land use trends (including growth patterns and transportation system impacts), all of which deserve closer review and discussion.

Approach

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

General Methodology

We prepared this analysis in consultation with Kentucky agencies, in particular, with the staff at KEEC. 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[22] and its guidelines for States.[23] These inventory guidelines were developed based on the guidelines from the IPCC, the international organization responsible for developing coordinated methods for national GHG inventories.[24] The inventory methods provide flexibility to account for local conditions. The key sources of activity and projection data used are shown in Table 4. Table 4 also provides the descriptions of the data provided by each source and the uses of each data set in this analysis.

General Principles and Guidelines

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

- **Transparency:** We report data sources, methods, and key assumptions to allow open review and opportunities for additional revisions later based on input from others. In addition, we report key uncertainties where they exist.

- **Consistency:** To the extent possible, the inventory and projections were designed to be externally consistent with current or likely future systems for State and national GHG emission reporting. We have used the EPA tools for State inventories and projections as a starting point. These initial estimates were then augmented and/or revised as needed to conform with State-based inventory and base-case projection needs. For consistency in making reference case projections, we define reference case actions for the purposes of projections as those *currently in place or reasonably expected over the time period of analysis*.

- **Priority of Existing State and Local Data Sources:** In gathering data and in cases where data sources conflicted, we placed highest priority on local and State data and analyses, followed by regional sources, with national data or simplified assumptions such as constant linear extrapolation of trends used as defaults where necessary.

- **Priority of Significant Emissions Sources:** In general, activities with relatively small emissions levels may not be reported with the same level of detail as other activities.

- **Comprehensive Coverage of Gases, Sectors, State Activities, and Time Periods:** This analysis aims to comprehensively cover GHG emissions associated with activities in Kentucky. 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 2007), with projections to 2010, 2015, 2020, 2025, and 2030.

[22] *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).

[23] http://yosemite.epa.gov/oar/globalwarming.nsf/content/EmissionsStateInventoryGuidance.html.

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

- **Use of Consumption-Based Emissions Estimates:** To the extent possible, we estimated emissions that are caused by activities that occur in Kentucky. For example, we reported emissions associated with the electricity consumed in Kentucky. 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.

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 Kentucky. This entails accounting for the electricity sources used by Kentucky 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 Kentucky, 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.

Table 4. Key Sources for Kentucky 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. US EPA SIT contains default data for each State for most of the information required for an inventory for years from 1990 to 2007. 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 1990-2007 from RCI fuel combustion, transportation, industrial processes, agriculture and forestry, and waste. We use SIT emission factors (CO_2, CH_4, and N_2O per British thermal unit (Btu) consumed) to calculate energy use emissions.
US DOE Energy Information Administration (EIA) State Energy Data (SED)	EIA SED provides energy use data in each State, annually to 2007 for all RCI sectors and fuels	EIA SED is the source for most energy use data. Emission factors from US EPA SIT are used to calculate energy-related emissions.
EIA State Annual Electric Utility Data — EIA 906/920 Database	EIA provides information on the electric power industry generation by primary energy source for 1990 – 2007.	EIA 906/920 Database was used to determine the mix of in-state electricity generation by fuel. Electricity sales were projected off of 2007 sales provided in this reference.
EIA State Electricity Profiles	EIA provides information on electric power industry capability, generation, retail sales, and average retail price for 1990 through 2007 in this database.	Kentucky Electricity Profiles were used to determine the total electricity sales by sector for 1990-2007.

Source	Information provided	Use of Information in this Analysis
EIA AEO2009	EIA AEO2009 projects energy supply and demand for the US from 2006 to 2030. Energy production and consumption are estimated on a regional basis.	EIA AEO2009 is used to project electricity generation by fuel and changes in fuel use by the RCI sectors.
Kentucky Transportation Cabinet	Growth rates for projected vehicle miles traveled (VMT).	The growth rates were used to project onroad VMT.
US Department of Transportation (DOT), Office of Pipeline Safety (OPS)	Natural gas transmission pipeline mileage, distribution pipeline mileage, and number of services for 1990–2007.	OPS data entered into SIT to calculate historical emissions. Transmission and distribution pipeline emissions projected based on analysis of historical data.
EIA Natural Gas Navigator	EIA provides the number of gas and gas condensate wells and amount of gas flared and vented in Kentucky for 1990-2007.	Natural Gas Navigator data entered into SIT to calculate historical emissions. Gas well emissions and gas flaring emissions projected based on analysis of historical data.
PennWell Corporation Oil and Gas Journal	PennWell reports the number of gas processing plants in Kentucky for 1990-2007.	PennWell data entered into SIT to calculate historical emissions. Emissions projected based on analysis of historical data.
EIA Petroleum Navigator	Volume of crude oil production in Kentucky, regional crude oil input, regional refining capacity, and Kentucky's refining capacity for 1990-2007	EIA data entered into SIT to calculate historical emissions. Oil production emissions and oil refining emissions projected based on analysis of historical data.
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.

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 1990-2007 period associated with the generation of electricity to meet electricity demand in Kentucky. It also describes the data sources, key assumptions, and methodology used to develop a reference case projection (forecast) of GHG emissions from the Base Year of 2007 over the 2008-2030 period associated with meeting electricity demand in the state. Specifically, the following topics are covered in this Appendix:

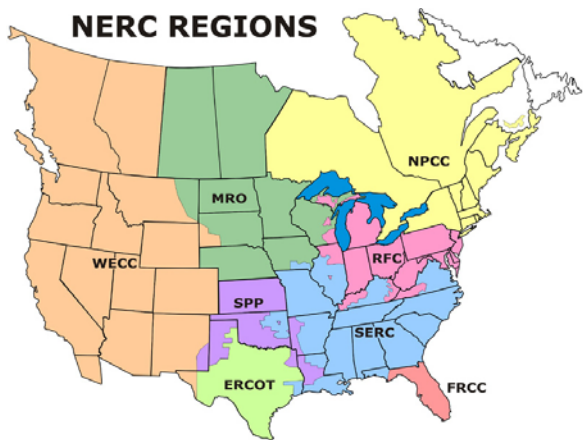
- *Data Sources:* This section provides an overview of the data sources that were used to develop the inventory and forecast, including publicly accessible websites where this information can be obtained and verified.
- *Greenhouse Gas Inventory methodology:* This section provides an overview of the methodological approach used to develop the Kentucky 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 Kentucky GHG forecast for the electric supply sector.
- *Greenhouse Gas Inventory Results:* This section provides an overview of key results of the Kentucky GHG inventory for the electric supply sector.
- *Greenhouse Gas Forecast Results:* This section provides an overview of key results of the Kentucky GHG forecast for the electric supply sector.

Data Sources

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

- *2007 EIA-906/920 Monthly Time Series Data.* This is a database file available from the Energy Information Administration (EIA) of the United States (US) Department of Energy (DOE). The information in the database is based on information collected from utilities in Forms EIA-906/920 and EIA-860 for the forecast Base Year of 2007. Data were extracted for Kentucky. Data from these forms provide, among other things, fuel consumption and net generation in power stations located in Kentucky for 2007 by plant type. This information can be accessed from http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html.
- *Annual Energy Outlook 2009.* This is an output of an EIA analysis using the National Energy Modeling System (NEMS), a model that forecasts electric expansion/electricity demand in the US. In particular, regional outputs for the East Central Area Reliability Coordination Agreement (ECAR) region and the Southeastern Reliability Council (SERC) region were

used (see map). For the purposes of the analysis, 75% of the state was assumed to be within SERC and the balance within ECAR. The ECAR and SERC results include forecasts of transmission and distribution losses through the year 2030. 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.



- *Monthly Cost and Quality of Fuels for Electric Plants.* This information is available from the Federal Energy Regulatory Commission (FERC). The database relies on information collected from utilities in the FERC-423 form. It was used to determine the share of coal type (i.e., whether bituminous or sub-bituminous) as well as the coal quantity consumed in Kentucky power plants over the period 1990-2007. It was also used to determine the share of oil type (i.e., whether fuel oil #2, #4, #5, or #6) as well as the oil quantity consumed in Kentucky power plants over the period 1990-2007. It can be accessed directly from http://www.eia.doe.gov/cneaf/electricity/page/ferc423.html.
- *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.
- *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 2007. 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 2007. 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 2007. 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 2007. 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 2007. It can be accessed directly from http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea_sum.html
- *Energy conversion factors.* This is based on Table A-31 of Appendix 2 in the USEPA's 2009 GHG Inventory for the US. The table is entitled "Key assumptions for estimating CO2 emissions". This information can be accessed directly from the following website: http://www.epa.gov/climatechange/emissions/downloads09/Annex2.pdf.
- *Fuel combustion oxidation factors.* This is based on the IPCC's assumed default values. This information can be accessed directly from: http://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch1wb1.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. 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/publications_and_data/publications_and_data_reports.htm.

Greenhouse Gas Inventory Methodology

The GHG inventory period was considered to be 1990-2007. The methodology used to develop the Kentucky 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. It involved applying GHG emission factors to annual fuel consumed in KY for the production of electricity at utility/non-utility and combined heat and power facilities.

The GHG inventory was estimated on both a production and consumption basis. The production estimate involved tallying up the GHG emissions associated with the operation of power plants physically located in Kentucky, regardless of ownership. The consumption estimate involved tallying up the GHG emissions associated with consumption of electricity in Kentucky, regardless of where the electricity was produced.

Also, the GHG inventory was 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 as these are accounted for in other parts of the overall state GHG inventory.

The assumptions and calculation process is briefly summarized below in the bullets below. Key Outputs for the 2007 Base Year are summarized in Table A1 and Figure A1.

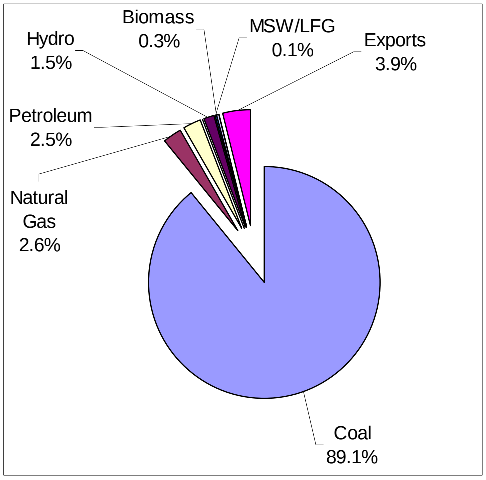
- Determine gross annual primary energy consumption by Kentucky power and CHP stations by plant and fuel type. For coal, this involved determining the coal quality shares (i.e., share of bituminous or sub-bituminous); for oil, this involved determining the oil quality shares (i.e., share of fuel oil #2, #4, #5, and #6 used).
- Determine gross annual generation associated with net power exports. This is the amount of electric generation associated with out-of-state demand.
- Multiply gross annual primary energy consumption by Kentucky power and CHP stations by the appropriate CO_2e emission factors. This provides an estimate of Kentucky GHG inventory on a production basis.
- Multiply annual gross generation associated with net power exports by the weighted average carbon emission intensity (in units of metric tons of CO_2e per megawatt-hour [tCO_2e/MWh]) of the KY power supply sector. This provides an estimate of GHG emissions produced in-state but associated with out-of-state electricity demand.
- Subtract the emissions associated with net power exports from the production-based emissions. This provides an estimate of the GHG inventory on a consumption basis.

Table A1. Summary of Kentucky Electric Generator Characteristics for the 2007 Base Year (utilities and non-utilities only)

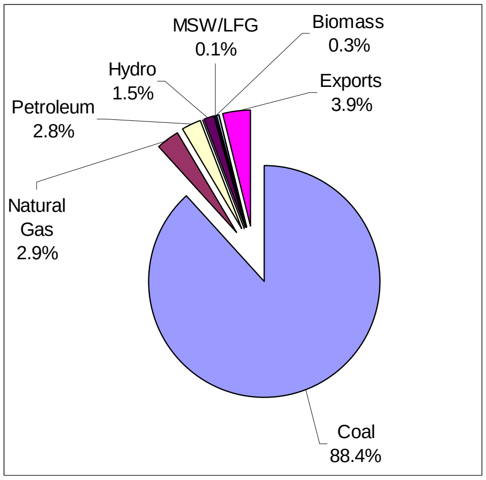
Fuel	Gross Generation (GWh)	Net Generation (GWh)	Fuel use (Trillion Btu)	Heat rate (Btu/KWh)	Emissions (MtCO_2e)
Coal	97,294	90,483	973	9,998	90.38
Natural Gas	1,632	1,600	20	12,190	1.07
Other Gases	5	5	0	NA	0.00
Petroleum	2,848	2,791	32	11,382	2.36
Nuclear	0	0	0	NA	0.00
Hydroelectric	1,669	1,669	17	10,320	0.00
Geothermal	0	0	0	NA	0.00
Solar/PV	0	0	0	NA	0.00
Wind	0	0	0	NA	0.00
MSW Landfill gas	93	93	1	10,500	0.05
Biomass	0	0	0	NA	0.00
Other wastes	16	16	0	10,500	0.01
Pumped storage	0	0	0	NA	0.00
Exports	4,220	3,939	43	10,076	3.83
Imports	0	0	0	NA	0
Total (production-based)	***103,557***	***96,656***	***1,043***		***93.86***
Total (consumption-based)	***99,336***	***92,718***	***1,001***		***90.04***

Figure A1. Total KY Generation, energy and CO2e emissions (electric generators and CHP) – 2007 Base Year

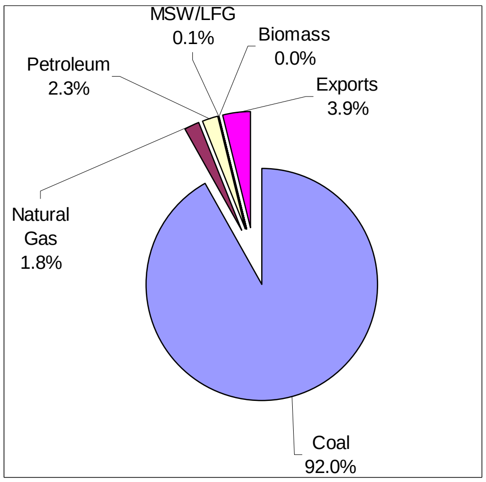
a. Gross Generation (109,740 GWh)



b. Primary Energy (1,115 Trillion Btu)



c. Emissions (99.60 MMtCO2e)



Greenhouse Gas Forecast Methodology – Reference Case

The GHG forecast period was considered to be 2007 – 2030, with 2007 as the historical Base Year. Ideally, constructing a GHG forecast should be based on detailed system planning information for KY over the entire planning period, including information such as projected sales, gross in-state generation, supply-side efficiency improvements, planned capacity additions and retirements by plant type/vintage, and changes over time regarding losses associated with on-site use and transmission and distribution (T&D).

While some of this information was available in Kentucky, some key data were not available at the time the forecast was prepared. Therefore, it was necessary to use the data that was available and pose working assumptions for data that was unavailable. For the period 2008 through and including 2030, these assumptions, together with the methodological steps used for forecasting CO_2e emissions, are described below. Key Outputs are summarized in Table A2.

Total electricity sales. Growth rates were based on the Total Energy Forecast for PSC Regulated Electric G&T Utilities as obtained from the KY PSC and were assumed as outlined below:

- 2008 – 2012: 2.62%/year
- 2012 – 2016: 1.13%/year
- 2016 – 2020: 1.32%/year
- 2020 – 2024: 1.32%/year
- 2024 – 2028: 1.30%/year
- 2028 – 2030: 1.45%/year

Coal quality. It was assumed that the coal quality used in Kentucky power stations (i.e., share of anthracite, bituminous, lignite, sub-bituminous, and coal wastes used) was the same as the Base Year.

Gross generation. Gross generation was calculated using the following assumptions:

- The growth rate for gross generation on a production basis (i.e., net generation plus on-site electricity use for all in-state units) was assumed to grow at the same rate as in-state sales.
- The resource mix remained the same in all forecast years as in the Base Year.
- Transmission and distribution (T&D) losses (in %) were assumed to be equal to the SERC/ECAR average as reported in AEO2009.
- Gross generation on a consumption basis was calculated on a pro rata basis after accounting for T&D losses and plant-specific on-site losses.
- Gross generation associated with exports was calculated as the difference between the production and consumption estimates.

Combustion efficiency. Improvements of fuel-specific heat rates were assumed to be consistent with trends in the SERC/ECAR average as reported in AEO2009.

Primary energy use. Primary energy use was calculated using the following assumptions:

- Primary energy use by fuel type was calculated as the product of fuel-specific gross generation and fuel-specific heat rate.

- The production-based estimate of primary energy use was calculated as the sum of the fuel-specific calculations above
- The consumption-based estimate of primary energy use was calculated by multiplying the system heat rate by estimate of consumption-based gross generation.
- The primary energy use associated with exports was calculated as the difference between the production and consumption based estimates.

Carbon dioxide-equivalent emissions. Total emissions of CO2, CH4, and N2O were calculated using the following assumptions:

- Global warming potentials of 1, 21, and 310 were applied to CO2, CH4, and N2O, respectively, in order to calculate CO2e emissions.
- Oxidation factors of 0.99, 0.995, and 0.99 were applied to coal, natural gas, and oil, respectively, in order to calculate CO2e emissions.
- Production-based CO2e emissions by fuel type were calculated as the product of fuel-specific primary energy and fuel-specific GHG emission factors.
- Consumption-based CO2e emissions were calculated as the product of system CO2e intensity (i.e., tCO2e/MWh) and the consumption-based estimate of gross generation.
- The CO2e emissions associated with exports was calculated as the difference between the production and consumption based estimates.

Table A2. Summary of Kentucky Electric Generator Characteristics for the 2007 Base Year (utilities, non-utilities, and CHP)

Key Assumptions	2007	2030	Average Annual Growth / Change (%)
Kentucky retail electricity demand (GWh)	92,404	130,526	1.51%
Gross generation from Kentucky power stations and CHP facilities (GWh)	109,740	155,014	1.51%
to meet Kentucky retail electricity demand	105,268	148,696	1.51%
exported to ECAR/SERC regions	4,472	6,317	1.51%
Transmission and Distribution (T&D) Losses (%)	4.5%	5.0%	0.42%

Results

The following subsections provide an overview of the results of the GHG emissions inventory and reference case projections estimated using the assumptions and methodological approach described above.

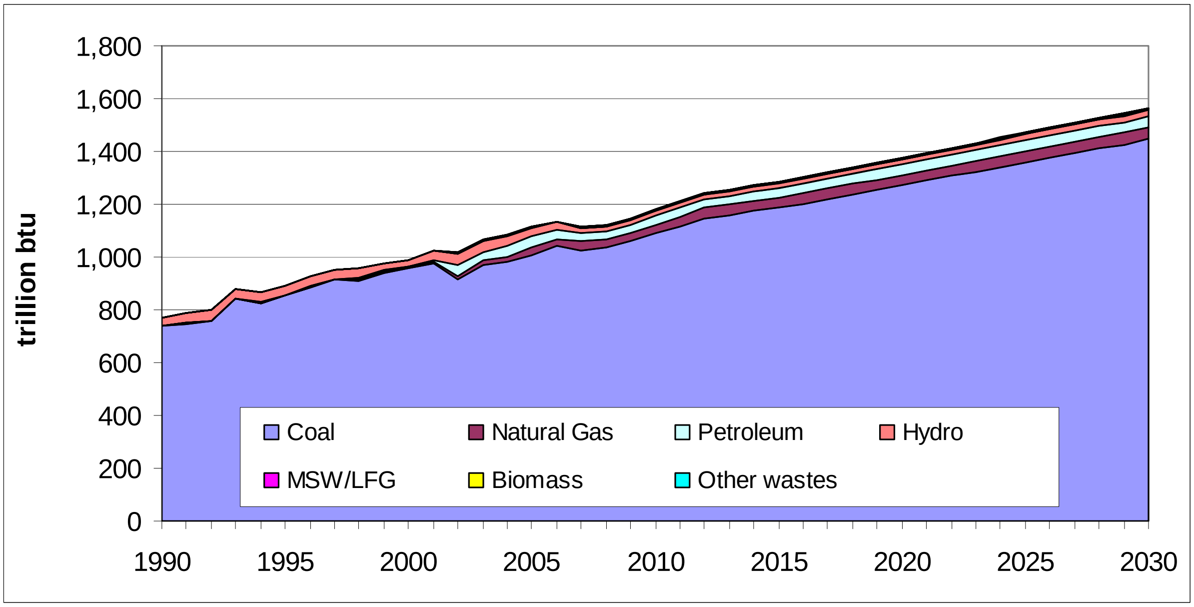
Primary Energy Consumption

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

Gross Generation

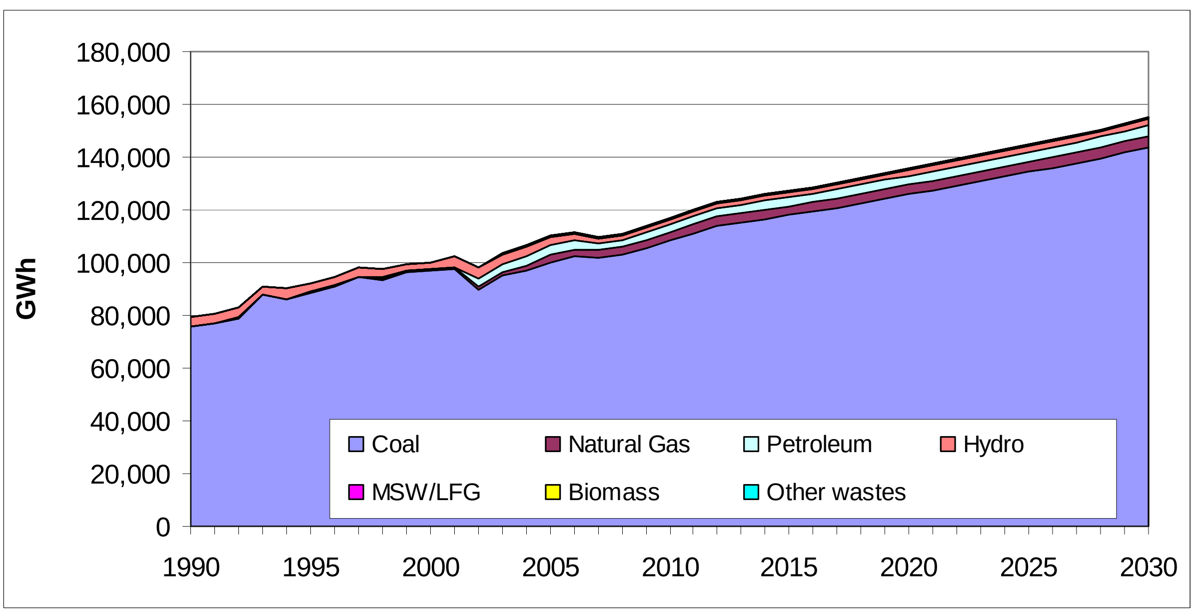
Total gross generation by Kentucky power plants and CHP facilities is summarized in Figure A3. Gross generation in Kentucky is dominated by steam units using coal. The composition of electric generation to meet local demand and for export is summarized in Figure A4.

Figure A2. Total Gross Primary Energy Use



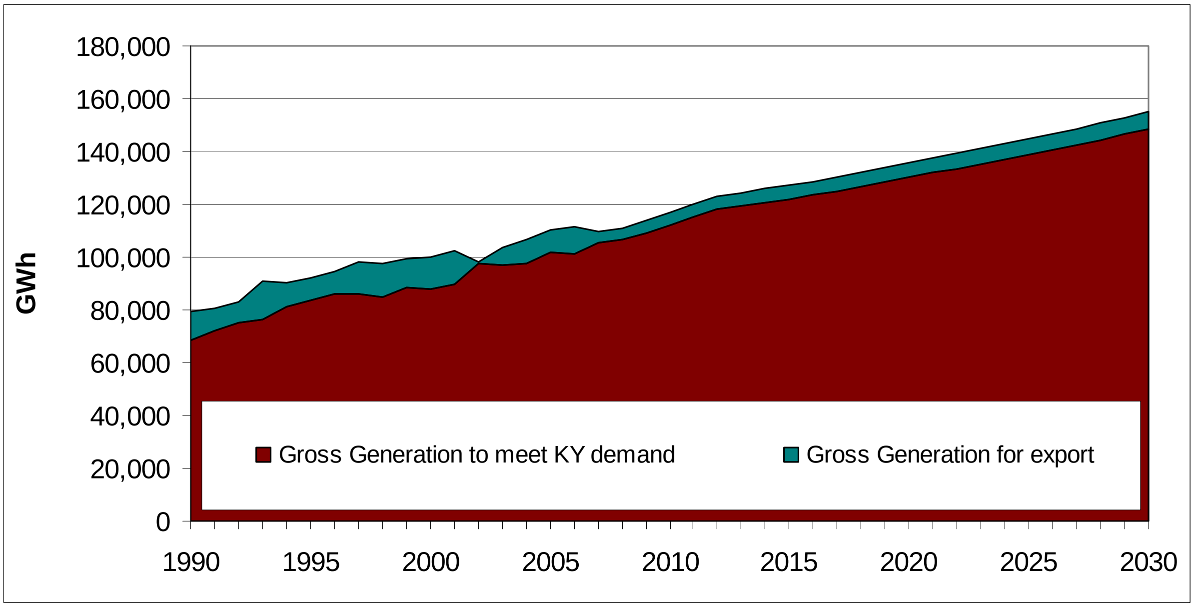
Source: Results in table based on approach described in text.

Figure A3. Total Gross Generation



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

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

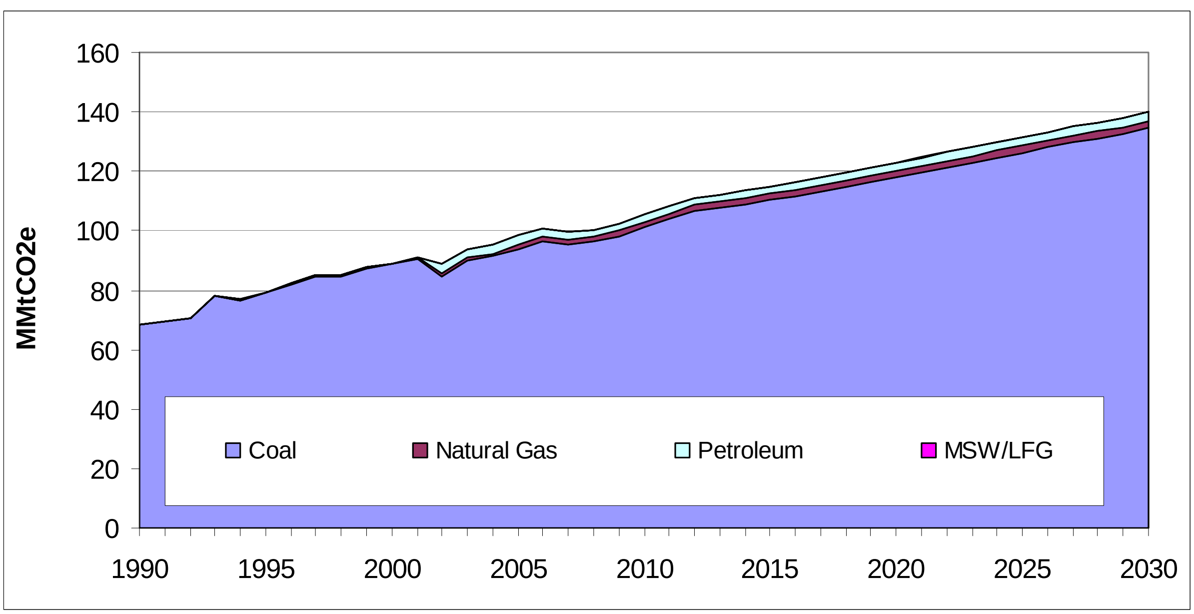


Source: Results in table based on approach described in text.

Total Gross GHG Emissions

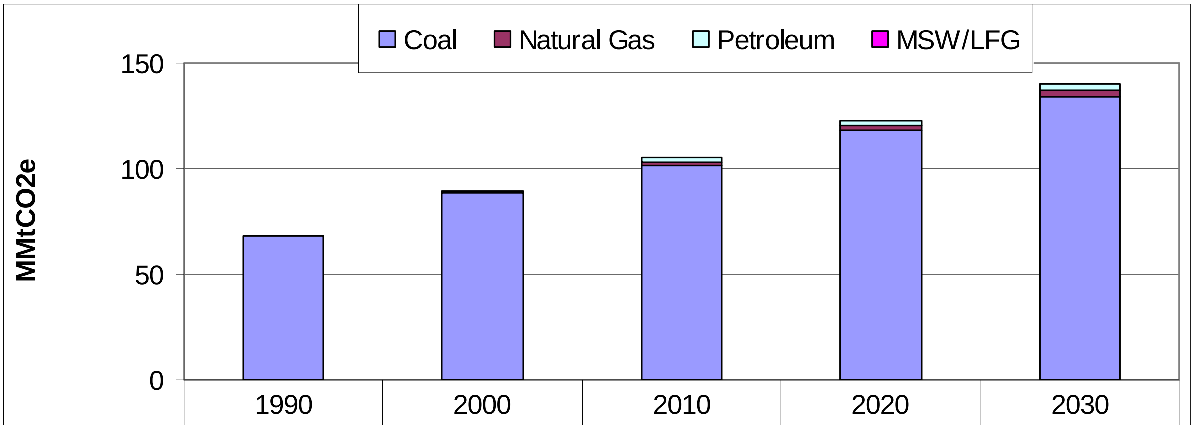
Total emissions associated with generation by Kentucky power plants are summarized in Figures A5 and A6 by fuel (production basis). On a production basis, emissions were about 99.6 $MMtCO_2e$ in 2007 and are projected to increase to about 140.0 $MMtCO_2e$ in 2030, representing an overall increase of about 41% during this 23-year period.

Figure A5. Total Gross GHG Emissions Associated with Kentucky Electricity Production by Fuel Type, all years



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

Figure A6. Total Gross GHG Emissions Associated with Kentucky Electricity Production by Fuel Type, every 10 years



	1990	2000	2010	2020	2030
MSW/LFG	0	0	0	0	0
Petroleum	0	0	2	3	3
Natural Gas	0	0	2	2	2
Coal	68	89	101	118	134

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

Key Uncertainties

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

- For the inventory period, 1990-2007, the data used in this initial preliminary analysis are based on state-specific, well-vetted historical data. The uncertainty associated with these reported values is considered to be low.
- For the forecast period, 2007-2030:
  - ✓ *Sales:* The forecast relies on the most recent KY sales forecast assembled by the KY PSC on the basis of utility Integrated Resource Plans. The uncertainty associated with these reported values is considered to be acceptable.
  - ✓ *Other:* Annual values in the forecast rely on simplifying assumptions regarding fuel mix, level of exports, on-site electricity use, transmission and distribution losses, and improvements in combustion efficiency. The uncertainty associated with these assumed values is considered to be high.

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

Overview

Activities in the RCI[25] sectors produce carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions when fuels are combusted to provide space heating, water heating, process heating, cooking, and other energy end-uses. Carbon dioxide accounts for over 99% of these emissions on a million metric tons (MMt) of CO_2 equivalent (CO_2e) basis in Kentucky. 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.[26] Direct use of oil, natural gas, coal, and wood in the RCI sectors accounted for an estimated 31 $MMtCO_2e$ of gross greenhouse gas (GHG) emissions in 2005.[27]

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.[28] The default data used in SIT for Kentucky are from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data* (SED). SIT information goes through 2007, after which emissions need to be forecasted.

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

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

[26] 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.

[27] 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.

[28] 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.

document.[29] The fossil fuel types for which the EIIP methods are applied in the SIT software to account for carbon storage include the following categories: asphalt and road oil, coking coal, distillate fuel, feedstocks (naphtha with a boiling range of less than 401 degrees Fahrenheit), feedstocks (other oils with boiling ranges greater than 401 degrees Fahrenheit), LPG, lubricants, miscellaneous petroleum products, natural gas, pentanes plus,[30] petroleum coke, residual fuel, still gas, and waxes. Data on annual consumption of the fuels in these categories as chemical industry feedstocks were obtained from the EIA SED.

Table B1 shows historic and projected growth rates for electricity sales by sector. For 2008 to 2030, the annual growth rate in the electricity sales for all of the RCI sectors combined is estimated to be 1.5%. Data provided by the Kentucky Public Service Commission (PSC) included electricity sale growth rates for overall electricity sales in the state associated with major regulated utilities. These growth rates were assumed to be representative of overall sales for all electricity production facilities. However, electricity sale growth rates associated with the residential, commercial, and industrial sectors were not available and have been estimated based on the approach described below.

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

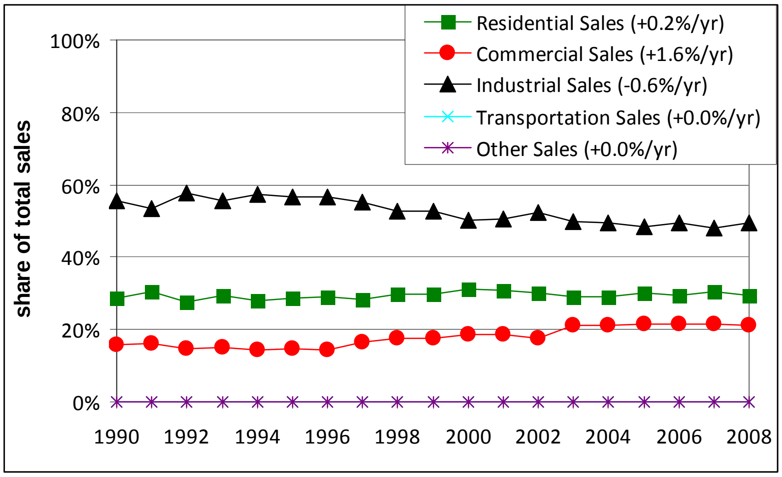
Sector	**1990-2008***	**2008-2030**
Residential	2.8%	1.5%
Commercial	2.9%	3.0%
Industrial	2.0%	0.7%
Total	**2.4%**	**1.5%**

* 1990-2007 compound annual growth rates calculated from Kentucky electricity sales by year from EIA state electricity profiles (Table 8), http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html.

A comparison was first made of the sector electricity sale shares for the period 1990-2008 to discern any obvious trends that could be useful is projecting sectoral sales. This comparison is summarized in Figure B1 and shows that noticeable trends are evident. For example, over the 1990-2008 historical period, the share of residential sales has been growing at a rate of 0.2%/year while the share of industrial sales has been declining at a rate of 0.6%/year. To account for the fact that the "Other sales" category has been assimilated into the other sectors from 2003 onward, an adjustment was made in which its share was assimilated pro-rata into the other sectors on a pro-rata basis for the period 1990-2003.

Figure B1: Summary of Sectoral Share Trends of Electricity Sales in Kentucky

[29] EIIP, Volume VIII: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004.
[30] A mixture of hydrocarbons, mostly pentanes and heavier fractions, extracted from natural gas.



For the purposes of developing an initial projection of sectoral electricity sales in Kentucky, it was assumed that the trends in sectoral electricity sales would continue over the 2009-2030 period in a manner similar to the 1990-2008 period. Table B2 summarizes the projected shares in 2008 and 2030 after normalizing to 100%. Intervening year shares were estimated by linear interpolation.

Table B2: Summary of Assumptions for Sectoral Shares of Electricity Sales in Kentucky

Sector	Electricity Sale Shares 2008	Electricity Sale Shares 2030
Residential Sales	29.5%	29.5%
Commercial Sales	21.1%	29.0%
Industrial Sales	49.4%	41.5%
Transportation Sales	0.0%	0.0%
Other Sales	0.0%	0.0%
All Sector Sales	100.0%	100.0%

Once sectoral shares were estimated for each demand sector for each year in the forecast period, these shares were multiplied by the projected total sales that had been previously calculated by use of the Kentucky PSC's overall electricity sale growth rates. A summary of the projected sectoral sales is summarized in Table B3 for 2008 and 2030, together with average annual growth rates over the 2008-2030 period. It is important to note that these sectoral electricity sale estimates have high uncertainty bounds and should be reviewed and vetted by the RCI TWG before they are used in any analysis of GHG mitigation options for RCI sectors.

Table B3: Summary of Projected Sectoral Electricity Sales in Kentucky, 2008-2030

Sector	Electricity sales (GWh) 2008	Electricity sales (GWh) 2030	Average annual growth rate (%/yr)

Residential Sales	27,562	38,545	1.54%
Commercial Sales	19,669	37,793	3.01%
Industrial Sales	46,198	54,188	0.73%
Transportation Sales	0	0	0.00%
Other Sales	0	0	0.00%
All Sector Sales	93,429	130,526	1.53%

Table B4 shows historical and projected growth rates for energy use by sector and fuel type. Reference case emissions from direct fuel combustion were estimated based on fuel consumption forecasts from EIA's *Annual Energy Outlook 2009* (AEO2009).[31] For the RCI sectors, annual growth rates for natural gas, oil, wood, and coal were calculated from the AEO2009 regional forecast that EIA prepared for the East South Central modeling region. For the residential sector, the AEO2009 annual growth rate in fuel consumption from 2007 through 2030 was normalized using the AEO2009 population forecast and then weighted using Kentucky's population forecast over this period. Kentucky's rate of population growth is expected to average about 0.73% annually between 2007 and 2030.[32] Growth rates for the commercial and industrial sectors were based on the AEO2009 East South Central regional estimates of growth in fuel consumption 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).

[31] EIA AEO2009 with Projections to 2030 (http://www.eia.doe.gov/oiaf/archive.html#aeo).
[32] Population data for historical years (1990-2008) is from http://ksdc.louisville.edu/kpr/popest/est.htm . Kentucky population projections (2009-2030) are from "Projections of Total Population" (http://ksdc.louisville.edu/kpr/pro/projections.htm).

Table B4. Historical and Projected Average Annual Growth in Energy Use in Kentucky, by Sector and Fuel, 1990-2030

	1990-2007[a]	2007-2010[b]	2010-2015[b]	2015-2020[b]	2020-2025[b]	2025-2030[b]
Residential						
petroleum	-1.9%	1.9%	-1.6%	0.4%	0.6%	0.4%
natural gas	-0.6%	6.5%	-0.4%	0.4%	0.3%	0.0%
coal	-5.3%	2.9%	-1.7%	-0.5%	-0.6%	-0.5%
wood	-3.5%	2.0%	0.6%	1.5%	0.5%	0.6%
Commercial						
petroleum	-2.6%	-1.5%	-0.3%	0.3%	0.7%	0.6%
natural gas	0.4%	2.9%	-0.2%	0.1%	0.4%	0.3%
coal	-0.6%	-0.5%	0.0%	0.0%	0.0%	0.0%
wood	-1.4%	0.0%	0.0%	0.0%	0.0%	0.0%
Industrial						
petroleum	2.0%	-5.8%	0.9%	-0.4%	-0.3%	-0.5%
natural gas	2.5%	-3.1%	0.7%	-0.6%	0.0%	-0.8%
coal	-5.4%	-7.1%	1.7%	-0.1%	-0.4%	-1.4%
wood	14.0%	-1.6%	-0.6%	0.9%	0.8%	0.7%

[a] Compound annual growth rates calculated from EIA SED historical consumption by sector and fuel type for Kentucky. Latest year for which EIA SED information was available for each sector and fuel type is 2007. 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 2007 are calculated from AEO2009 projections for EIA's East South Central region. Regional growth rates for the residential sector are adjusted for Kentucky's projected population.

Results

Figures B2, B3, and B4 show historical and projected emissions for the RCI sectors in Kentucky from 1990 through 2030. 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, allocated to the RCI subsectors using the methodology described above.

The residential sector's share of total RCI emissions from direct fuel use and electricity was 24% in 1990, increased to 26% in 2005, and is projected to increase slightly to 27% in 2030. The commercial sector's share of total RCI emissions from direct fuel use and electricity use was 16% in 1990, increased to 18% in 2005, and is projected to increase to 26% by 2030. The industrial sector's share of total RCI emissions from direct fuel use and electricity use was 60% in 1990, decreased to 56% in 2005, and is projected to decrease to 47% by 2030. Emissions associated with the generation of electricity to meet RCI demand accounts for about 87% of the emissions for the residential sector, 88% of the emissions for the commercial sector, and 67% of the emissions for the industrial sector, on average, over the 1990 to 2030 time period. From 1990 to 2030, natural gas consumption is the next highest source of emissions for the residential and commercial sectors, accounting, on average, for about 11% and 9% of total emissions, respectively. For the industrial sector, emissions associated with the combustion of petroleum, coal, and natural gas account for about 16%, 9%, and 8% respectively, on average, from 1990 to 2030.

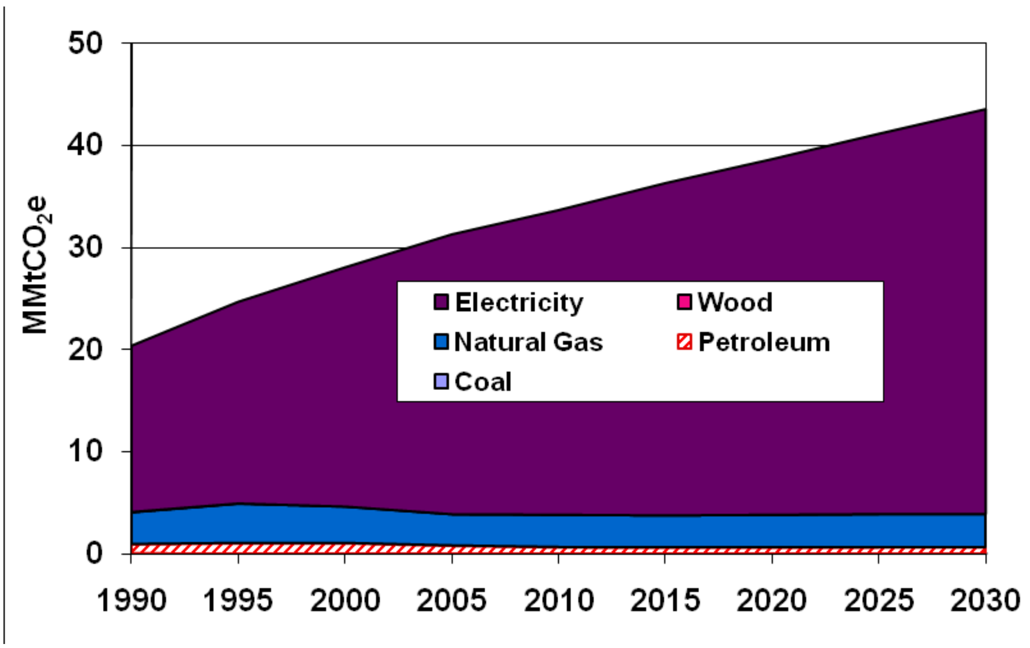
Residential Sector

Figure B2 presents the emission inventory and reference case projections for the residential sector. Figure B2 was developed from the emissions data in Table B5a. Table B5b 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 20 MMtCO$_2$e, and are estimated to increase to about 44 MMtCO$_2$e by 2030. Emissions associated with the generation of electricity to meet residential energy consumption demand accounted for about 80% of total residential emissions in 1990, and are estimated to increase to 91% of total residential emissions by 2030. In 1990, natural gas consumption accounted for about 15% of total residential emissions, and is estimated to account for about 7% of total residential emissions by 2030. Residential sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 1.0 MMtCO$_2$e combined, and accounted for about 5% of total residential emissions. By 2030, emissions associated with the consumption of these three fuels are estimated to decrease slightly to 0.7 MMtCO$_2$e, accounting for 2% of total residential sector emissions by that year.

For the 25-year period 2005 to 2030, residential-sector GHG emissions associated with the use of electricity, natural gas and wood are expected to increase at average annual rates of about 1.5%, 0.2% and 0.8% respectively. Emissions associated with the use of coal and petroleum are expected to decrease annually by about -3.0% and -0.7% respectively. Total GHG emissions for this sector increase by an average of about 1.3% annually over the 25-year period.

Figure B2. Residential Sector GHG Emissions from Fuel Consumption



Source: CCS calculations based on approach described in text.

Note: Emissions associated with coal and wood combustion are too small to be seen on this graph. GHG emissions include all six standard GHGs, expressed in $MMtCO_2e$.

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

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025	2030
Coal	0.07	0.04	0.06	0.06	0.03	0.03	0.03	0.03	0.03
Petroleum	0.87	1.00	0.99	0.74	0.62	0.58	0.59	0.61	0.62
Natural Gas	3.10	3.85	3.57	3.07	3.17	3.13	3.19	3.24	3.24
Wood	0.10	0.08	0.04	0.05	0.06	0.06	0.06	0.06	0.07
Electricity	16.29	19.76	23.44	27.41	29.84	32.56	34.83	37.25	39.65
Total	20.43	24.73	28.10	31.33	33.71	36.36	38.71	41.19	43.60

Source: CCS calculations based on approach described in text.

Table B5b. Residential Sector Proportions of Total Emissions by Fuel Type (%)

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025	2030
Coal	0.4%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%
Petroleum	4.3%	4.0%	3.5%	2.4%	1.8%	1.6%	1.5%	1.5%	1.4%
Natural Gas	15.2%	15.6%	12.7%	9.8%	9.4%	8.6%	8.3%	7.9%	7.4%
Wood	0.5%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.1%
Electricity Consumption	79.7%	79.9%	83.4%	87.5%	88.5%	89.5%	90.0%	90.4%	90.9%

Source: CCS 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.

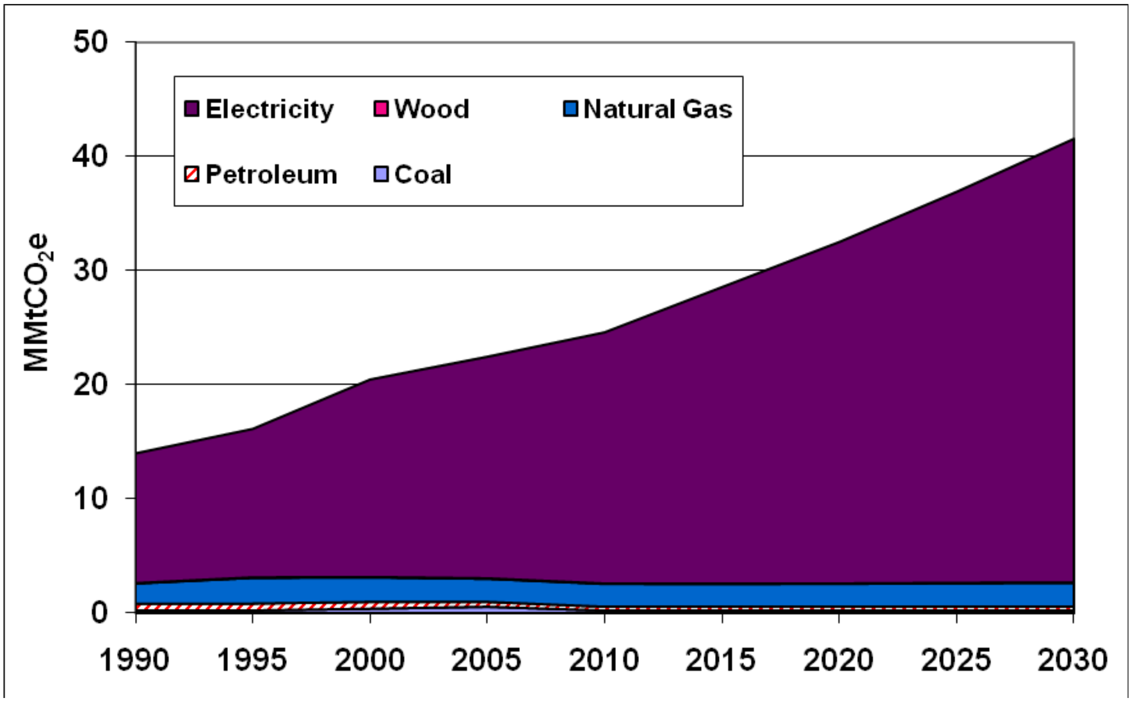
Commercial Sector

Figure B3 presents the emission inventory and reference case projections for the commercial sector. Figure B3 was developed from the emissions data in Table B6a. Table B6b shows 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 14 $MMtCO_2e$, and are estimated to increase to about 42 $MMtCO_2e$ by 2030. Emissions associated with the generation of electricity to meet commercial energy consumption demand accounted for about 81% of total commercial emissions in 1990, and are estimated to increase to 93% of total commercial emissions by 2030. In 1990, natural gas consumption accounted for about 13% of total commercial emissions and is estimated to account for about 5% of total commercial emissions by 2030. Commercial sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 0.9 $MMtCO_2e$ combined, and accounted for about 6% of total commercial emissions. By 2030, emissions associated with the consumption of these three fuels are estimated to be 0.7 $MMtCO_2e$ and to account for 2% of total commercial sector emissions.

For the 25-year period from 2005 to 2030, commercial sector GHG emissions associated with the use of electricity and natural gas are expected to increase at average annual rates of about 2.8%, and 0.1% respectively. Emissions associated with the use of coal, petroleum and wood are expected to decline from 2005 levels at average annual rates of -3.5%, -0.4% and -0.1%, respectively. Total GHG emissions for this sector increase by an average of about 2.5% annually over the 25-year period.

Figure B3. Commercial Sector GHG Emissions from Fuel Consumption



Source: CCS calculations based on approach described in text.
Note: Emissions associated with coal and wood combustion are too small to be seen on this graph. GHG emissions include all six standard GHGs, expressed in $MMtCO_2e$.

Table B6a. Commercial Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025	2030
Coal	0.28	0.26	0.42	0.60	0.25	0.25	0.25	0.25	0.25
Petroleum	0.60	0.63	0.62	0.44	0.37	0.37	0.37	0.39	0.40
Natural Gas	1.76	2.25	2.14	2.02	1.99	1.97	1.99	2.03	2.06
Wood	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Electricity	11.37	13.01	17.30	19.42	22.02	26.00	29.93	34.27	38.88
Total	14.02	16.17	20.49	22.49	24.63	28.59	32.55	36.94	41.59

Source: CCS calculations based on approach described in text.

Table B6b. Commercial Sector Proportions of Total Emissions by Fuel Type (%)

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025	2030
Coal	2.0%	1.6%	2.1%	2.7%	1.0%	0.9%	0.8%	0.7%	0.6%
Petroleum	4.3%	3.9%	3.0%	2.0%	1.5%	1.3%	1.2%	1.0%	1.0%
Natural Gas	12.5%	13.9%	10.4%	9.0%	8.1%	6.9%	6.1%	5.5%	5.0%
Wood	0.1%	0.07%	0.03%	0.04%	0.03%	0.03%	0.03%	0.02%	0.02%
Electricity Consumption	81.1%	80.5%	84.4%	86.4%	89.4%	90.9%	92.0%	92.8%	93.5%

Source: CCS 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.

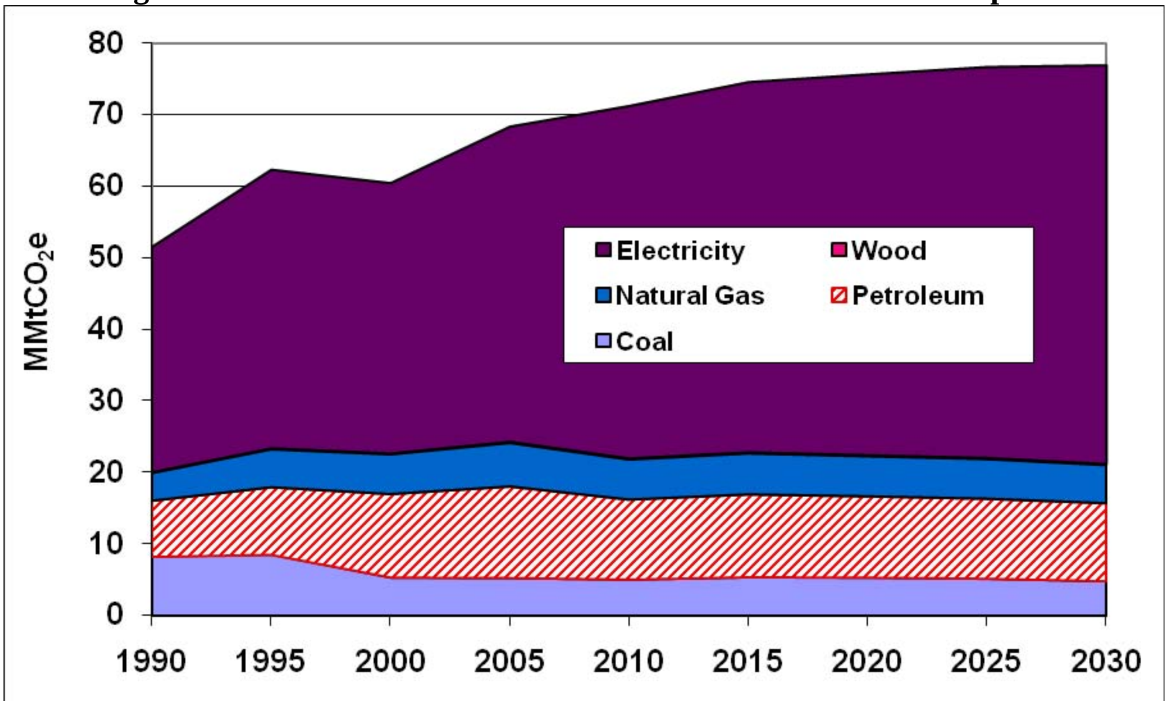
Industrial Sector

Figure B4 presents the emission inventory and reference case projections for the industrial sector. Figure B4 was developed from the emissions data in Table B7a. Table B7b shows 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 51 $MMtCO_2e$ and are estimated to increase to about 77 $MMtCO_2e$ by 2030. Emissions associated with the generation of electricity to meet industrial energy consumption demand accounted for about 61% of total industrial emissions in 1990, and are estimated to increase to about 73% of total industrial emissions by 2030. In 1990, natural gas consumption accounted for about 8% of total industrial emissions, and is estimated to decrease slightly to 7% of total industrial emissions by 2030. Coal consumption accounted for about 16% of total industrial emissions in 1990, and is estimated to decline to about 6% of total industrial emissions by 2030. In 1990, petroleum consumption accounted for about 15% of total industrial emissions, and is estimated to decrease to about 14% of total industrial emissions by 2030. Emissions associated with wood consumption by the industrial sector are about 0.1% of total emissions or less from 1990 through 2030.

For the 25-year period from 2005 to 2030, industrial sector GHG emissions associated with the use of electricity and wood are expected to increase at an average annual rate of about 0.9% and 0.4%, respectively. Emissions associated with the use of petroleum, coal, and natural gas are expected to decrease annually by about -0.6%, -0.4%, and -0.5%, respectively. Total GHG emissions for the industrial sector increase by about 0.5% annually over the 25-year period.

Figure B4. Industrial Sector GHG Emissions from Fuel Consumption



Source: CCS calculations based on approach described in text.
Note: Emissions associated with wood combustion are too small to be seen on this graph. GHG emissions include all six standard GHGs, expressed in $MMtCO_2e$.

Table B7a. Industrial Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025	2030
Coal	8.19	8.47	5.30	5.23	5.00	5.33	5.29	5.13	4.77
Petroleum	7.86	9.47	11.70	12.83	11.22	11.60	11.39	11.20	10.93
Natural Gas	3.87	5.31	5.55	6.10	5.61	5.74	5.60	5.55	5.34
Wood	0.00	0.01	0.01	0.04	0.04	0.03	0.04	0.04	0.04
Electricity	31.52	38.96	37.80	44.07	49.28	51.77	53.24	54.66	55.74
Total	51.45	62.23	60.35	68.25	71.14	74.48	75.55	76.58	76.83

Source: CCS calculations based on approach described in text.

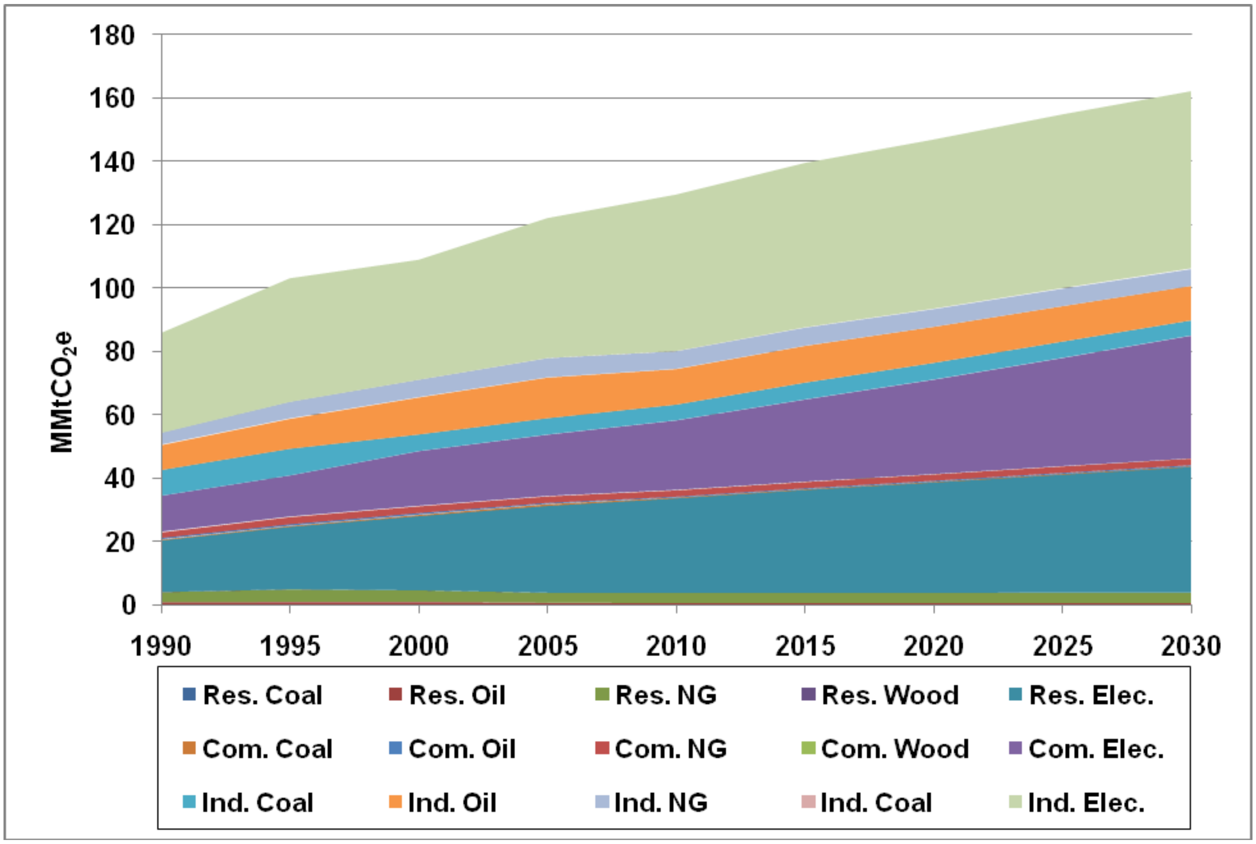
Table B7b. Industrial Sector Proportions of Total Emissions by Fuel Type (%)

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025	2030
Coal	15.9%	13.6%	8.8%	7.7%	7.0%	7.2%	7.0%	6.7%	6.2%
Petroleum	15.3%	15.2%	19.4%	18.8%	15.8%	15.6%	15.1%	14.6%	14.2%
Natural Gas	7.5%	8.5%	9.2%	8.9%	7.9%	7.7%	7.4%	7.2%	7.0%
Wood	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%
Electricity	61.3%	62.6%	62.6%	64.6%	69.3%	69.5%	70.5%	71.4%	72.6%

Source: CCS 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.

Figure B5 illustrates the GHG emissions from the individual residential, commercial, and industrial sectors by fuel type.

Figure B5. RCI GHG Emissions from Fuel Consumption by Fuel Type and Sector



Source: CCS calculations based on approach described in text.
GHG emissions include all six standard GHGs, expressed in $MMtCO_2e$.
Res. = Residential sector; Com. = Commercial sector; Ind. = Industrial sector; NG = natural gas; Elec. = Electricity

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 East 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 Kentucky to the extent that such data become available.
- The AEO2009 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 of the largest sources of greenhouse gas (GHG) emissions in Kentucky. In 2005, carbon dioxide (CO_2) accounted for about 97% of transportation GHG emissions from fuel use. Most of the remaining GHG emissions from the transportation sector are due to nitrous oxide (N_2O) emissions from gasoline engines.

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 onroad vehicles, the CO_2 emission factors are in units of pounds (lb) per million British thermal unit (MMBtu) and the methane (CH_4) and N_2O emission factors are both in units of grams per vehicle mile traveled (VMT). Key assumptions in this analysis are listed in Table C1. The default fuel consumption data within SIT were used to estimate emissions, with the most recently available fuel consumption data (2007 in most cases) from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data* (SED) included in the SIT.[35] The default VMT data in SIT were replaced with annual VMT supplied by the Kentucky Transportation Cabinet (KYTC).[36] The State-level Kentucky VMT was allocated to vehicle types using the default vehicle mix data in SIT from the Federal Highway Administration (FHWA)[37].

Onroad Vehicles

Onroad vehicle gasoline and diesel emissions were projected based on VMT forecasts provided by KYTC[4] and growth rates developed from national vehicle type VMT forecasts reported in EIA's *Annual Energy Outlook* 2009 (AEO2009). The AEO2009 data were incorporated because they indicate significantly different VMT growth rates for certain vehicle types (e.g., much higher growth rates for heavy-duty diesel VMT compared to light-duty gasoline vehicle VMT over this period). The procedure first applied the AEO2009 vehicle type-based national growth rates to 2008 estimates of Kentucky VMT by vehicle type. These data were then used to calculate the estimated proportion of total VMT by vehicle type in each year. Next, these proportions were applied to the KYTC estimates for total projected VMT in the State for each

[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] Jesse Mayes, Transportation Engineer Specialist, Kentucky Transportation Cabinet.
[37] Highway Statistics, Federal Highway Administration, http://www.fhwa.dot.gov/policy/ohpi/hss/index.htm.

year, using a total annual growth rate of 2.2%, to yield the vehicle type VMT estimates. The resulting annual VMT growth rates by vehicle type are displayed in Table C2.

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

Vehicle Type and Pollutants	Methods
Onroad gasoline, diesel, natural gas, and LPG vehicles – CO_2	**Inventory (1990 – 2007)** EPA SIT and fuel consumption from EIA SED **Reference Case Projections (2008 – 2030)** Gasoline and diesel fuel projected using VMT projections from KYTC, adjusted by current fuel efficiency improvement projections from EPA. Other onroad fuels projected using East South Central Region fuel consumption projections from EIA AEO2009 adjusted using state-to-regional ratio of population growth.
Onroad gasoline and diesel vehicles – CH_4 and N_2O	**Inventory (1990 – 2008)** EPA SIT with State total VMT replaced by KYTC VMT allocated to vehicle types using default data in SIT. **Reference Case Projections (2009 – 2030)** VMT projected annual growth rate from KYTC.
Non-highway fuel consumption (jet aircraft, gasoline-fueled piston aircraft, boats, locomotives) – CO_2, CH_4 and N_2O	**Inventory (1990 – 2007)** EPA SIT and fuel consumption from EIA SED. Commercial marine vessel fuel consumption based on national fuel consumption allocated to Kentucky based on Waterborne Commerce data. **Reference Case Projections (2008 – 2030)** Aircraft growth rates are based on estimates of operations data for Kentucky in the FAA's Terminal Area Forecast for 2007-2030 data. Rail and marine gasoline projected based on historical data.

Table C2. Kentucky Vehicle Miles Traveled Compound Annual Growth Rates

Vehicle Type	2008-2010	2010-2015	2015-2020	2020-2025	2025-2030
Heavy Duty Diesel Vehicle	2.77%	2.60%	2.34%	2.24%	2.21%
Heavy Duty Gasoline Vehicle	1.91%	1.92%	1.82%	1.80%	1.97%
Light Duty Diesel Truck	8.56%	11.11%	12.71%	11.47%	9.41%
Light Duty Diesel Vehicle	8.56%	11.11%	12.71%	11.47%	9.41%
Light Duty Gasoline Truck	2.13%	1.98%	1.83%	1.68%	1.59%
Light Duty Gasoline Vehicle	2.13%	1.98%	1.83%	1.68%	1.59%
Motorcycle	2.13%	1.98%	1.83%	1.68%	1.59%

Onroad gasoline and diesel fuel consumption were forecasted by developing a set of growth factors that adjusted the VMT projections to account for improvements in fuel efficiency. Fuel efficiency projections were taken from EPA's MOBILE6.2 model to represent projected fleetwide in-use fuel consumption, prior to the implementation of the new fuel efficiency standards resulting from the 2007 Energy Independence and Security Act. The resulting onroad fuel consumption growth rates are shown in Table C3. Growth rates for projecting CO_2 emissions from natural gas and LPG vehicles were calculated by allocating the AEO2009 consumption of these fuels in the East South Central region and allocating this to Kentucky based on the ratio of the State's projected population to the region's projected population. Similarly, growth rates for projecting CO_2 emissions from lubricants consumption were calculated based on the AEO2009 East South Central "other petroleum" category growth, also normalized using state to regional population projections.

Table C3. Kentucky Onroad Fuel Consumption Compound Annual Growth Rates

Fuel Growth Factors	2007-2010	2010-2015	2015-2020	2020-2025	2025-2030
Onroad gasoline	1.82%	1.82%	1.75%	1.68%	1.59%
Onroad diesel	3.11%	3.29%	3.50%	3.79%	3.87%
Natural Gas	8.10%	12.62%	6.37%	2.59%	0.95%
LPG	-4.22%	-0.27%	-0.28%	-0.26%	-0.20%
Lubricants	-1.00%	0.35%	0.12%	-0.05%	-0.12%

Aviation

For the aircraft sector, emission estimates for 1990 to 2007 are based on SIT methods and fuel consumption from EIA. Emissions were projected from 2008 to 2030 using the Terminal Area Forecast from the Federal Aviation Administration, adjusted by an estimate of improved aircraft efficiency, from the AEO2009. To estimate changes in jet fuel consumption, aircraft operations from air carrier, air taxi/commuter, and military aircraft were first summed for each year of interest. The post-2007 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 AEO2009. Because AEO2009 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 Kentucky, which was obtained from the FAA source noted above. The resulting compound annual average growth rates are displayed in Table C4.

Table C4. Kentucky Aviation Fuels Compound Annual Growth Rates

Fuel	2007-2010	2010-2015	2015-2020	2020-2025	2025-2030
Aviation Gasoline	-2.95%	0.41%	0.43%	0.46%	0.47%
Jet Fuel	-11.89%	1.53%	0.77%	0.62%	0.50%

Rail and Marine Vehicles

For the rail and recreational marine sectors, 1990-2007 estimates are based on SIT methods and fuel consumption from EIA. Marine gasoline consumption was projected to 2030 based on a linear regression of the 1990 through 2007 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), 1990-2007 emission estimates are based on SIT emission rates applied to estimates of Kentucky 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 Kentucky marine vessel fuel consumption. Kentucky fuel consumption estimates were developed by allocating 1990-2007 national diesel and residual oil vessel bunkering fuel consumption estimates obtained from EIA, excluding fuel used for international bunkering.[38] Marine vessel fuel consumption data were allocated to Kentucky using the marine vessel activity allocation methods/data compiled to support the development of EPA's National Emissions Inventory (NEI).[39] 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 Kentucky 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."[40] Growth rates for the commercial marine sector were calculated based on a forecasted trend of the resulting historical diesel and residual commercial marine fuel consumption.

The resulting compound annual average growth rates for the rail and marine categories are displayed in Table C5.

Table C5. Kentucky Rail and Marine Fuels Compound Annual Growth Rates

Fuel	2007-2010	2010-2015	2015-2020	2020-2025	2025-2030
Marine Gasoline	2.77%	1.42%	1.33%	1.24%	1.17%
Marine Diesel	1.86%	0.86%	0.82%	0.79%	0.76%
Marine Residual	-12.10%	-0.81%	-0.84%	-0.88%	-0.92%
Rail	0.00%	0.00%	0.00%	0.00%	0.00%

Nonroad Engines

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

[38] 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). Data for international bunker fuels obtained from EPA's *2009 Inventory of Greenhouse Gas Emissions and Sinks*, Table 3-53, available at http://www.epa.gov/climatechange/emissions/index.html, and earlier versions for some intermediate years.
[39] See methods described in ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002nei_mobile_nonroad_methods.pdf
[40] "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 Kentucky percentage of national waterborne tonnage.

including nonroad vehicles such as snowmobiles and dirt bikes, are included in the inventory and forecast for the residential, commercial, and industrial (RCI) sectors (see Appendix B). Table C6 shows how EIA divides gasoline and diesel fuel consumption between the transportation, commercial, and industrial sectors.

Table C6. EIA Classification of Gasoline and Diesel Consumption

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

Results

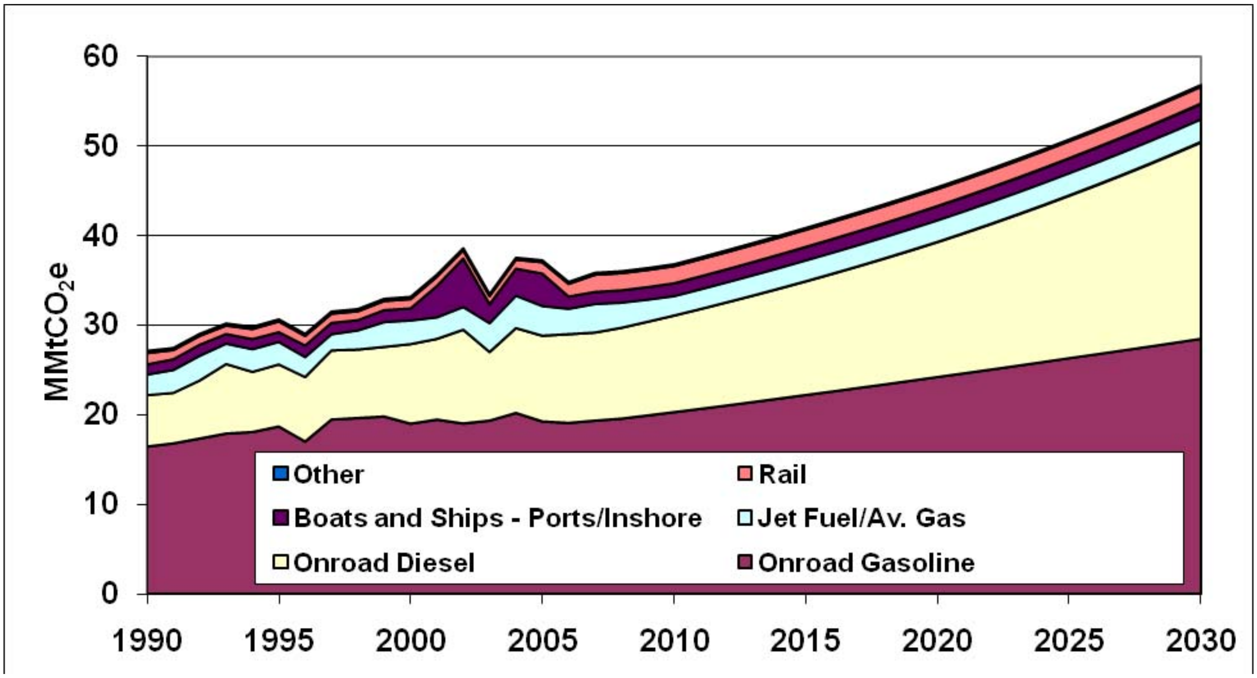
As shown in Figure C1, onroad gasoline and diesel consumption accounts for the largest share of transportation GHG emissions. Emissions from onroad gasoline vehicles increased by about 17% from 1990 to 2005 to account for 61% of total transportation emissions in 2005. GHG emissions from onroad diesel fuel consumption increased by 66% from 1990 to 2005, and by 2005 accounted for 23% of GHG emissions from the transportation sector. Emissions from boats and ships along Kentucky waterways accounted for 4% of transportation emissions in 2005. Aircraft emissions increased 45% between 1990 and 2005, and made up 8% of Kentucky transportation emissions in 2005. Rail emissions increase by 1% between 1990 and 2005, and made up 4% of Kentucky's transportation emissions in 2005. Emissions from all other categories combined (natural gas and LPG, and oxidation of lubricants) contributed less than 1% of total transportation emissions in 2005.

GHG emissions from all onroad vehicles combined are projected to increase by 75% between 2005 and 2030. This growth comes primarily from the diesel sector, with onroad gasoline emissions projected to increase 48% and emissions from onroad diesel consumption projected to increase by 129% between 2005 and 2030. Kentucky emissions from boats and ships decrease 53% over the forecast period. Similarly, emissions from aviation fuels are projected to decrease by 22% between 2005 and 2030. See Table C7 and Figure C1 for more information.

Table C7. Transportation GHG Emissions by Fuel, 1990-2030

Source	1990	1995	2000	2005	2010	2015	2020	2025	2030
Onroad Gasoline	16.4	18.7	19.0	19.2	20.3	22.2	24.2	26.3	28.5
Onroad Diesel	5.8	7.0	8.9	9.6	10.8	12.7	15.1	18.2	22.0
Jet Fuel/Av. Gas	2.3	2.6	2.7	3.4	2.2	2.4	2.5	2.6	2.6
Boats and Ships - Ports/Inshore	1.2	1.1	1.4	3.6	1.4	1.5	1.6	1.6	1.7
Rail	1.3	1.2	1.0	1.3	1.9	1.9	1.9	1.9	1.9
Other	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total	***27.2***	***30.7***	***33.2***	***37.3***	***36.8***	***40.9***	***45.5***	***50.8***	***56.9***

Figure C1. Transportation GHG Emissions by Source and Fuel, 1990-2030



Source: CCS calculations based on approach described in text.

Sensitivity Test Results Based Upon Alternative VMT Forecast

The Transportation and Land Use Technical Working Group (TLU TWG) recommended to the KCAPC that an alternative VMT forecast be developed to determine the sensitivity of transportation emissions to the VMT growth assumptions in the BAU reference case projections. This recommendation was based on a concern that the BAU VMT annual growth rate of 2.2% does not reflect recent Kentucky or national historical patterns in VMT. The KCAPC approved the development of an alternative growth scenario that shows about 20% increase in VMT between 2005 and 2030 based upon an assumption that VMT growth mirrors projected population growth. With the approval of this recommendation by the KCAPC, an alternative VMT projection was developed with the results presented here.

The annual growth rates from the official state forecast for population growth[41] for each year were applied to the latest historical year of VMT data, 2008, through 2030. These alternative VMT estimates were then used as the only change from the BAU GHG reference case projection in order to produce a 'sensitivity analysis' result for a forecast of transportation sector GHG emissions.

Table C8 shows the VMT annual growth rates used in the alternative sensitivity test analysis. Table C9 shows the annual fuel consumption growth rates that result from the alternative VMT forecast. Table C10 shows the transportation GHG emissions forecast using the alternative VMT projections. The sensitivity test shows that the alternative VMT growth rates produce a significant difference in forecast GHG emissions for on-road vehicles. The baseline forecast for onroad gasoline GHG emissions is 28.5 $MMtCO_2e$ in the year 2030, while the alternative scenario produces an estimate of 20.4 $MMtCO_2e$, which represents a difference of 8.1 $MMtCO_2e$. The baseline forecast for onroad diesel GHG emissions is 22.0 $MMtCO_2e$ for the year 2030, while the alternative scenario produces an estimate of 15.7 $MMtCO_2e$, which represents a difference of 6.3 $MMtCO_2e$. The overall GHG forecast estimate for the transportation and land use sector changes from 56.9 $MMtCO_2e$ in 2030 to 42.6 $MMtCO_2e$, which represents a difference of 14.3 $MMtCO_2e$ in 2030.

Table C8. Kentucky Vehicle Miles Traveled Compound Annual Growth Rates using Alternate VMT Projections

Vehicle Type	2008-2010	2010-2015	2015-2020	2020-2025	2025-2030
Heavy Duty Diesel Vehicle	1.34%	1.15%	0.87%	0.74%	0.68%
Heavy Duty Gasoline Vehicle	0.50%	0.48%	0.36%	0.31%	0.44%
Light Duty Diesel Truck	7.05%	9.55%	11.09%	9.84%	7.77%
Light Duty Diesel Vehicle	7.05%	9.55%	11.09%	9.84%	7.77%
Light Duty Gasoline Truck	0.71%	0.54%	0.37%	0.19%	0.07%
Light Duty Gasoline Vehicle	0.71%	0.54%	0.37%	0.19%	0.07%
Motorcycle	0.71%	0.54%	0.37%	0.19%	0.07%

Table C9. Kentucky Onroad Fuel Consumption Compound Annual Growth Rates using Alternate VMT Projections

Fuel Growth Factors	2007-2010	2010-2015	2015-2020	2020-2025	2025-2030
Onroad gasoline	0.41%	0.39%	0.29%	0.20%	0.08%
Onroad diesel	1.68%	1.84%	2.01%	2.27%	2.32%

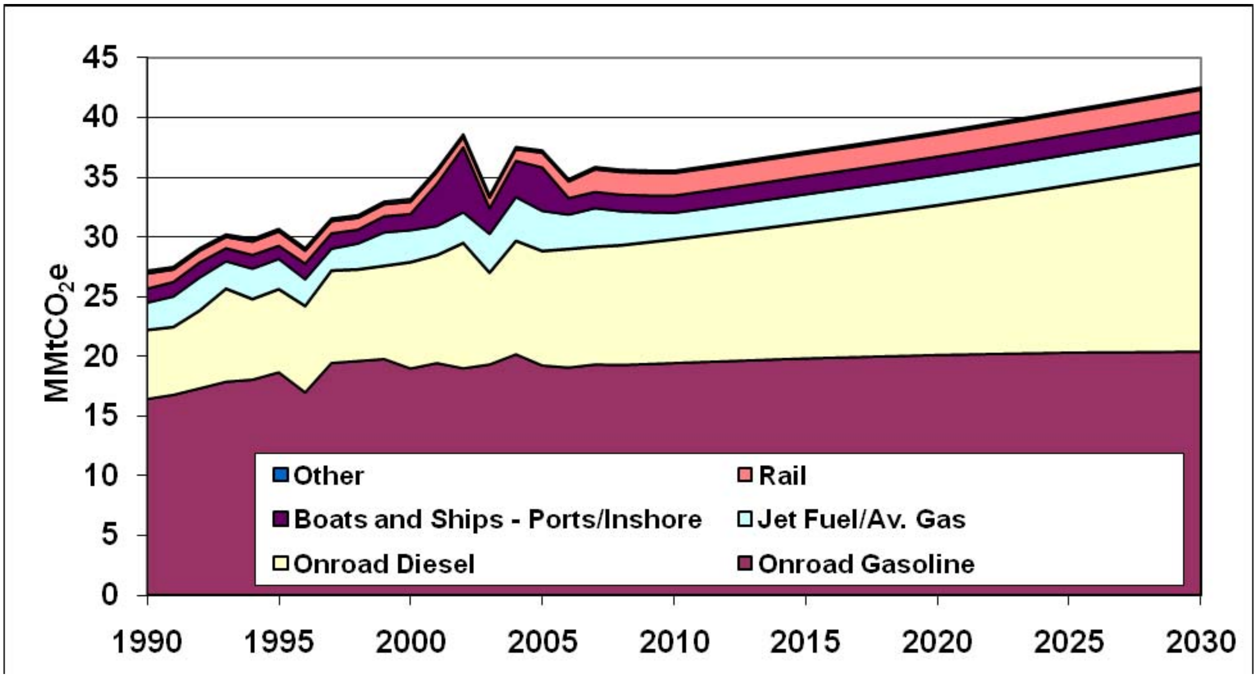
Table C10. Transportation GHG Emissions by Fuel using Alternate VMT Projections, 1990-2030

Source	1990	1995	2000	2005	2010	2015	2020	2025	2030
Onroad Gasoline	16.4	18.7	19.0	19.2	19.4	19.8	20.1	20.3	20.4
Onroad Diesel	5.8	7.0	8.9	9.6	10.4	11.3	12.5	14.0	15.7

[41] The population growth rates are from the Kentucky State Data Center, University of Louisville, http://ksdc.louisville.edu/kpr/pro/projections.htm

Jet Fuel/Av. Gas	2.3	2.6	2.7	3.4	2.2	2.4	2.5	2.6	2.6
Boats and Ships - Ports/Inshore	1.2	1.1	1.4	3.6	1.4	1.5	1.6	1.6	1.7
Rail	1.3	1.2	1.0	1.3	1.9	1.9	1.9	1.9	1.9
Other	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total	***27.2***	***30.7***	***33.2***	***37.3***	***35.6***	***37.2***	***38.8***	***40.7***	***42.6***

Figure C2. Transportation GHG Emissions by Source and Fuel using Alternate VMT Projections, 1990-2030



Key Uncertainties

Uncertainties in Onroad Fuel Consumption

A major uncertainty in this analysis is the conversion of the projected VMT to fuel consumption. These are based on first allocating Kentucky's total VMT projections by vehicle type using national vehicle type growth projections from AEO2009 modeling, which may not reflect Kentucky conditions. The conversion of the VMT data to fuel consumption also includes national assumptions regarding fuel economy by vehicle type.

Energy Independence and Security Act of 2007

The reference case projections documented here do not include the corporate average fuel economy (CAFE) or biofuels provisions (or any other provisions) of the Energy Independence and Security Act of 2007. Increases in vehicle fuel economy resulting from this act would lead to reduced CO_2 emissions from onroad vehicles. Reductions attributable to the CAFE provisions of this Act are quantified as a recent action.

Uncertainties in Aviation Fuel Consumption

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

Uncertainties in Marine Fuel Consumption

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

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

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 Kentucky, 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;[42]
  - Consumption of limestone, dolomite, and soda ash;
- Sulfur hexafluoride (SF_6) from transformers used in electric power transmission and distribution (T&D) systems;
- Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) from consumption of substitutes for ozone-depleting substances (ODS) used in cooling and refrigeration equipment; and
- PFCs from aluminum production.

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

- CO_2 from taconite production;
- Nitrous oxide (N_2O) from nitric and adipic acid production;
- HFCs, PFCs, and SF_6 from semiconductor manufacturing;
- SF_6 from magnesium production and processing; and
- HFCs from HCFC-22 production.

Emissions and Reference Case Projections

Greenhouse gas emissions for 1990 through 2006 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.[43] Table D1 identifies for each emissions source category the information needed for input into SIT to calculate emissions, the data sources used for the analysis described here, and the historical years for which emissions were calculated based on the availability of data.

[42] Note that CO_2 emissions from urea application is estimated as part of the same category as ammonia production.
[43] 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 - 2006	Metric tons (Mt) of clinker produced and masonry cement produced each year.	Historical production for Kentucky from USGS Minerals Yearbook, Cement Statistics and Information (http://minerals.usgs.gov/minerals/pubs/commodity/cement/index.html#myb).
Lime Manufacture	1990-2006	Mt of lime produced each year.	Historical production for Kentucky from USGS Minerals Yearbook, Lime Statistics and Information.(http://minerals.usgs.gov/minerals/pubs/commodity/lime/index.html#myb).
Limestone and Dolomite Consumption	1994 - 2006	Mt of limestone and dolomite consumed.	Historical consumption (sales) for Kentucky 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; data for 1994 were used for 1990 – 1993 as a surrogate to fill in production data missing for these years.
Soda Ash Consumption	1990 - 2006	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/). -- National emissions from *US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005*, US EPA, Report #430-R-07-002, April 2007 (http://epa.gov/climatechange/emissions/usinventoryreport.html). -- US (1990-2000 and 2000-2005) and state (2000-2005) population from US Census Bureau (http://www.census.gov/popest/states/NST-ann-est.html). -- State (1990-2000) population from US Census Bureau (http://www.census.gov/popest/archives/2000s/vintage_2001/CO-EST2001-12/CO-EST2001-12-24.html).
Iron and Steel Production	1990-2007	Mt of crude steel produced by production method.	The basic activity data needed are the quantities of crude steel produced (defined as first cast product suitable for sale or further processing) by production method. Default steel production data are not available in SIT for 1990 – 1996; data for 1997 were used for 1990 – 1996 as a surrogate to fill in production data missing for these years.
Ammonia Production and Urea Application	1990-2006	Mt of ammonia produced and urea consumed	SIT default activity data for urea application for 1990-2006; no default activity data for ammonia production in Kentucky; urea activity data is based on national USGS data.
ODS Substitutes	1990 - 2006	Based on state's population and estimates of emissions per capita from the US EPA national GHG inventory.	References for US EPA national emissions and US Census Bureau national and state population figures are cited under the data sources for soda ash above.
Electric Power	1990 -	Emissions from 1990	National emissions are apportioned to the state based on the ratio of

Source Category	Time Period	Required Data for SIT	Data Source
T&D Systems	2006	to 2006 based on the national emissions per kilowatt-hour (kWh) and state's electricity use provided in SIT.	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.
Aluminum Production	1990-2006	Mt of aluminum produced	Historical production for Kentucky from USGS Minerals Yearbook, Aluminum Annual Report.

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: 1990-2006, 1995-2006, and 2000-2006 (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 2007 through 2030

			Annual Growth Rates (%)				
Source Category	**Projection Assumptions**	**Data Source**	**2006 to 2010**	**2010 to 2015**	**2015 to 2020**	**2020 to 2025**	**2025 to 2030**
Cement Manufacture	Growth rates computed from Portland Cement Association's Cement Outlook 2008	Portland Cement Association's Cement Outlook 2008	-1.21	2.07	1.75	1.49	1.22
Lime Manufacture	Smallest historical annual decline in state production from each of three periods analyzed	Annual change in Kentucky lime production:1990-2006 = 2.93%; 1996-2006 = 1.32%; and 2000-2006 = 7.55%	1.32	1.32	1.32	1.32	1.32
Limestone and Dolomite Consumption	No growth assumption based on conflicting state historical consumption trends; forecast information too broad	Annual change in Kentucky limestone and dolomite consumption:1990-2006 = 11.03%; 1996-2006 = 9.29%; and 2000-2006 = 25.49%	0.00	0.00	0.00	0.00	0.00
Soda Ash Consumption	Growth rate computed from 2006-2016 employment projections in Basic Chemical Manufacturing sector	Workforce KY 2006-2016 Basic Chemical Manufacturing employment	-1.01	-1.01	-1.01	-1.01	-1.01

			Annual Growth Rates (%)				
Source Category	**Projection Assumptions**	**Data Source**	**2006 to 2010**	**2010 to 2015**	**2015 to 2020**	**2020 to 2025**	**2025 to 2030**
Iron and Steel Production	No change assumed due to anomalously large historical growth rates for a limited historical period and conflicting projected decline in Kentucky Primary Metals employment		0.00	0.00	0.00	0.00	0.00
Urea Consumption	Smallest historical annual decline in state consumption from each of three periods analyzed	Annual change in Kentucky urea consumption: 1990-2006 = -1.72%; 1996-2006 = -0.41%; and 2000-2006 = -2.24%	-0.41	-0.41	-0.41	-0.41	-0.41
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	4.80	6.37	5.03	6.70	6.70
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.	-1.05	-0.86	-0.79	-0.79	-0.79
Aluminum Production	National growth rate	Annual growth rates calculated based on US national emissions for 2005-2020 for "Technology-Adoption" scenario for Aluminum Production from Appendix D, Table D-9 in Global Anthropogenic Emissions of Non-CO2 Greenhouse Gases 1990-2020 (EPA Report 430-R-06-003); http://www.epa.gov/nonco2/econ-inv/international.html, assumed 2020-2030 growth same as 2015-2010	-0.35	-0.26	-0.22	-0.22	-0.22

Results

Figures D1 and D2 show historical and projected emissions for the industrial processes sector from 1990 to 2030. Table D3 shows the historical and projected emission values upon which Figures D1 and D2 are based. Total gross Kentucky GHG emissions were about 4.8 $MMtCO_2e$ in 1990, 6.5 $MMtCO_2e$ in 2005, and are projected to increase to about 12.5 $MMtCO_2e$ in 2030. Emissions from the overall industrial processes category are expected to grow by about 2.7% annually from 2005 through2030, as shown in Figures D1 and D2, with emissions growth primarily associated with the increasing use of HFCs and PFCs in refrigeration and air conditioning equipment.

Figure D1. GHG Emissions from Industrial Processes, 1990-2030

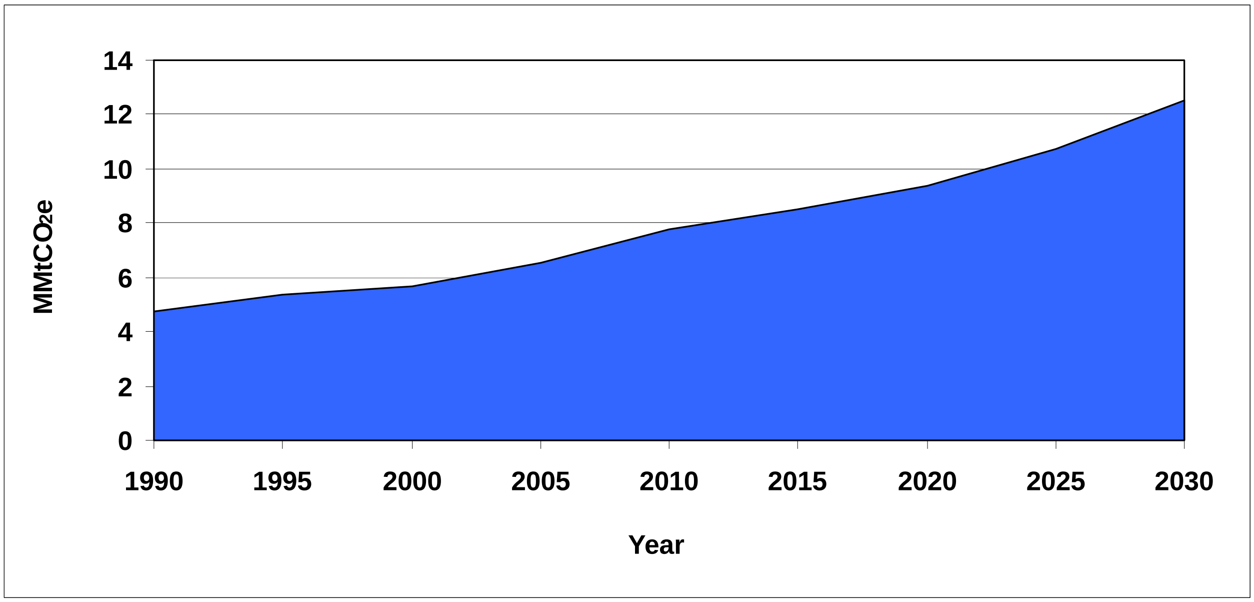


Figure D2. GHG Emissions from Industrial Processes, 1990-2030, by Source

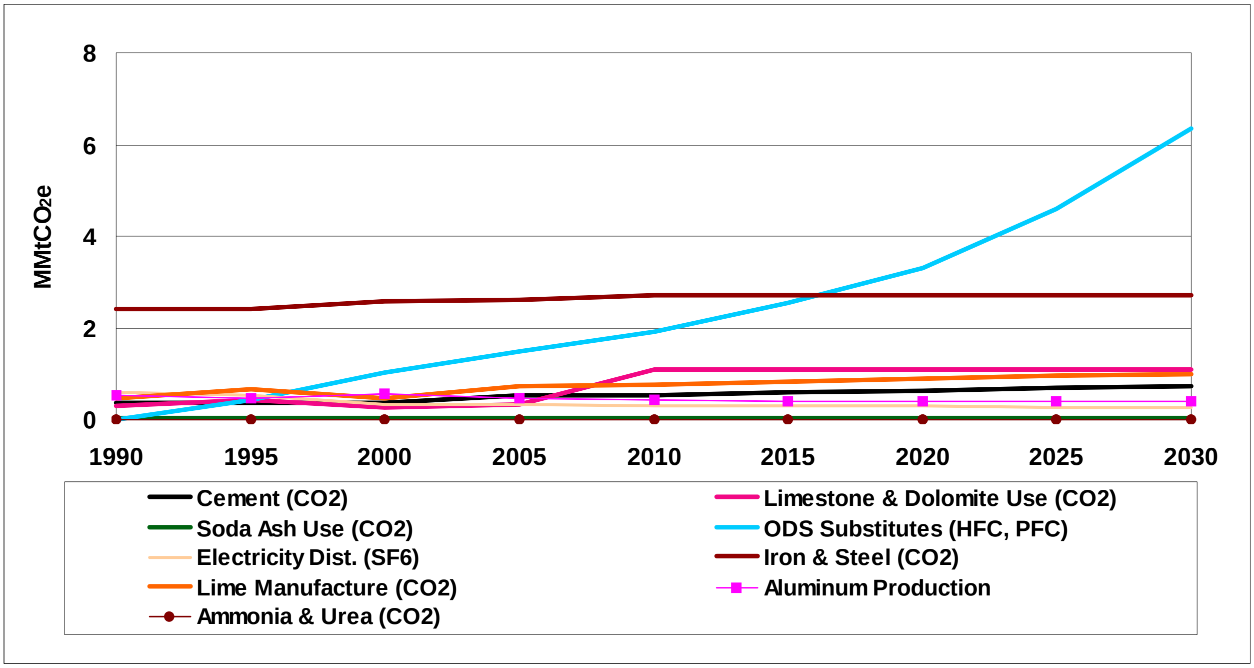


Table D3. Historical and Projected Emissions for the Industrial Processes Sector ($MMtCO_2e$)

Industry / Pollutant	1990	1995	2000	2005	2010	2015	2020	2025	2030
Cement (CO2)	0.37	0.36	0.35	0.54	0.53	0.59	0.64	0.69	0.73
Lime Manufacture (CO2)	0.46	0.67	0.48	0.72	0.77	0.83	0.88	0.94	1.01
Limestone & Dolomite Use (CO2)	0.31	0.43	0.28	0.32	1.08	1.08	1.08	1.08	1.08
Soda Ash Use (CO2)	0.040	0.040	0.038	0.036	0.034	0.033	0.031	0.029	0.028
Iron & Steel (CO2)	2.43	2.43	2.57	2.62	2.70	2.70	2.70	2.70	2.70
Ammonia and Urea (CO2)	0.011	0.009	0.010	0.007	0.008	0.008	0.008	0.008	0.008
ODS Substitutes (HFC, PFC)	0.005	0.42	1.02	1.48	1.90	2.56	3.32	4.59	6.35
Electricity Dist. (SF6)	0.60	0.53	0.34	0.34	0.31	0.29	0.28	0.27	0.26
Aluminum Production	0.53	0.47	0.57	0.46	0.42	0.41	0.40	0.40	0.39
Total	**4.75**	**5.35**	**5.65**	**6.52**	**7.75**	**8.50**	**9.35**	**10.7**	**12.5**

Cement Manufacture

The default production data used for Kentucky shows that both clinker and masonry cement are produced in the State. 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%. Lime accounts for approximately 60% 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 and Table D3, emissions from this source are estimated to be about 0.4 $MMtCO_2e$ in 1990 and are projected to increase to about 0.7 $MMtCO_2e$ by 2030. Historical clinker and masonry cement production data for Kentucky obtained from the USGS (see Table D1) and the default emission factors in SIT were used to calculate CO_2 emissions for 1990-2006. Emissions were projected through 2030 using rates specific to each projection period that were computed from Portland Cement Association's Cement Outlook 2008.

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.).

Emissions associated with lime manufacture were estimated for 1990 through 2006 using the amount of lime produced and an emission factor of 0.75 $MtCO_2$ per ton high-calcium lime and 0.87 $MtCO_2$ per ton dolomitic lime produced. The annual growth rate was developed from an analysis of historical growth, selecting the smallest historical annual decline in state production (1.32% from 1996 to 2006) from each of three periods analyzed. CO_2 emissions from lime production in Kentucky were estimated at about 0.46 $MMtCO_2e$ in 1990, 0.72 $MMtCO_2e$ in 2005, and 0.94 $MMtCO_2e$ in 2030.

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.[44]

[44] 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

Historical limestone and dolomite consumption (sales) data for Kentucky obtained from the USGS (see Table D1) and the default emission factors in SIT were used to calculate CO_2 emissions for 1990-2006. Default data were not available in the SIT for the years from 1990 to 1993, so the 1994 emissions estimate was applied to these years. Emission projections from 2007 to 2030 are held constant at 2006 levels, reflecting the conflicting trends observed for the historical periods analyzed. Relative to total industrial non-combustion process emissions, CO_2 emissions from limestone and dolomite consumption are low (about 0.31 $MMtCO_2e$ in 1990, 0.32 $MMtCO_2e$ in 2005, and 1.08 $MMtCO_2e$ in 2030).

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 based on the state's population and national per capita soda ash consumption from the US EPA national GHG inventory. Growth in this category was estimated as a 1.01% annual decline based on 2006-2016 employment projections in the Basic Chemical Manufacturing sector for Kentucky. CO_2 emissions from soda ash consumption are low, estimated at about 0.04 $MMtCO_2e$ in 1990, 0.04 $MMtCO_2e$ in 2005, and at about0.03 $MMtCO_2e$ in 2030.

Iron and Steel Production

The SIT shows production of iron and steel in Kentucky from 1997 through 2006. The production of iron and steel generate 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 Kentucky's CO_2 emissions from iron and steel production (see Table D1). The basic activity data needed are the quantities of crude steel produced (defined as first cast product suitable for sale or further processing) by production method. Default SIT emission factors of 0.08 $MtCO_2$ per Mt, 1.46 $MtCO_2$ per Mt, and 1.72 $MtCO_2$ per Mt production were used for EAF steel production from scrap metal, BOF production without coke ovens, and BOF production with coke ovens, respectively. Emissions estimated for 1997 were also applied to the years 1990-1996 since the production data were missing for those years. As shown in Figure D2 and Table D3, emissions in 1990 were 2.4 $MMtCO_2e$ and are projected to increase slightly to about 2.7 $MMtCO_2e$ in 2030. No growth was assumed for iron and steel emissions from 2007 to 2030 due to anomalously large historical growth rates for a limited historical period in combination with a conflicting projected decline in Kentucky Primary Metals employment.

Ammonia Production/Urea Application

under the methods for the agricultural sector), and (3) limestone used in cement production (which is counted in the methods for cement production).

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

The default production and consumption data in SIT show no ammonia production in Kentucky over the historical period. Emissions from urea application are estimated to be fairly low at 0.011 $MMtCO_2e$ in 1990, decreasing to 0.007 in 2005, and increasing slightly to 0.008 by 2030. and decreased to 0.49 $MMtCO_2e$ in 2005 (see blue line in Figure D2). A decline in growth of 0.41% annually from 2007 to 2030 was applied based on the smallest historical annual decline in state consumption from each of three periods analyzed.

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*.[45] 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 in Kentucky from this sector are estimated to have increased from 0.01 $MMtCO_2e$ in 1990 to about 1.5 $MMtCO_2e$ in 2005, and to further increase to 6.3 $MMtCO_2e$ in 2030. The projected rates of increase for these emissions are 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, 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.[46]

As shown in Figure D2 and Table D3, SF_6 emissions from electric power T&D are about 0.60 $MMtCO_2e$ in 1990 and decrease to about 0.34 $MMtCO_2e$ in 2005. Emissions further decrease t

[45] 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.

[46] 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.

about 0.26 $MMtCO_2e$ in 2030. Emissions in Kentucky from 1990 to 2006 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 Kentucky's 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 2007-2030 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 Kentucky. The decline in SF_6 emissions in the future reflects expectations of future actions by the electric power industry to reduce these emissions.

Aluminum Production

Emissions of tetrafluoromethane and hexafluoroethane, both PFCs, occur during the reduction of alumina in the primary smelting process. The aluminum production industry is thought to be the largest source of these two PFCs. Emissions from aluminum production are calculated in the SIT by multiplying the quantity of aluminum produced by an emission factor of 0.4255 Mt carbon equivalent per Mt aluminum produced.

The SIT shows aluminum production activity in Kentucky throughout the historical period. Emissions were then projected using national growth rates based on US national emissions for 2005-2020 for a technology adoption scenario for the aluminum production industry as indicated in Table D2. GHG emissions in Kentucky from aluminum production are estimated at 0.53 $MMtCO_2e$ in 1990, 0.46 $MMtCO_2e$ in 2005, and declining to 0.39 $MMtCO_2e$ in 2030.

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 Kentucky manufacturers in these industries, and the specific nature of the production processes used in Kentucky. Emissions in this draft inventory were based on default activity data provided in the SIT. These data should be reviewed and modified as necessary based on actual data reported by Kentucky facilities.
- The projected largest source of future industrial emissions, HFCs and PFCs used in cooling applications, is subject to several uncertainties as well. Emissions through 2030 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, magnesium casting, and taconite 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 the electricity T&D and semiconductor industries, 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 Kentucky.[47] In 2007, emissions from the subsector accounted for an estimated 7.64 million metric tons (MMt) of CO_2 equivalent (CO_2e) of total gross greenhouse gas (GHG) emissions in Kentucky, and are estimated to decrease to 6.90 $MMtCO_2e$ by 2030.

Emissions and Reference Case Projections

Oil and Gas Production
In 2007, Kentucky's crude oil production totaled 7,000 barrels (bbls) per day, accounting for only 0.1% of US production. The peak year of oil production in Kentucky was 1983 (22,000 bbls per day). Production steadily declined until 2000 and has remained relative stable since.[48] Proved crude oil reserves are 24 million bbls, which is also 0.1% of the US total.[49] Though Kentucky has only minor oil production, it is home to two operating petroleum refineries located in Catlettsburg and Somerset. Both of these primarily process petroleum received from out of state: Catlettsburg from the Gulf Coast and Somerset from neighboring states. The crude oil distillation capacity between the two facilities is 231,500 bbls per day.[50]

Kentucky is also responsible for about 1% of the Nation's natural gas production, the majority of which originates in the Big Sandy field located in eastern portion of the State. In 2007, Kentucky consumed approximately 230 billion cubic feet (Bcf) of natural gas while it produced only 95 Bcf. The majority of the difference was supplied by pipeline from the Gulf Coast. Industry is responsible for about 50% of the natural gas consumption in the State.[50]

The vast majority (99%) of Kentucky's oil and gas emissions comes from the natural gas sector, predominantly in the production and transportation of natural gas through the State's transmission pipelines. Historically, pipeline fuel consumption was the leading contributor; however, there has been a steep decline in this subsector since the mid-1990s and it now accounts for only 17% of natural gas emissions.

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

[47] 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.
[48] US Department of Energy (DOE), Energy Information Administration (EIA), "Crude Oil Production", accessed from http://tonto.eia.doe.gov/dnav/pet/pet_crd_crpdn_adc_mbblpd_a.htm, December 2009.
[49] US DOE, EIA, "Crude Oil Proved Reserves, Reserves Changes, and Production," accessed from http://tonto.eia.doe.gov/dnav/pet/pet_crd_pres_dcu_SKY_a.htm, December 2009.
[50] "State Energy Profiles: Kentucky", US DOE, EIA website, accessed from http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=KY, December 2009.

(EIIP) guidance[51] 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 nearly 16,600 active gas-producing wells in the state, 4 operational gas processing plants, and more than 24,000 miles of gas pipelines, there are significant uncertainties associated with estimates of Kentucky's 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 Kentucky 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)[52] and the US Department of Transportation's Office of Pipeline Safety (OPS).[53] Emissions were estimated using the SIT, with reference to methods/data sources outlined in the EIIP guidance document for natural gas and oil systems.[54] Emissions of CO_2, CH_4, and N_2O associated with pipeline natural gas combustion were estimated using SIT emission factors[55] and Kentucky's 1990-2007 natural gas data from EIA for the "consumed as pipeline fuel" category.[56]

Unfortunately OPS has not collected data from pipeline operators using a consistent set of reporting requirements over the 1990-2007 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 Kentucky pipeline records report data as multi-state totals. To estimate a complete time-series of natural gas transmission/gathering pipeline data, CCS compiled surrogate data to back-cast the 2001 transmission/gathering pipeline mileage and the 2004 distribution pipeline mileage/service counts for each year back to 1990.

---

[51] Emission Inventory Improvement Program, Volume VIII: Chapter 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems," August 2004.
[52] US DOE, EIA website, http://www.eia.doe.gov/, December 2009.
[53] US Department of Transportation, Office of Pipeline Safety, "Distribution, Transmission and Liquid Annual Data," accessed from http://ops.dot.gov/stats/DT98.htm, December 2009.
[54] Emission Inventory Improvement Program, Volume VIII: Chapter. 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems", August 2004.
[55] 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.
[56] US DOE, EIA, *State Energy Consumption, Price, and Expenditure Estimates (SEDS)*, accessed from http://www.eia.doe.gov/emeu/states/_seds.html, December 2009.

Coal Mining Emissions
Methane occurs naturally in coal seams, and is typically vented during mining operations for safety reasons. Coal mine methane emissions are usually considerably higher, per unit of coal produced, from underground mining than from surface mining. Underground coal mines continue to emit CH_4 the mines have been abandoned or shut down. The rate of CH_4 emitted decreases over time, and is also affected by factors such as gas content and characteristics of coal, flooding, CH_4 flow capacity of the mine, the presence of vent holes, and mine seals.

Kentucky had 417 operational coal mines (more than any other state), which together produced more than 115 million short tons of coal in 2007.[57] Of Kentucky's 417 coal mines in 2007, 201 were underground and 216 were surface mines. This inventory includes CH_4 emissions from operational coal mines as reported by the US EPA, and includes emissions from underground coal mines, surface mines, and post-mining activities.[58]

Table E1 provides an overview of data sources and approaches used to develop fossil fuel sector emission estimates for Kentucky, including a description of the surrogate data that were used to back-cast natural gas transmission/gathering and distribution 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 Kentucky. 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 (AEO) 2009 forecast data for each 5-year time-frame over the 2007-2030 analysis period (except the final time period which includes 2022 to 2030), and the other using the historical 1990-2007 activity data for each of 3 periods (i.e., 1990 to 2007, 1995 to 2007, and 2000 to 2007). Because available AEO forecast information is for a broad region that may not reflect Kentucky-specific trends (e.g., AEO forecasts of natural gas production are for the East South Central Region, which includes 3 states in addition to Kentucky), the AEO forecast growth rates were only used when they were in-line with the Kentucky historical growth rates. Therefore, some oil and gas production sector projections are based on state-level historical activity/emissions trends. In cases where of each the three historical periods indicated continual growth or decline, the period with the smallest annual rate of growth/decline was used in the projection. This conservative assumption was adopted because of the uncertainty associated with utilizing historical trends to estimate future emission activity levels.

It is important to note that potential improvements to production, processing, and pipeline technologies that could result in GHG emissions reductions are generally not accounted for in the projections analysis.

---

[57] *Annual Coal Report 2008, Preliminary Release*, DOE/EIA-0584 (2008), "Table 1. Coal Production and Number of Mines by State and Mine Type, 2008-2007," US DOE, EIA, September 2009, http://www.eia.doe.gov/cneaf/coal/page/acr/table1.html.
[58] US Environmental Protection Agency, "Inventory Of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007", April 2009

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

	Approach to Estimating Historical Emissions		Surrogate Data Used to Backcast	Forecasting Approach
Activity	***Required SIT Data***	***Data Source***	**Activity to 1990**	***Projection Assumption***
Natural Gas Production	Number of gas/ associated wells	Gas wells - EIA[59]		Annual growth rate (1.84%) based on smallest annualized increase in the number of natural gas wells from each of 3 periods analyzed (1995-2007).
Natural Gas Processing	Number of gas processing plants	*Oil and Gas Journal*[60]		Assumed no growth because last 9 years of data show nearly constant number of gas processing plants (excluding anomaly in 2002).
Natural Gas Transmission	Miles of gathering pipeline	Office of Pipeline Safety[53]	KY natural gas production as reported by EIA[61]	Used AEO 2009[62] East South Central natural gas flows projections since annual decline over forecast period (-0.70%) is in-line with long-term historical KY transmission emissions trend.
	Miles of transmission pipeline		Average of volume of natural gas transported into KY and transported out of KY, from EIA[63]	
	Number of gas transmission compressor stations	EIIP[64]		
	Number of gas storage compressor stations	EIIP[65]		

[59] US DOE, EIA, "Kentucky Natural Gas Number of Gas and Gas Condensate Wells," accessed from http://tonto.eia.doe.gov/dnav/ng/hist/na1170_sky_8a.htm, December 2009.
[60] PennWell Corporation, "Worldwide Gas Processing," *Oil and Gas Journal* (1990-2007 June/July issues).
[61] US DOE, EIA, "Natural Gas Withdrawals and Production," accessed from http://tonto.eia.doe.gov/dnav/ng/ng_prod_sum_a_EPG0_FPD_mmcf_a.htm, December 2009.
[62] US DOE, Energy Information Administration, "Annual Energy Outlook 2009 with Projections to 2030," accessed from http://www.eia.doe.gov/oiaf/archive/aeo09/index.html, December 2009.
[63] US DOE, EIA, "International & Interstate Movements of Natural Gas by State," accessed from http://tonto.eia.doe.gov/dnav/ng/ng_move_ist_a2dcu_nus_a.htm, December 2009.
[64] Number of gas transmission compressor stations = miles of transmission pipeline x 0.006 – EIIP, Volume VIII: Chapter 5, March 2005.
[65] 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** – *Required SIT Data*	*Data Source*	**Surrogate Data Used to Backcast Activity to 1990**	**Forecasting Approach** – *Projection Assumption*
Natural Gas Distribution	Miles of distribution pipeline by pipeline material type Total number of services Number of unprotected steel services Number of protected steel services	Office of Pipeline Safety[53]	Sum of industrial, residential and commercial KY natural gas consumers, from EIA[66]	Used AEO 2009 East South Central natural gas consumption projections since annual growth over forecast period (0.69%) is in-line with long-term historical KY distribution emissions trend.
Natural Gas Pipeline Fuel Use (CO_2, CH_4, N_2O)	Volume of natural gas consumed by pipelines	EIA[56]		Assumed no growth due to volatility in historical data and inconsistency with AEO 2009 projections.
Oil Production	Annual production	EIA[67]		Annual growth rate (2.27%) based on smallest annualized increase in historical oil production from each of 3 periods analyzed (1995-2007).
Oil Refining	Annual volume refined	EIA[68]		Annual rate of decline (-0.07%) based on smallest annualized decrease in historical oil refining from each of 3 periods analyzed (1990-2007).
Oil Transport	Annual volume transported	Unavailable (per SIT, assumed oil refined = oil transported)		(same as oil refining)
Coal Mining	Methane emissions in million cubic feet	US EPA[16]		Used AEO Central Appalachia coal production projections since annual decline over forecast period (-1.95%) is in-line with long-term historical KY coal mining emissions trend.

[66] US DOE, EIA, "Number of Natural Gas Consumers," accessed from http://tonto.eia.doe.gov/dnav/ng/ng_cons_num_a_EPG0_VN3_Count_a.htm . December 2009.
[67] US DOE, EIA, "Annual Kentucky Field Production of Crude Oil," accessed from http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=mcrfpky1&f=A, December 2009.
[68] Refining is assumed to be equal to the total input of crude oil into PADD II times the ratio of Kentucky's refining capacity to PADD II'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, EIA, "Petroleum Navigator." PADD capacity data accessed from http://tonto.eia.doe.gov/dnav/pet/hist/8_na_8do_r20_4a.htm. PADD crude input data accessed from http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=mgirip22&f=A. State capacity data accessed from http://tonto.eia.doe.gov/dnav/pet/hist/8_na_8do_sky_4a.htm, December 2009.

Results

Table E2 displays the estimated emissions from the fossil fuel industry in Kentucky for select years over the period 1990 to 2030. Emissions from this sector declined by 10% from 1990 to 2007 and are projected to decline by an additional 10% between 2007 and 2030. Natural gas production and transmission and coal mining are the major contributors to both recent historic and future year emissions.

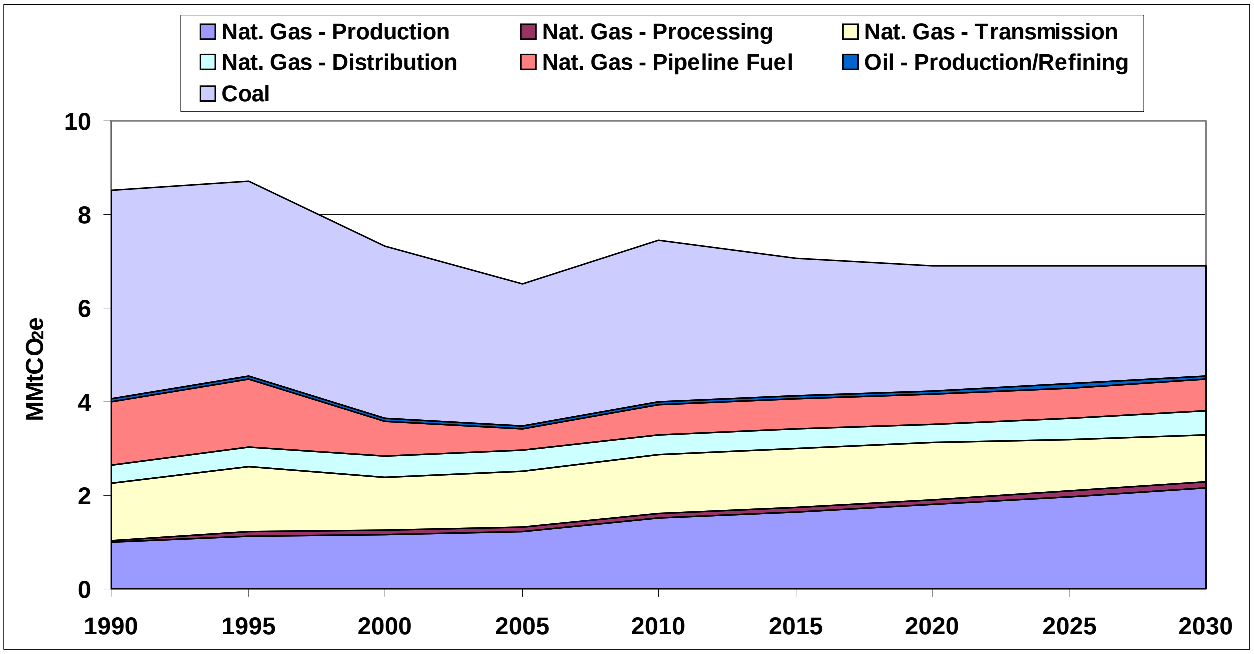
Table E2. Historical and Projected Emissions for the Fossil Fuel Industry

(Million Metric Tons CO_2e)	1990	1995	2000	2005	2007	2010	2015	2020	2025	2030
Fossil Fuel Industry	8.51	8.70	7.33	6.50	7.64	7.46	7.05	6.91	6.91	6.90
Natural Gas Industry	4.00	4.49	3.59	3.43	3.83	3.95	4.06	4.17	4.30	4.47
Production	*0.99*	*1.13*	*1.16*	*1.22*	*1.43*	*1.51*	*1.65*	*1.81*	*1.98*	*2.17*
Processing	*0.05*	*0.08*	*0.10*	*0.10*	*0.10*	*0.10*	*0.10*	*0.10*	*0.10*	*0.10*
Transmission	*1.23*	*1.41*	*1.12*	*1.20*	*1.21*	*1.26*	*1.26*	*1.21*	*1.12*	*1.01*
Distribution	*0.37*	*0.41*	*0.44*	*0.45*	*0.44*	*0.42*	*0.40*	*0.40*	*0.45*	*0.54*
Flaring	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
Pipeline Fuel	*1.36*	*1.46*	*0.76*	*0.45*	*0.65*	*0.65*	*0.65*	*0.65*	*0.65*	*0.65*
Oil Industry	0.08	0.06	0.06	0.05	0.05	0.05	0.06	0.06	0.07	0.08
Production	*0.07*	*0.05*	*0.05*	*0.04*	*0.04*	*0.04*	*0.05*	*0.05*	*0.06*	*0.07*
Refining	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*
Coal Mining	4.43	4.15	3.68	3.03	3.75	3.46	2.93	2.67	2.53	2.35

Note: CCS calculations based on approach described in text.

Figure E1 displays process-level emission trends from the fossil fuel industry, on an $MMtCO_2e$ basis.

Figure E1. Fossil Fuel Industry Emission Trends (MMtCO$_2$e)



Source: CCS calculations based on approach described in text.

Key Uncertainties

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

- Current levels of fugitive emissions. These are based on industry-wide averages, and until estimates are available for local facilities, significant uncertainties remain.
- Due to data limitations associated with OPS reporting, natural gas distribution, 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.[69]
- Because pipeline emissions are a function of both pipeline mileage/service counts and the type of pipeline material (e.g., plastic vs. cast iron), this approach does not account for emissions changes that would have occurred from any changes in pipeline material between 1990 and 2004.
- Projections of future production of fossil fuels. The assumptions used for the projections do not reflect all potential future changes that could affect GHG emissions, including potential changes in regulations and emissions-reducing improvements in oil and gas production, processing, and pipeline technologies.

[69] For example, gathering pipeline emissions were back-cast to pre-2001 years by applying the ratio of Kentucky natural gas production in each pre-2001 year to Kentucky 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 both livestock and crop production. These include emissions and sinks of carbon dioxide (CO_2) in agricultural soils. Energy emissions related to agricultural practices (combustion of fossil fuels to power agricultural equipment) are included in the residential, commercial, and industrial (RCI) fuel consumption sector estimates (see Appendix B). The primary GHG sources and sinks - livestock production and crop production are further subdivided as follows:

- *Livestock production – enteric fermentation:* CH_4 emissions from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock. Microbes in the animal digestive system break down food and emit CH_4 as a by-product. More CH_4 is produced in ruminant livestock because of digestive activity in the large fore-stomach.
- *Livestock production – manure management:* CH_4 and N_2O emissions from the storage and treatment of livestock manure (e.g., in compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition. The environmental conditions of decomposition drive the relative magnitude of emissions. In general, the more anaerobic the conditions are, the more CH_4 is produced because decomposition is aided by CH_4-producing bacteria that thrive in oxygen-limited conditions. In contrast, N_2O emissions are increased under aerobic conditions.
  Emission estimates from manure management are based on manure that is stored and treated on livestock operations (e.g. dairies, feedlots, swine operations). Emissions from manure deposited directly on land by grazing animals and emissions from manure that is applied to agricultural soils as an amendment are accounted for in the next sector.
- *Livestock production, agricultural soils – livestock:* this source sector covers N_2O emissions resulting from animal excretions directly on agricultural soils (e.g. pasture, paddock or range) or manure spreading on agricultural soils.
- *Crop production, agricultural soils – fertilizers:* The management of agricultural soils can result in N_2O emissions and net fluxes of 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 the underlying soil nitrification and de-nitrification cycle, which produces N_2O as a by-product.
  The emissions estimation methodologies used in this inventory account for several sources of N_2O emissions from agricultural soils, including decomposition of crop residues, synthetic and organic fertilizer application, manure application, sewage sludge application, nitrogen fixation, and histosols (high organic soils, such as wetlands or peatlands) cultivation (see additional agricultural soils subsectors below).
  Both direct and indirect emissions of N_2O occur from the application of manure, fertilizer, and sewage sludge to agricultural soils. Direct emissions occur at the site of application and indirect emissions occur when nitrogen leaches to groundwater or in surface runoff and enters the nitrification/denitrification cycle.

- *Crop production, agricultural soils – crops:* this source sector covers N_2O emissions from decomposition of crop residues, production of nitrogen fixing crops, and the cultivation of histosols.
- *Crop production, agricultural soils – liming:* the practice of adding limestone and dolomite to agricultural soils (for neutralizing acidic soil conditions) results in CO_2 emissions.
- *Crop production, agricultural soils – rice cultivation:* CH_4 emissions occur during rice cultivation; however, rice is not grown in Kentucky.
- *Crop production, agricultural soils – soil carbon:* the net flux of CO_2 in agricultural soils depends on the balance of carbon losses from management practices and gains from organic matter inputs to the soil. Carbon dioxide is absorbed by plants through photosynthesis and ultimately becomes the carbon source for organic matter inputs to agricultural soils. When inputs are greater than losses, the soil accumulates carbon and there is a net sink of CO_2 into agricultural soils. In addition, soil disturbance from the cultivation of histosols releases large stores of carbon from the soil to the atmosphere in the form of CO_2 (Note: N_2O emissions from cultivation of histosols are covered under the *Agricultural soils - crops* sector above).
- *Crop production, residue burning:* CH_4 and N_2O emissions are produced when crop residues are burned (CO_2 is emitted as well, however, since the source of carbon is biogenic, these emissions are not included in the inventory).

Emissions and Reference Case Projections

Inventory Data

GHG emissions for 1990 through 2006 were estimated using the United States Environmental Protection Agency's (US EPA) State Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[70] 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, 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.[71]

Data on crop production in Kentucky from 1990 to 2006 and on the number of animals in the state from 1990 to 2006 were obtained from the United States Department of Agriculture (USDA), National Agriculture Statistical Service (NASS) and incorporated as defaults in SIT.[72] The default SIT manure management system assumptions for each livestock category were used for this inventory. SIT data on fertilizer usage came from *Commercial Fertilizers*, a report from

[70] GHG emissions were calculated using SIT, with reference to Emission Inventory Improvement Program, 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.
[71] Revised 1996 1ntergovermental Panel on Climate Change 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/).
[72] USDA, NASS (http://www.nass.usda.gov/Statistics_by_State/Kentucky/index.asp).

the Fertilizer Institute. Details for each of the livestock and crop production subsectors are provided below.

Livestock production – enteric fermentation. SIT default data on livestock populations are taken from the USDA NASS and are available from 1990-2006. Methane emission factors specific to each type of animal by region (e.g. dairy cattle, beef cattle, sheep, goats, swine, and horses) are provided in SIT.

Livestock production – manure management. The same population data used above for enteric fermentation are also used as input to estimate CH_4 and N_2O emissions from manure management. Population estimates are multiplied by an estimate for typical animal mass and a volatile solids (VS) production rate to estimate the total VS produced. The VS estimate for each animal type is then multiplied by a maximum potential CH_4 emissions factor and a weighted CH_4 conversion factor to derive total CH_4 emissions. The methane conversion factor adjusts the maximum potential methane emissions based on the types of manure management systems employed in Kentucky.

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

Livestock and Crop Production, agricultural soils - fertilizers, crops, and livestock. The fertilizers subsector covers direct and indirect N_2O emissions from the application of synthetic and organic fertilizers. The crops subsector covers N_2O emissions from nitrogen fixing crops, decomposition of crop residues, and cultivation of high organic content soils (histosols). The livestock subcategory covers N_2O emissions from animal excretions directly onto the land area or from manure applied to soils as an amendment.

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

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

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

Another direct emissions source of N_2O from agricultural soils comes from animal excretions directly onto the land area (e.g. pasture, paddock, or range). This requires data on animal population, mass and N emitted per unit of animal mass, as well as the amount of manure left on the soil.

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

Data on crop production in Kentucky from 1990 to 2006 from the USDA NASS were used to calculate N_2O emissions from crop residues and crops that fix nitrogen, as well as CH_4 emissions from agricultural residue burning. Emissions for the other agricultural crop production practices categories (i.e., synthetic and organic fertilizers) were also calculated through 2006.

Data were not available to estimate nitrogen released by the cultivation of histosols (i.e., the number of acres of high organic content soils). However, as discussed in the following section for soil carbon, the Natural Resources Ecology Laboratory at Colorado State University estimated zero CO_2 emissions for organic soils in Kentucky for 1997, suggesting that the area of cultivated high organic content soils was either very small or zero in Kentucky. Therefore, N_2O emissions from cultivated histosol soils were also assumed to be zero.

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

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

Crop production – soil carbon. Net carbon fluxes from agricultural soils have been estimated by researchers at the Natural Resources Ecology Laboratory at Colorado State University, and are reported in the *U.S. Inventory of Greenhouse Gas Emissions and Sinks*[73] and the *U.S. 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 *U.S. Agriculture and*

[73] *U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2006* (and earlier editions), US Environmental Protection Agency, Report # 430-R-06-002, April 2006. Available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

Forestry Greenhouse Gas Inventory. Currently, these are the best available data at the state-level for this category. The inventory also reports national estimates of CO_2 emissions from limestone and dolomite application from the United States Geological Survey (USGS).[74] However, these are now included above under the *Agricultural soils – liming* subsector.

Carbon dioxide fluxes resulting from specific management practices were reported. These practices include: conversions of cropland resulting in either higher or lower soil carbon levels; additions of manure; participation in the Federal Conservation Reserve Program (CRP); and cultivation of organic soils (with high organic carbon levels). For Kentucky, Table F2 shows a summary of the latest estimates available from the USDA, which are for 1997.[75] These data show that changes in agricultural practices are estimated to result in a net sink of 1.14 $MMtCO_2e$/yr in Kentucky. Since data are not yet available from USDA to make a determination of whether the emissions are increasing or decreasing, the net sink of 1.14 $MMtCO_2e$/yr is assumed to remain constant.

Note that emissions from agricultural soils estimated using the SIT were multiplied by a national adjustment factor to reconcile differences between methodologies used in EPA's National Inventory of Greenhouse Gas Emissions and the SIT. The national adjustment factor varies substantially from year to year resulting in the introduction of noise into the agricultural soils categories. The Agriculture, Forestry and Waste Technical Working Group should discuss whether the National Adjustment Factor should be applied in the Kentucky Inventory and Forecast.

Crop production – residue burning. Agricultural residue burning is conducted in Kentucky. The default SIT method was used to calculate emissions along with NASS crop production data through 2006. The SIT methodology calculates emissions by multiplying the amount (e.g., bushels or tons) of each crop produced by a series of factors to calculate the amount of crop residue produced, the resultant dry matter, the carbon/nitrogen content of the dry matter, the fraction of dry matter burned, the combustion efficiency, and emission factors for N_2O and CH_4. Future work on this category should include an assessment to refine the SIT default assumptions.

Reference Case Projections

Future reference case emissions from both livestock and crop production were estimated based on the annual growth rate in emissions [million metric ton (MMt) carbon dioxide equivalent (CO_2e) basis] for each source sector from 1990 to 2006. For livestock production, the default data in SIT accounting for the percentage of each livestock category using each type of manure management system was used for this inventory.

[74] 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/.

[75] *U.S. 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 F2. The sum of the first nine columns is equivalent to the mineral soils category.

Table F1 shows the annual growth rates applied to estimate the reference case projections by agricultural sector. Emissions from enteric fermentation and agricultural soils were projected based on the annual growth rate in historical emissions ($MMtCO_2e$ basis) for these categories in Kentucky for 1990 to 2006.

Table F1. Growth Rates Applied for the Agricultural Sector

Agricultural Category	Growth Rate	Basis for Annual Growth Rate*
Enteric Fermentation	-0.03%	Historical emissions for 1990-2006.
Manure Management	-0.9%	Historical emissions for 1990-2006.
Agricultural Burning	0.9%	Historical emissions for 1990-2006.
Agricultural Soils – Direct Emissions		
Fertilizers	-1.0%	Historical emissions for 1990-2006.
Crop Residues	-0.3%	Historical emissions for 1990-2005. 2005 was used instead of 2006, because that year is seen as an outlier.
Nitrogen-Fixing Crops	-0.9%	Historical emissions for 1990-2005. 2005 was used instead of 2006, because that year is seen as an outlier.
Histosols	n/a	Not included in inventory.
Livestock	-1.7%	Historical emissions for 1990-2006.
Agricultural Soils – Indirect Emissions		
Fertilizers	-0.7%	Historical emissions for 1990-2006.
Livestock	-3.1%	Historical emissions for 1990-2006.
Leaching/Runoff	-1.3%	Historical emissions for 1990-2006.

* Compound annual growth rates shown in this table were calculated using the growth rate in historical emissions ($MMtCO_2e$ basis) from 1990 through the most recent year of data. These growth rates were applied to forecast emissions from the latest year of inventory data to 2025.

The growth rates for enteric fermentation and manure management are driven by livestock populations and manure management methods. From 1990 through 2006, dairy cattle populations declined by about 45%. The growth rate for beef cattle during the 16-year period from 1990 through 2006 was 5%. The swine population in Kentucky declined about 65% from 1990 through 2006. The growth rates shown in Table F1 are calculated using the trend in emissions from 1990 through 2006 associated with the historical livestock populations and default SIT assumptions on manure management systems used in Kentucky. Future work should include an evaluation to improve the growth rates used for the reference case projections (e.g. based on available studies of future agricultural activity in Kentucky). Such an evaluation should also include an assessment to improve the growth rates for forecasting emissions associated with the use of fertilizers containing nitrogen. Use of fertilizers that contain nitrogen in Kentucky indicated a total growth rate of 12% between 1990 and 2006; however, fertilizer use peaked in 2004.

Results

As shown in Figure F1, gross GHG emissions from agricultural sources range between about 7.89 and 6.59 $MMtCO_2e$ from 1990 through 2030, respectively. See Table F2 for more information on Kentucky gross GHG emissions. Enteric fermentation is the only major emissions category growing in the forecast period in Kentucky, and accounted for about 48% (3.25 $MMtCO_2e$) of total agricultural emissions in 1990 and is estimated to account for about 58% (3.16 $MMtCO_2e$) of total agricultural emissions in 2030. The manure management category, accounted for 7.1% (0.48 $MMtCO_2e$) of total agricultural emissions in 1990 and is estimated to account for about 7.5% (0.41 $MMtCO_2e$) of total agricultural emissions in 2030. The agricultural soils category shows 1990 emissions accounting for 61% (4.15 $MMtCO_2e$) of total agricultural emissions and 2030 emissions estimated to be about 55% (3.00 $MMtCO_2e$) of total agricultural emissions. Because soil carbon is estimated to be a net sink of CO_2 in Kentucky, it is not included in the gross GHG emissions. See Table F3 for more information on soil carbon estimates. Including the CO_2 sequestration from soil carbon changes, the historic and projected emissions for the agriculture sector on a net basis would range between about 6.75 and 5.45 $MMtCO_2e$/yr from 1990 through 2030, respectively.

Table F2. Gross GHG Emissions from Agriculture 1990-2030 ($MMtCO_2e$)

Source Sector	1990	1995	2000	2005	2010	2015	2020	2025	2030
Enteric Fermentation	3.25	3.47	2.91	3.12	3.14	3.06	3.02	3.04	3.16
Manure Management	0.48	0.52	0.48	0.53	0.45	0.42	0.40	0.40	0.41
Ag Soils-Fertilizers	0.79	0.75	0.79	0.81	0.73	0.71	0.69	0.66	0.64
Ag Soils-Crops	0.77	0.74	0.79	0.88	0.75	0.75	0.75	0.75	0.75
Ag Soils-Livestock	2.11	2.07	1.73	2.38	1.87	1.80	1.73	1.66	1.60
Ag Soils-Liming	0.48	0.32	0.24	0.13	0.09	0.06	0.04	0.02	0.02
Agricultural Burning	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Gross Total	**7.89**	**7.88**	**6.96**	**7.88**	**7.05**	**6.81**	**6.65**	**6.56**	**6.59**
Soil Carbon (Cultivation Practices)	-1.14	-1.14	-1.14	-1.14	-1.14	-1.14	-1.14	-1.14	-1.14
Net Total	**6.75**	**6.74**	**5.82**	**6.74**	**5.91**	**5.67**	**5.51**	**5.42**	**5.45**

Table F3. GHG Emissions from Soil Carbon Changes Due to Cultivation Practices ($MMtCO_2e$)

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
0.95	(0.11)	(0.07)	(0.84)	(0.04)	(0.77)	0.00	(0.11)	(0.15)	0.00	(1.14)

Based on USDA 1997 estimates. Parentheses indicate net sequestration.

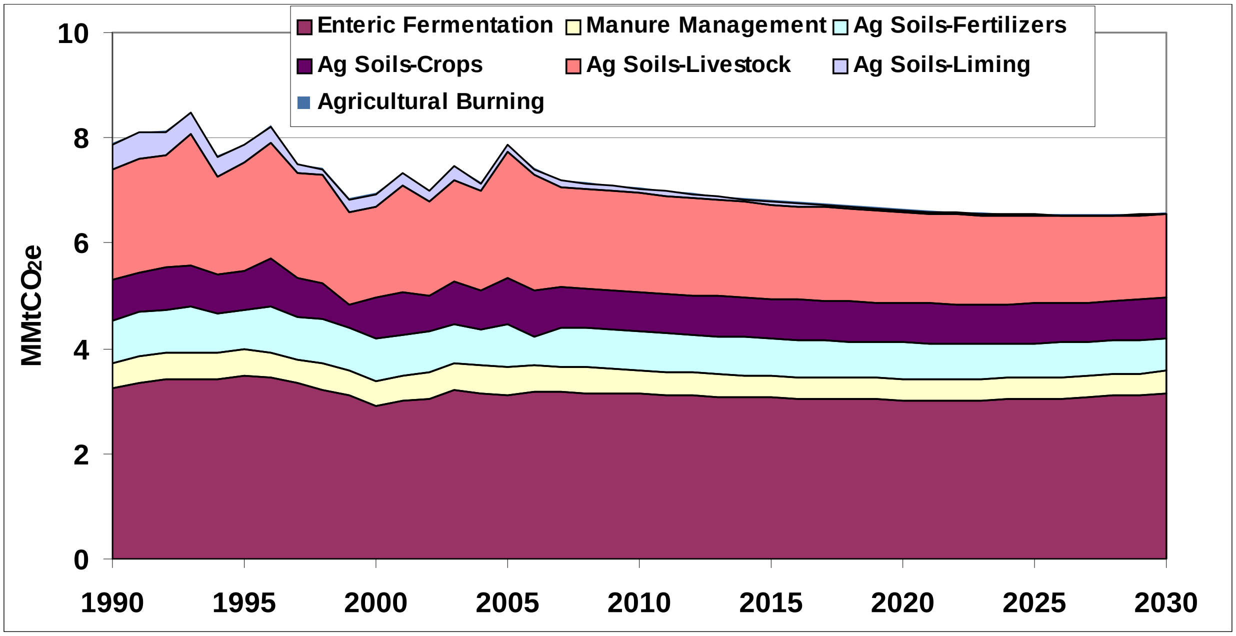
[1] Losses from annual cropping systems due to plow-out of pastures, rangeland, hayland, set-aside lands, and perennial/horticultural cropland (annual cropping systems on mineral soils, e.g., corn, soybean, cotton, and wheat).

[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.

Figure F1. Gross GHG Emissions from Agriculture 1990-2030



Source: CCS 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 in Kentucky); emissions for agricultural residue burning are too small to be seen in this chart. Soil carbon sequestration is not shown (see Table F2).

Agricultural burning emissions were estimated to be very small based on the SIT activity data (<0.02 $MMtCO_2e$/yr from 1990 to 2006). This agrees with the USDA Inventory which also reports a low level of residue burning emissions (0.02 $MMtCO_2e$).[76]

The only standard IPCC source categories missing from this report are N_2O emissions from cultivation of histosols.

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 that are dependent on several variables, including manure production levels, volatile solids contents of manures, 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. CCS believes that the largest contributors to uncertainty in emissions from manure management are the emission factors, which are derived from limited data sets.

[76] http://www.usda.gov/oce/global_change/AFGG_Inventory/AppendixB.pdf *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2005*. Global Change Program Office, Office of the Chief Economist, US Department of Agriculture.

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 Conservation Reserve Program acreage to retire and possibly return to active cultivation prior to 2030, the current size of the CO_2 sink could be appreciably affected (possibly even turning this net sink into a net source of CO_2 in the future).

Another contributor to uncertainty in the emission estimates is the projection assumptions. This inventory assumes that the average annual rate of change in future year emissions will follow the historical average annual rate of change from 1990 through 2006. For example, the historical data for 1990 through 2006 show an increase in the use of fertilizers. However, since 2004 fertilizer use has declined, which may be the start of a trend towards reduced fertilizer use. In such a case, the predicted growth of 1990-2006 may be an overestimate.

Note that emissions from agricultural soils estimated using the SIT were multiplied by a national adjustment factor to reconcile differences between methodologies used in EPA's National Inventory of Greenhouse Gas Emissions and the SIT. The Agriculture, Forestry and Waste Technical Working Group should discuss whether the National Adjustment Factor is appropriate for Kentucky's Inventory and Forecast, or if agricultural soils emissions estimates should be unadjusted.

Trees on agricultural lands are included in the forestry I&F through statistical plot sampling and are grouped together with all other forest acres. Trees on agricultural lands are also included in the National Woodland Owners survey of forests on private lands. However, since trees on agricultural lands are grouped together with all other forest acres and not separated into their own category, they have not been included in the agriculture I&F. It would be helpful in the future to delineate the inventory of trees on agricultural lands since these would most likely be managed differently than traditional forest lands.

Appendix G. Waste Management

Overview

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);
- 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

Municipal Solid Waste Historical and Projected Management Profile

The basis for the municipal solid waste (MSW) management profile was the 2009 Division of Waste Management Annual Report.[77] These data present the amount of MSW landfilled in Kentucky, the amount of waste imported, the amount of waste exported, and the amount of waste recycled for the years 1994 through 2008. The state data summaries provided the quantity of waste composted and the amount of waste combusted at waste-to-energy (WTE) facilities.[78] Note that food waste composting data were not available. The composting totals represent yard waste only.

MSW generation is defined as the sum of MSW landfill disposal, MSW combustion, and MSW recovery. MSW combustion includes combustion at WTE facilities, combustion of commercial and institutional waste without energy recovery, and open burning of residential waste. Recovery includes recycling and composting.

The MSW generation totals presented in the KY DEP Waste Management Annual Report do not include combustion. Therefore, the recycling percentages calculated in this appendix will not match those from the KY DEP report. KY DEP states that the 2005 MSW recycling rate in Kentucky was 23.4%, compared to the national 2005 MSW recycling rate of 30.0%. However, the 2005 MSW recycling rate for Kentucky when combustion is included is 21.3%.[79]
The amount of waste generated was back-cast for each year between 1990 and 1994 by applying the calculated 1994 per-capita MSW generation rate (based on US Census Bureau population data) to the population in Kentucky for 1990 through 1993. The MSW generation was forecast through 2030 by applying a growth factor of 2.6% to the per-capita generation for each year during the period 2009-2030. This growth factor is the average annual change in per-capita

[77] KY DEP. 2009. "Kentucky Division of Waste Management Annual Report." Available at: http://www.waste.ky.gov/NR/rdonlyres/0B9284F4-BA60-4A58-97C5-F4E51F041AE1/0/DWMannualreport2009FINAL.pdf.
[78] KY DEP. "State Data Report." Available for years 2004 through 2007 at: http://www.waste.ky.gov/branches/rla/Statewide+Solid+Waste+Management+Report.htm.
[79] Note that the KY MSW recycling rates do not include composting.

generation over the period 1995-2008 (1994 was omitted from this calculation, as the per-capita generation rate was very low and would have produced very large generation estimates for future years). The amount of waste recycled, composted, landfilled, and combusted were estimated in the back-cast and projected years by maintaining the ratios of waste managed through these methods for the periods 1990-1993, and 2009-2030, respectively. A subset of the data and projections are presented in Table G1.

Industrial waste is not explicitly included in the profile presented in Table G1. However, it is likely that industrial waste is co-mingled with MSW at some of the waste disposal facilities in Kentucky.

Table G1. MSW Management Profile – Historical and Projected (short tons)

	1990	1995	2000	2005	2010	2015	2020	2025	2030
MSW Disposed + Diverted	3,854,180	5,081,168	4,964,650	6,369,594	7,691,122	8,900,035	10,265,175	11,815,380	13,597,132
Non-energy MSW Incineration & Open Burning	418,359	293,490	306,620	332,176	428,773	553,459	714,405	922,153	1,190,314
MSW Generated	4,272,539	5,374,657	5,271,270	6,701,771	8,119,895	9,453,494	10,979,580	12,737,533	14,787,446
KY Population	3,686,892	3,887,427	4,041,769	4,165,958	4,265,117	4,351,188	4,424,431	4,489,662	4,554,998
Generation per capita	1.16	1.38	1.30	1.61	1.90	2.17	2.48	2.84	3.25
Total MSW Landfilled in KY	3,655,128	4,476,904	4,375,652	5,157,185	5,373,596	6,120,430	6,963,777	7,921,451	9,022,170
MSW Imported (landfilled)	183,786	269,833	515,136	663,686	909,423	1,035,816	1,178,544	1,340,620	1,526,904
MSW Exported (landfilled)	125,549	210,728	202,029	191,923	287,194	413,587	556,315	718,391	904,675
Kentucky MSW Landfilled	3,596,891	4,417,799	4,062,545	4,685,422	4,751,367	5,498,201	6,341,548	7,299,222	8,399,941
MSW Combusted (Waste-to-Energy)	47,434	58,260	53,575	61,789	62,659	72,508	83,630	96,259	110,775
MSW Diverted	209,855	605,108	848,530	1,622,383	2,877,096	3,329,326	3,839,998	4,419,898	5,086,417
MSW Recycled	183,607	529,423	742,398	1,429,490	2,517,236	2,912,902	3,359,701	3,867,069	4,450,220
MSW Composted	26,248	75,685	106,132	192,893	359,860	416,424	480,297	552,830	636,196

The process of estimating direct GHG emissions from the waste sector is detailed in the following section of this appendix. These GHG emissions estimates utilize the landfill disposal information in the above table in order to estimate methane emissions from landfills in Kentucky. The direct GHG emissions estimates do not capture the embedded energy in landfilled waste that could have been recycled. These materials represent a large potential for life-cycle GHG reductions as a result of the emissions from raw materials extraction and new product manufacturing that are avoided when waste is recycled, rather than landfilled. It is the experience of CCS that approximately 10% of estimated GHG reductions from additional recycling efforts are attributed to direct reductions in methane at landfills, while the remainder of the GHG reductions are based on a reduction in life-cycle emissions. Composting also reduces life-cycle GHG emissions from waste management, as the finished compost product may be applied to crop fields, gardens, and landscape construction sites to increase soil carbon and moisture retention, and reduce the need for fossil fuel-derived nitrogen fertilizers.

Solid Waste Management

MSW Landfills. For solid waste management, CCS used the US EPA State Inventory Tool (SIT),[80] the historical and projected waste management profile detailed above, and the US EPA Landfill Methane Outreach Program (LMOP) landfills database[81] as starting points to estimate emissions. The LMOP data serve to identify which landfills currently utilize landfill gas to energy (LFGTE) technology, and to estimate annual waste emplacement for each landfill.

A list of landfills in the state available at the KY DEP website was used to supplement the LMOP database.[82] These additional data included information on one site that was not present in the LMOP database (the Hopkins County Regional Landfill). The KY DEP website also contains a county-by-county data report for 2007, which helped CCS estimate the amount of waste disposed at each landfill in 2007.[83] Six of these sites collect landfill gas (LFG) for use in a LFGTE combustion facility, with one more expecting to capture and utilize LFG by 2009. The Outler Loop Bioreactor had a pipeline to GE Appliance Park installed in 1996; after that year its emissions were assumed to be zero.[84] Eight other landfills have flaring equipment.[85] The rest of the sites were assumed to be uncontrolled. KY DEP provided a list of 50 landfills that were closed between 1992 and 1995. Waste emplacement data are not available for these landfills so they were not included in the inventory. Consequently, the total historical emissions for this sector reported in this inventory are an underestimate.

Annual waste emplacement was only available for 2004 through 2007. However, the data is very disaggregated, and CCS did not have the resources to compile the data for 2004, 2005, and 2006.

---

80 U.S. EPA. “State Greenhouse Gas Inventory Tool, Draft 2/26/2010.” Excel model and User Guide available at: http://securestaging.icfconsulting.com/sit/
81 LMOP database is available at: http://www.epa.gov/lmop/proj/index.htm. Retrieved on December 12, 2009.
82 KY DEP. 2008. “2007 Statewide Municipal Solid Waste Management Update.” Available at: http://www.waste.ky.gov/NR/rdonlyres/BC9C4AE9-75B8-4E23-B53F-ABC9B0D1B445/0/2007StatewideSolidWasteSummaryrevised9508.pdf.
83 KY DEP. 2008. “2007 County Annual Report Summary.” Available at: http://www.waste.ky.gov/NR/rdonlyres/C439D7BB-DB52-49A3-A180-D2B35A06F3D6/0/2007ARSummary.pdf.
84 Communicated to R. Anderson, CCS by George Gilbert, KY DEP, May, 2010.
85 Communicated to R. Anderson, CCS by Tim Hubbard, George Gilbert, and Ron Gruzesky, KY DEP, April 2010.

CCS adjusted the landfill disposal totals from the 2007 County-by-County Data Report, so that the total amount of waste landfilled was equal to the landfill disposal total from the 2007 Statewide Solid Waste Management Report. This adjustment was necessary because the county-by-county data does not include any imported waste. CCS used the adjusted 2007 disposal totals and total waste-in-place data from the LMOP database to estimate annual emplacement at each landfill. The 2007 waste emplaced was subtracted from the total waste emplaced, and the remaining amount was divided by the number of years the landfill was open to estimate historical annual emplacement.

Historical annual waste emplacement was entered into SIT for each landfill to estimate CH_4 emissions. For the LFGTE and flared landfills, CCS assumed that the overall methane collection and control efficiency is 75%.[86] Of the methane not captured by a landfill gas collection system, it is further assumed that 10% is oxidized before being emitted to the atmosphere. Recent literature corroborates the use of an oxidation rate, supporting a default oxidation rate of 10%.[87]

For forecast years it was assumed that flaring equipment would be installed once a landfill reached 1 million tons of waste emplaced. It was assumed that landfills that have crossed this threshold but which do not yet have a flare would have one operational by 2011. It was assumed that no new LFGTE would be installed during the policy period.[88] Future emissions were estimated by assuming linear growth in the amount of waste landfilled (1.13%).

Composting. *Not included in GHG I&F.* Composting is a GHG mitigation strategy because it is thought to produce fewer GHG emissions than landfill disposal, and provides a finished product that can serve as a soil amendment that reduces the need for fossil fuel-based fertilizers and . However, any composting operations in Kentucky are likely emitters of CH_4 and N_2O. The Climate Action Reserve (CAR) is currently drafting a Composting Protocol that will provide methods for quantifying GHG emissions from composting operations. However, at this time, CCS has not quantified GHG emissions from composting operations.

Industrial Solid Waste Landfills. CCS used the EPA State Inventory Tool (SIT) default for industrial solid waste landfills. This default is based on national data indicating that industrial landfilled waste is emplaced at approximately 7 percent of the rate of MSW emplacement. We assumed that this additional industrial waste emplacement occurs beyond that already addressed in the emplacement rates for MSW sites described above. Due to a lack of data, no controls were assumed for industrial waste landfilling.

[86] As per EPA's AP-42 Section on Municipal Solid Waste Landfills: http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf.
[87] Jeffrey P. Chanton, David K. Powelson, and Roger B. Green , "Methane Oxidation in Landfill Cover Soils, is a 10% Default Value Reasonable?" J Environ Qual 2009 38: 654-663. Review available at: http://www.terradaily.com/reports/Landfill_Cover_Soil_Methane_Oxidation_Underestimated_999.html
[88] There are no pending LFGTE applications at this time in Kentucky, as communicated to R. Anderson, CCS by George Gilbert, KY DEP, May, 2010.

Solid Waste Combustion

WTE Combustion. Waste-to-energy combustion emissions are not accounted for in this I&F sector, as those emissions would be counted in the Electricity Supply I&F.

Incineration. There is no controlled combustion within the state.

Residential Open Burning. Open burning of MSW at residential sites (e.g. backyard burn barrels) is illegal in Kentucky, however some open burning likely contributes to GHG emissions. The US EPA's 2002 National Emissions Inventory estimates the quantity of waste burned at residential sites in Kentucky.[89] Emissions from open burning were calculated using SIT emissions factors and waste characteristics for municipal waste combustion. Future emissions were estimated using a 1% annual growth rate. Most illegal open burning investigated by the Air Quality division is industrial, such as demolition debris and tires.[90] However, there is no data on how much of this occurs so it was not included in the total.

Wastewater Management

Municipal WW 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.[91] The key SIT default values are shown in Table G2 below. A revised value for the percentage of state residents not on septic (46%) was provided by KY DEP. Municipal wastewater emissions were based on the growth rate for 1990-2007, which was 0.97% per year.

Table G2. SIT Key Default Values for Municipal Wastewater Treatment

Variable	Default Value
BOD	0.09 kg /day-person
Amount of BOD anaerobically treated	16.25%
CH_4 emission factor	0.6 kg/kg BOD
Kentucky residents not on septic	46%
Water treatment N_2O emission factor	4.0 g N_2O/person-yr
Biosolids emission factor	0.005 kg N_2O-N/kg sewage-N

Source: U.S. EPA State Inventory Tool – Wastewater Module; methodology and factors taken from U.S. EPA, Emission Inventory Improvement Program, Volume 8, Chapter 12, October 1999: www.epa.gov/ttn/chief/eiip/techreport/volume08/.

Industrial WW Management. For industrial wastewater emissions in Kentucky, SIT provides default assumptions and emission factors for the red meat industry. The SIT default activity data were used to estimate emissions for red meat production. Emissions were projected to 2030

[89] EPA, ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/nonpoint/2002nei_final_nonpoint_documentation0206version.pdf
[90] Communicated to R. Anderson, CCS by John Lyons, Air Quality Division, April 2010.
[91] Processing and emissions data from individual wastewater treatment plants were not available; communicated to R. Anderson, CCS by Peter Goodman, Division of Water, April 2010.

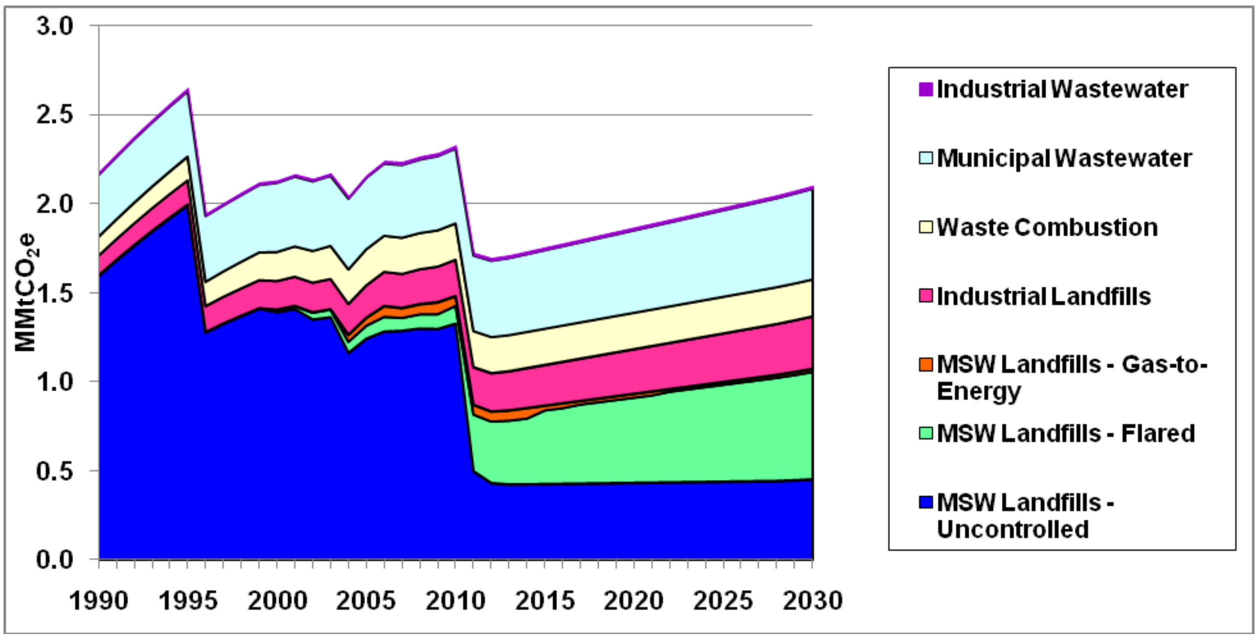
based on the 1990-2007 annual growth rate (0.01%). Data for other industries including Fruits & Vegetables, Poultry, Pulp & Paper, and Bourbon were not available.[92]

Results

Figure G1 and Table G3 show the emission estimates for the waste management sector. Overall, the sector accounts for 2.09 $MMtCO_2e$ in 2005. By 2030, emissions are expected to grow slightly to 2.10 $MMtCO_2e$/yr. The largest contributor to waste management emissions is the solid waste sector, in particular, solid waste landfills. In 2005, uncontrolled, flared, and LFGTE municipal landfills accounted for 60% of total waste management emissions. By 2030, the contribution from these sites is expected to be about 22%. Industrial landfills accounted for 8% and 14% of the sector's emissions in 2005 and 2030, respectively. Waste combustion accounted for about 9% of the waste sector emissions in 2005 and 10% in 2030.

In 2005, about 19% of the waste management sector emissions were contributed by municipal wastewater treatment systems and 1% of emissions 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 existing controls or management practices (e.g. anaerobic digesters served by a flare or other combustion device). By 2030, the contribution to the total waste sector emissions from municipal and industrial wastewater treatment sectors are expected to represent 24% and 1% of emissions, respectively.

Figure G1. Kentucky GHG Emissions from Waste Management



Notes: MSW - Municipal Solid Waste

Table G3. Kentucky GHG Emissions from Waste Management ($MMtCO_2e$)

[92] Communicated to R. Anderson, CCS by Peter Goodman, Division of Water, April 2010.

Source	1990	1995	2000	2005	2010	2015	2020	2025	2030
MSW Landfills - Gas-to-Energy	0.00	0.00	0.00	0.04	0.05	0.03	0.02	0.01	0.02
MSW Landfills - Flared	0.00	0.00	0.01	0.07	0.10	0.42	0.48	0.55	0.60
MSW Landfills - Uncontrolled	1.59	1.99	1.39	1.24	1.33	0.42	0.43	0.44	0.45
Industrial Landfills	0.11	0.14	0.16	0.18	0.20	0.23	0.25	0.27	0.29
Waste Combustion	0.11	0.13	0.17	0.20	0.21	0.21	0.21	0.21	0.21
Municipal Wastewater	0.35	0.37	0.39	0.40	0.42	0.44	0.46	0.49	0.51
Industrial Wastewater	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	**2.18**	**2.65**	**2.13**	**2.16**	**2.33**	**1.75**	**1.87**	**1.98**	**2.10**

Key Uncertainties

Data for closed landfills that are not covered by the LMOP database are not available. Therefore, such landfills are not included in this analysis. The modeling only accounts for currently uncontrolled sites that will need to apply controls during the period of analysis due to triggering the requirements of the federal New Source Performance Standards/Emission Guidelines but does not account for new landfills that will be uncontrolled. As noted above, the available data do not cover all of the open and closed landfills in Kentucky, particularly the 50 closed in the early 1990's. For this reason, emissions are underestimated for landfills.

Landfills are considered a sink for carbon, as some landfilled waste contains biogenic carbon that is either perpetually trapped in the landfill, or is released at a much slower rate that it would be if it were not landfilled. Currently, the estimated value for this sink is considered in the Forestry I&F Appendix. The landfill carbon sink estimates in that appendix are based on population data and default parameters, rather than the waste management profile described in this appendix.

For industrial landfills, emissions were estimated using national defaults (with industrial landfills emitting 7% of MSW landfill emissions). It could be that the available MSW emplacement data within the KY DEP data used to model the MSW emissions already captures some industrial LF emplacement. As with overall MSW landfill emissions, industrial landfill emissions are projected to increase between 2005 and 2030. Hence, the industrial landfill inventory and forecast has a significant level of uncertainty and should be investigated further. For example, the existence of active industrial landfills that are not already represented in the LMOP database should be determined. If there are no separate sites just for industrial waste and the existing municipal waste emplacement data are thought to include all industrial wastes, then the separate estimate for industrial landfill emissions can be excluded from the inventory.

The State of Kentucky has no waste combustion facilities that are active, and open burning of waste is illegal. Some open burning is known to occur, but there is significant uncertainty about the quantity. Residential open burning was estimated based on national emissions inventory methods and rural population estimates. Illegal burning of industrial waste such as demolition debris and tires may occur in the state but there is no data currently available to estimate this so it was not included in the inventory. Likewise the burning of storm debris was not included. State-level data of open burning surveys would improve this element of the I&F.

According to the SIT default assumption, zero wastewater biosolids are applied to soils. In this inventory, N_2O emissions associated with these biosolids would be included in the wastewater sector. It is likely that some biosolids are applied to soils in Kentucky. Therefore, emissions from this source are likely underestimated. The SIT Agriculture Module contains estimates of total Activated Sewage Sludge soil application and the associated GHG emissions. Other key uncertainties with the wastewater sector are associated with the application of SIT default values for the parameters listed in Table G2 above (e.g. the fraction of BOD that is anaerobically decomposed). The SIT defaults for emission factors used to estimate wastewater emissions were derived from national data. Waste combustion emissions were also based on a factor derived from national data.

Data on industrial wastewater were not available for most industries including: fruits and vegetables, pulp and paper, poultry, and bourbon. Therefore these are not represented in this inventory. Hence the estimate of emissions from industrial wastewater is likely an underestimate. The addition of activity data from these industries would improve the I&F.

Appendix H. Forestry & Land Use

Overview

Forestland emissions refer to the net carbon dioxide (CO_2) flux[93] from forested lands in Kentucky, which account for about 50% of the state's land area.[94] The dominant forest type in Kentucky is oak-hickory which made up about 77% of forested lands in 1997. Other common forest types are oak-pine at 7% of forested land, and maple-beech-birch at 6% of forested land.

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

The forestry sector GHG emissions (including net CO_2 flux) are 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.
- *Urban Forestry and Land Use:* this covers carbon sequestration in urban trees, flux associated with carbon storage from landscape waste and food scraps in landfills, and nitrous oxide (N_2O) emissions from settlement soils (those occurring as a result of application of synthetic fertilizers).

Inventory and Reference Case Projections

Forested Landscape

For over a decade, the United States Forest Service (USFS) has been developing and refining a forest carbon modeling system for the purposes of estimating forest carbon inventories. The methodology is used to develop national forest CO_2 fluxes for the official *US Inventory of Greenhouse Gas Emissions and Sinks*. The national estimates are compiled from state-level data. The Kentucky 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.[95] Additional forest carbon information is in the form of specific carbon conversion factors.[96]

---

[93] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.
[94] Total forested acreage is 12.7 million acres in 1997. Acreage by forest type available from the USFS at: http://www.fs.fed.us/ne/global/pubs/books/epa/states/KY.htm. The total land area in Kentucky is 25 million acres (http://www.50states.com/kentucky.htm).
[95] 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: 1990-2007 (and earlier editions), US Environmental Protection Agency, April 2009, available at: http://epa.gov/climatechange/emissions/usinventoryreport.html. Both Annex 3.12 and Chapter 7 LULUCF are useful

The forest CO_2 flux methodology relies on input data in the form of plot-level forest volume statistics from the Forest Inventory Analysis (FIA). 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 FORCARB system is provided in a number of publications.[97]

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

In preparing these estimates, USFS estimates the amount of forest carbon in different forest types as well as separate carbon pools. The different forest types also include separate ownership classes: 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.[98]

Annualized FIA data, as shown in Table H1, display a net decrease in forested area (6% between 1990 and 2005). Information on the number of forest surveys and the year these were conducted was not accessible from the FIA database during the development of this appendix due to a problem with the web site hosting the FIADB 2.1 component of the Carbon Calculation Tool.[99]

---

sources of reference. See also Smith, J.E., L.S. Heath, and M.C. Nichols (in press), *US Forest 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.

[96] 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.

[97] 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.

[98] 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.

[99] http://www.nrs.fs.fed.us/pubs/2394.

Underlying data, including the years for which forest surveys were conducted, will be added in subsequent revisions to this Appendix. Based on annualized data, forest land decreased linearly from 1990 to 2005, which appears to have caused a reduction in carbon stocks in most carbon pools. However, modeled gains in the live tree pools led to overall carbon stocks remaining fairly level between 1990 and 2005 as shown in Table H1.

Table H1. USFS Forest Carbon Pool Data for Kentucky

Forest Pool	1990 (MMtC)	1995 (MMtC)	2000 (MMtC)	2005 (MMtC)
Live Tree – Above Ground	310.7	315.4	320.1	324.8
Live Tree – Below Ground	59.7	60.5	61.4	62.2
Understory	15.2	14.8	14.5	14.1
Standing Dead	14.3	14.1	13.9	13.7
Down Dead	24.7	25.1	25.5	25.8
Forest Floor	37.2	36.4	35.6	34.8
Soil Carbon	204.1	200.9	197.6	194.3
Totals	**666**	**667**	**668**	**670**
Forest Area	**1990 (10^3 acres)**	**1993 (10^3 acres)**	**2004 (10^3 acres)**	**2005 (10^3 acres)**
All Forests	5,081	4,985	4,889	4,793
Timberland	4,945	4,851	4,757	4,664

MMtC = million metric tons of carbon. Positive numbers indicate net emission. Multiply MMtC by 3.67 (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), November 2007.

In addition to the forest carbon pools, additional carbon is stored in biomass removed from the forest for the production of HWP. Carbon remains stored in the durable wood products pool or is transferred to landfills where much of the carbon remains stored over a long period of time. The USFS uses a model referred to as WOODCARB2 for the purposes of modeling national HWP carbon storage.[100] Limited and somewhat dated state-level information for Kentucky was provided to CCS by USFS.[101]

As shown in Table H2, about 1.4 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 shown in this table is the total flux estimate including all forest pools of -2.3 $MMtCO_2e$/yr.[102]

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.

[100] 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.
[101] Obtained from the Harvested Wood Product model developed by Ken Skog, USFS.
[102] 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), November 2007.

The forest carbon flux estimates provided in the summary tables at the front of this report are those without the soil carbon pool. The resulting estimates provided at the bottom of Table H2 are in line with the observed changes in forest area and carbon stocks during this time period (i.e. losses in forest area offset by growing live tree carbon pools).

Table H2. USFS Annual Forest CO_2 Fluxes for Kentucky

Forest Pool	1990-2005 Flux ($MMtCO_2$)
Forest Carbon Pools (non-soil)	-3.3
Soil Organic Carbon	2.4
Harvested Wood Products	-1.4
Totals	**-2.3**
Totals (excluding soil carbon)	**-4.7**

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, November 2007.

For historical emission estimates, CCS used the annualized carbon flux and carbon stock data for the period 1990-2005 using the Carbon Calculation Tool. For the reference case projections (2005-2030), 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.

Urban Forestry & Land Use

GHG emissions from urban forestry and land use for 1990 through 2005 were estimated using the US EPA State Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for this sector.[103] 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.[104] Table H3 displays the emissions and reference case projections for Kentucky.

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 grew from 2,604 square kilometers

[103] GHG emissions were calculated using SIT, with reference to EIIP, Volume VIII: Chapter 8.
[104] 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/).

[km^2] to 3,479 km^2 between 1990 and 2005) was multiplied by the state estimate of the percent of urban area with tree cover (30% for Kentucky) 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.[105] Estimates of urban area in the intervening years (1990-1999) and subsequent years (2001-2005) are interpolated and extrapolated, respectively.

Table H3. Urban Forestry Emissions and Reference Case Projections (MMtCO_2e)

	1990	1995	2000	2005	2015	2025	2030
Urban Trees	-0.71	-0.80	-0.86	-0.94	-0.94	-0.94	-0.94
Landfilled Yard Trimmings and Food Scraps	-3.46	-1.82	-1.15	-0.88	-0.88	-0.88	-0.88
N_2O from Settlement Soils	0.08	0.08	0.09	0.08	0.08	0.08	0.08
Total	**-4.09**	**-2.53**	**-1.92**	**-1.73**	**-1.73**	**-1.73**	**-1.73**

Estimates of net carbon flux of landfilled yard trimmings and food scraps were calculated by estimating the change in landfill carbon stocks between inventory years. The SIT estimates for the amount of landfilled yard trimmings decreased significantly during the 1990's. CCS believes that this is consistent with changes in the waste management industry during this period. Therefore, the forecast was based on an extrapolation of the flux from 2000-2005, which show relatively constant rates of landfilling these materials.

Settlement soils include all developed land, transportation infrastructure, and human settlements of any size. Projections for urban trees and settlement soils were kept constant at 2005 levels. Table H4 provides a summary of the estimated flux for the entire forestry and land use sector.

Table H4. Forestry and Land Use GHG Emissions and Reference Case Projections (MMtCO_2e)

Subsector	1990	1995	2000	2005	2015	2025	2030
Forested Landscape (excluding soil carbon)	-4.71	-4.71	-4.71	-4.71	-4.71	-4.71	-4.71
Urban Forestry and Land Use	-4.09	-2.53	-1.92	-1.73	-1.73	-1.73	-1.73
Forest Wildfires	0.29	0.87	1.72	0.66	0.68	0.68	0.68
Sector Total	**-8.51**	**-6.37**	**-4.91**	**-5.77**	**-5.75**	**-5.75**	**-5.75**

Wildfire and Prescribed Burning Emissions

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 total carbon flux calculations in the USFS modeling described above, CCS used SIT to estimate CH_4 and N_2O emissions. CCS used available state data from the State of Kentucky, Division of Forestry to estimate emissions.[106] Acres burned were used for the years 1990-2008 and the forest type of "other temperate forests" was assumed in SIT to calculate historical emissions. Note that these data

[105] 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.
[106] State of Kentucky, Division of Forestry: http://www.forestry.ky.gov/situationreport/.

appear to be restricted to wildfires and not to include any prescribed burns.

Due to the yearly fluctuation of forest fire data, projected emissions for 2009-2030 were assumed to be the average of 1990-2008 fire emissions. These emission estimates are presented in Table H4, along with the total emissions from the forestry and land use sector.

Key Uncertainties

It is important to note that there were methodological differences in the FIA surveys in the pre- versus post-1999 time-frame. The FIA data form the basis of the USFS forest carbon pool modeling and the different survey methods could produce varying 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 surveys 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 Kentucky is dominated by timberlands (productive forests), CCS does not believe that the definitional differences noted above have had a significant impact on the forest flux estimates provided in this report.

Also, FIA surveys since 1999 include all dead trees on the plots, but data prior to that are variable in terms of these data. The modifications to FIA surveys are a result of an expanded focus in the FIA program, which historically was only concerned with timber resources, while more recent surveys have aimed at a more comprehensive gathering of forest biomass data. In addition, the FIA program has moved from periodic to annual inventory methods – FIA now has Kentucky on a continuous 5-year cycle. The effect of these changes in survey methods has not been estimated by the USFS.

Regarding the forecast for the forested landscape, potentially the largest source of uncertainty relates to the influence that future changes in climate will have on Kentucky's forests to sequester carbon. Regarding future land use change, FIA data indicate that forested acreage is decreasing at the state-level. It is unclear whether these trends will continue.

Emissions from wildfires and prescribed burns were estimated. It appears that the available data from the KY Division of Forestry covered wildfires, but not prescribed burns. To the extent that prescribed burning is employed in the state, the emissions could represent an important data gap.

Much of the urban forestry and land use emission estimates rely on national default data and could be improved with state-specific data (e.g. urban area under canopy cover).

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

Original Reference: Material for this Appendix is taken from the *Inventory of US 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 US 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[107] 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 US 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

[107] 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 CH_4 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:

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

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

GWP values allow 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

Gas	Direct	Net_{min}	Net_{max}
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 CO_2 radiative forcing, the SAR response function for a CO_2 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 ofBlack 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.