ASSURING OHIO'S COMPETITIVENESS IN A CARBON-CONSTRAINED WORLD:

A Collaboration between Ohio University and The Ohio State University

Chapter 8: Task 1: Creation of a Statewide Emissions Inventory

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I. INTRODUCTION

Ohio was ranked fourth in the United States based on estimates of CO_2 emissions from fossil fuel consumption.[1] The bulk of Ohio CO_2 emissions comes from coal-fired power plants, various industries and vehicles. This report seeks to provides a detailed account of the contributions of different greenhouse gas (GHG) emission sources in Ohio. These GHG estimates will be useful to a wide array of public and private agencies in designing various climate change mitigation initiatives.

This inventory contains GHG emissions information at a very high resolution for the State of Ohio. The research team at Ohio University's Center for Air Quality, in collaboration with Ohio EPA, employed bottom-up calculations from best available data and models to develop emissions estimates with optimum accuracy. The data management program/inventory followed standard accounting protocols for quantifying GHG emissions to provide verifiable and transparent data. Emission factors for calculating GHG emissions were consistent with U.S. EPA and Intergovernmental Panel on Climate Change (IPCC) protocols. The estimates used the baseline year 2008 to support evaluation of potential future emission scenarios and policy evaluations.

The estimated GHG emissions in Ohio are primarily carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Fuel combustion in electricity generation, industries, commercial and residential areas, and the transportation sector were major emitters of CO_2 in 2008. Iron and steel industries in Ohio have significant process-related GHG emissions. Ruminants and solid waste landfills were significant emitters of CH_4. Considerable amounts of N_2O were also released due to livestock manure management and manufacturing of acrylonitrile and nitric acid.

[1] U.S. Energy Information Administration. (2010). *State CO_2 Emissions*. Retrieved from http://www.eia.gov/oiaf/1605/state/state_emissions.html

These GHGs have varying global warming potential (GWP) as shown in Table 1.[2] GWP is the measure of heat-trapping efficiency of one unit mass of a GHG with respect to one unit mass of CO_2 for a specific period of time. The total warming potential of all three gases (weighted by their GWP) was also reported as total CO_2-equivalent emissions for each source.

Table 1. Global Warming Potentials of Greenhouse Gases

Greenhouse Gases	Global Warming Potential (CO_2 eq.)
CO_2	1
CH_4	21
N_2O	310

The Task 1 project team also developed a public website which houses a database query system, visualization maps and analytical tools. Individual companies, service providers, policymakers and the general public can access information from the GHG website on individual emissions sources and data aggregated by county, source type and state total.

The following sections of this chapter discuss the inventory development process and summarize the findings of the 2008 GHG emissions in the State of Ohio.

[2] Inter-Government Panel on Climate Change. (2006). *2006 IPCC guidelines for national greenhouse inventories.* Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

II. INVENTORY PROCESS

Most of the recent investigations and estimations of GHG emissions conducted nationwide have focused on net estimates at state-, regional- and national-level resolutions with gross fuel consumption and process activity data at those levels generally provided by state and private agencies.[3,4] Moreover, these estimates used state or national mean emission factors for fuels, feed materials, industries and processes. The inherent uncertainties in the low resolution activity data and averaged emission factors can cause large discrepancies in the emission inventories' results.

The inventory developed for this project was developed using facility and county level QA/QC activity data, along with emission factors for individual process/equipment type. This database will help users to comprehend emissions reduction potential for individual facilities, process types, vehicle types, road types, fuel types or counties. The inventory process follows a standard approach used by state agencies and the U.S. EPA for emissions reporting and national inventory preparation. This process categorizes the state emission sources as follows:

POINT

These are sources (generally individual facility stacks) that have fixed locations and emit pollutants above a certain identified threshold. U.S. EPA and state agencies maintain a database of these sources with the information on their corresponding latitude and longitude, address, owner name and stack parameters for regulatory purposes. These sources report their activity data and emissions of criteria pollutants to state agencies and U.S. EPA. These reported

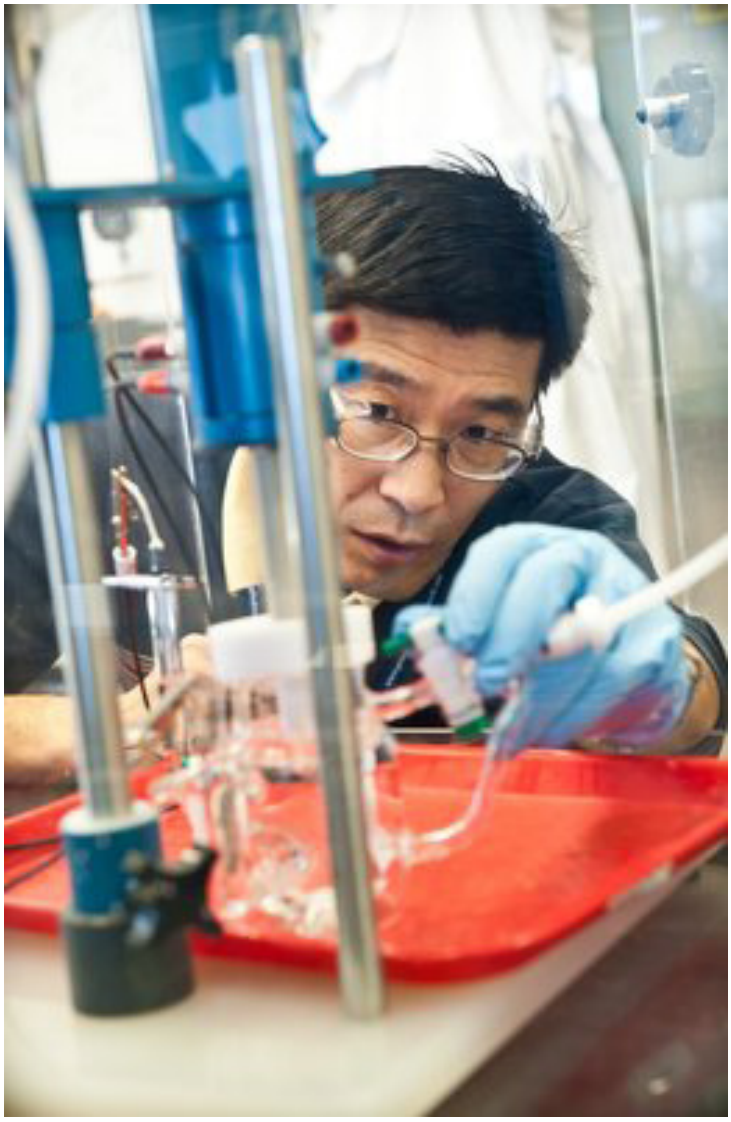
[3] U.S. Energy Information Administration. (2010). *State CO_2 Emissions*. Washington D.C. Retrieved from http://www.eia.gov/oiaf/1605/state/state_emissions.html

[4] World Resources Institute. (2007). *Charting the Midwest: An Inventory and Analysis of Greenhouse Gas Emissions in America's Heartland*. Washington, D.C.

values may be based on estimation or monitoring, depending on regulatory requirements and the individual facility's availability of resources.

AREA/NON-POINT

Some point sources cannot be identified individually such as residential heating and small commercial utilities. Also, diffuse sources such as wildfires, livestock and agriculture cannot be ascribed one fixed point location with latitude and longitude information. All these unidentified and diffuse sources are included in area sources, or "non-point" sources. Generally, activity or emissions data are not available for these individual sources. Historically, inventories have been developed for these sources at county-level resolution based on estimations and surrogates.



MOBILE

Emissions from movable vehicles, engines and equipment are included in themobile category. These sources are subdivided into **on-road** and **non-road** sources. Vehicles travelling on roads and highways are called on-road sources and include cars, trucks, buses and railroad locomotives. Non-road sources such as recreational boats, lawn mowers, agricultural and construction equipments do not move on fixed roads. Mobile source emissions are estimated using models like MOVES, MOBILE6, NONROAD, EMFAC and OFFROAD. These models were developed based on numerous research studies of engine performance, fuel type, and vehicle fleet pattern and engine cycles.

In the inventory process, point sources were estimated at the individual facility level while county-level estimates were used for area and mobile sources. Ohio EPA provided the project team with an inventory of activity data and criteria pollutant emissions for. The GHG emissions were estimated as a product of the activity data for GHG emitting sources and GHG emission factors for specific source profiles (provided by source categories codes). The emissions from mobile sources were simulated using U.S. EPA recommended models with updated input data from Ohio EPA. A brief summary of emissions estimation for each category is discussed below.

II.A. FUEL COMBUSTION

Ohio's economy is predominantly driven by the combustion of fossil fuels, such as electric power generation, steam and heat production for industrial processes, and space heating in residential and commercial locations. Accurate estimation of GHG emissions from fossil fuel burning is a significant component of any GHG inventory process.

Fossil fuel combustion, in chemical terms, is an exothermic reaction and defined as oxidation of hydrocarbons in the fuel to produce carbon dioxide and water along with energy. In the state inventory, fuel consumption data and their associated criteria emissions were provided. These data were available both for point and non-point sources. The investigation team revised some of the reported fuel consumption data (particularly for natural gas and gasoline) for combustion processes based on the activity computation from criteria pollutant emissions and U.S. EPA emission factors for corresponding pollutants. The U.S.

EPA database [5][6] provides nationally-averaged GHG emission factors for most of the fuels which may vary with type of combustion engine, process and fuel grade. The emission factors were compiled by the project team from various data sources such as U.S.EPA, CARB, NCDAQ, API and IPCC. Appendix 8-1 lists the detailed emission factors and data sources for different fuels.

Because **coal combustion** in power plants contributes the bulk of CO_2 emissions in Ohio, efforts were undertaken to compute facility-specific CO_2 emission factors. The project team developed facility-based emission factors for 25 facilities based on their supplier county's coal origin. Exhaustive computation methodology for these facilities is provided in Appendix 8-2.

In the state emission inventory for **residential heating**, fuel consumption for the entire state was allocated to counties based on population. The state energy data for Ohio was updated from 2006 to 2008, and new county fuel consumption profiles were generated by the project team.

GHG emissions are also largely contributed by vehicular traffic. **Non-road emissions** were simulated by the NONROAD model embedded in National Mobile Inventory Model (NMIM). NONROAD generates CO_2 emissions estimates for recreational vehicles and equipment used in logging, agricultural, construction, industrial and gardening. Non-road emissions were computed from the vehicle/equipment population, average load or horse power and emissions factors, and accounted for deterioration and/or new standards. County-level information including local emission control programs, vehicle class/roadway type combinations and meteorological data were provided in a national county database (NCD).

U.S.EPA MOBILE6 model provided within NMIM was proposed to estimate **on-road emissions** from highway vehicles. However, the project team employed Motor Vehicle Emissions Simulator (MOVES) version 2010 to compute county-level on-road emissions in Ohio. MOVES2010 is the best available EPA tool for estimating GHG emissions with significant improvements over MOBILE6. MOBILE6 calculates fleet average CO_2 emission rates from a lookup table of fuel economy by model year and fractions of vehicle miles traveled (VMT) by vehicle type and age. This model does not account for impacts of vehicle speed or operating modes on fuel consumption and subsequently, on CO_2. Also, fuel economy data ends around 2001, and CH_4 and N_2O emission factors are not available in MOBILE6. MOVES estimates GHG emissions based on second-by-

[5] U.S. Environmental Protection Agency. (2005). *Technology Transfer Network Clearinghouse for Inventories & Emissions Factor, Webfire*. Washington, D.C. Retrieved from http://cfpub.epa.gov/webfire/

[6] U.S. Environmental Protection Agency. (1995). *Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors*. Washington, D.C. Retrieved from http://www.epa.gov/ttnchie1/ap42/

second vehicle performance characteristics for various operating modes. The model generates emissions by county, time period, vehicle class, model year and fuel type. To compute 2008 on-road GHG emissions, MOVES utilized the most updated local input data for VMT, registration data, vehicle age distribution, meteorology, I/M programs, fuel supply and fuel formulation.

II.B. INDUSTRIAL PROCESSES

Significant quantities of GHGs are emitted from industrial processes in refineries (fugitive and vented emissions) and engineering production/ processing of chemicals, metals and minerals. The project team evaluated the major contributors from the available state point-source criteria emissions inventory. Comprehensive data for each process were not accessible within the scope of the study. Therefore, simple tier 1 (emission-factors based) calculations were employed utilizing coefficients from IPCC, U.S.EPA and API, instead of IPCC tier 2 or 3 calculations (material balance approach).

Appendix 8-3 illustrates the emission factors and their data sources. Activity data associated with direct GHG emitting processes were identified from source category descriptions in SCC. Policymakers will want to account for the uncertainty associated with these processes in future policy decisions.

II.C. AGRICULTURE - LIVESTOCK

Methane and nitrous oxide are also directly emitted from livestock on farms for beef and dairy production. To the project team's best knowledge, there was no previous effort to account for emissions from agricultural activities in Ohio. A crude estimate of GHG emissions from ruminants and manure management was made. Livestock population data were obtained from the PECHAN inventory for ammonia emissions. National livestock population distribution[7] was used to distribute the PECHAN-computed county totals for livestock population to different animal categories. Different parameters and emission factors for individual animal categories were also obtained from the U.S. 2008 inventory.

[7] U.S. Environmental Protection Agency. (2010). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2008.* Washington, D.C. Retrieved from http://www.epa.gov/climatechange/emissions/usgginv_archive.html

ENTERIC FERMENTATION

Methane is exhaled during the microbial fermentation of feed in the animal's digestive system. The amount of emissions depends upon the animal's digestive system (which varies with animal activity, breed and health) and the feed quantity and characteristics. Feed intake by an individual animal varies with its size, growth rate and production and thus differs among animal types and management practices such as animal feedlots, grazing and pasture. The methodology and calculations are discussed in detail in Appendix 8-4.

MANURE MANAGEMENT

Livestock and poultry manure management increases agricultural GHG emissions along with enteric fermentation from ruminants. Anaerobic decomposition of manure generates CH_4 in storage systems such as lagoons, tanks and pits. CH_4 emissions depend upon the ambient temperature, moisture, and manure storage time and composition. Manure characteristics vary by animal diet, growth rate and type. Direct N_2O emissions from the nitrification and denitrification cycle of organic nitrogen in manure and indirect N_2O production from nitrogen losses due to volatilization (as ammonia and nitrogen oxides) and runoff, are also contributed by manure management systems.

In the current inventory, the research team used U.S. EPA calculated parameters and methodology to compute GHG emissions from livestock manure management. A detailed discussion is provided in Appendix 8-5.

II.D. WASTE

OPEN BURNING

PECHAN has estimated the quantity of residential waste generated for open burning, utilizing the total mass of municipal solid waste (MSW) generated in 2007 and population data from the 2000 U.S. census. The total MSW generated was updated with 2008 data,[8] and then per capita waste generation was calculated. Burning of yard waste and non-combustible materials such as glass and metals were excluded. The CO_2 emission factor for open burning of MSW was obtained from a 1997 EPA report.[9] IPCC default emission factors were used for CH_4 and N_2O emissions for open burning of MSW.

[8] U.S. Environmental Protection Agency. (2009). *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2008.* Washington, D.C. Retrieved from http://www.epa.gov/osw/nonhaz/municipal/msw99.htm

[9] U.S. Environmental Protection Agency. (1997). *Evaluation of emissions from the open burning of household waste in barrels.* Washington, D.C.

LANDFILLS

CH_4 emissions from municipal solid waste landfills were estimated using a Landfill Air Emissions Estimation model and were provided by Ohio EPA.

III. KEY FINDINGS

According to the inventory estimates, the energy sector in Ohio contributed 93% of the total GHG emissions (CO_2e) during 2008. This was followed by emissions from industrial processes and agriculture, though their contribution to the total was relatively small (Figure 1 and Table 2). The bulk of emissions in the energy sector came from electric and heat utilities, heavily influenced by CO_2 emissions from coal burning (Table 2). The transportation sector also contributed substantial GHG emissions, followed by fuel combustion in industries, residential heating and commercial activities. Iron and lime manufacturing were key industries that significantly added GHG emissions among the industrial processes category. CH_4 emissions in livestock management and landfills also contributed to Ohio's overall GHG emissions.

Figure 2 depicts the locations and emissions strength of GHG-emitting facilities (point sources) along with the combined non-point and mobile emissions for each county. It provides a snapshot of the emissions strength along with the source regions. The highest county-level area emissions are noted in Hamilton, Franklin, Cuyahoga, Montgomery, Lucas and Summit Counties and are mostly a result of transportation. The biggest point sources are mostly power plants such as Gavin Power Plant (Gallia), Stuart Generating Station (Adams), Cardinal Power Plant (Jefferson), W.H. Sammis Plant (Jefferson), Miami Fort Station (Hamilton), Muskingum River Power Plant (Washington), and so on. A.K. Steel industry (Butler) also contributed high GHG emissions relative to these large power plants.

Figure 1. GHG Emissions (CO_2e) Distribution by Different Source Categories

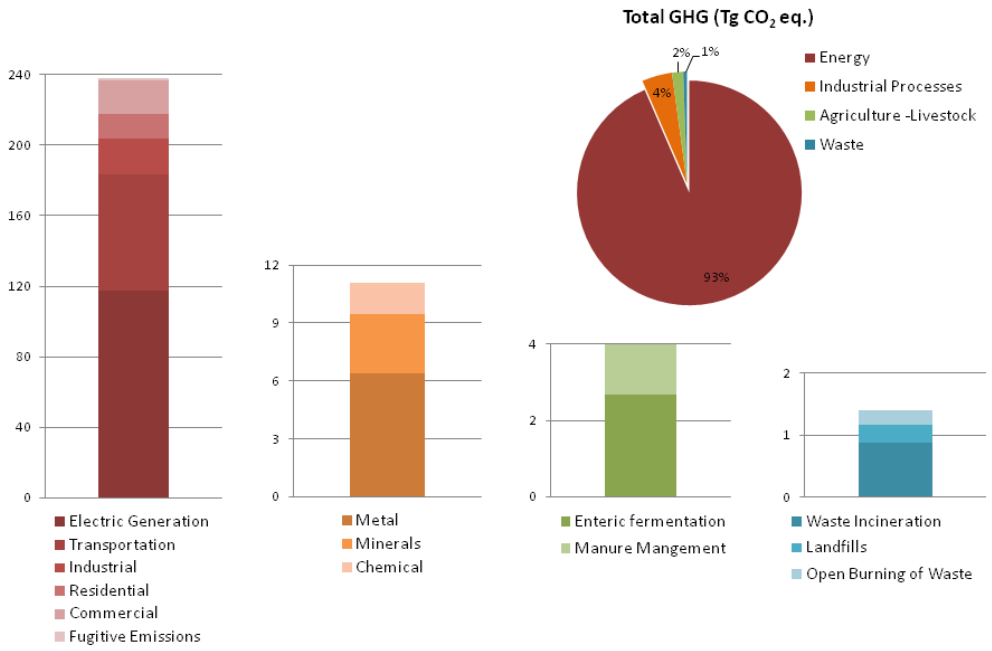
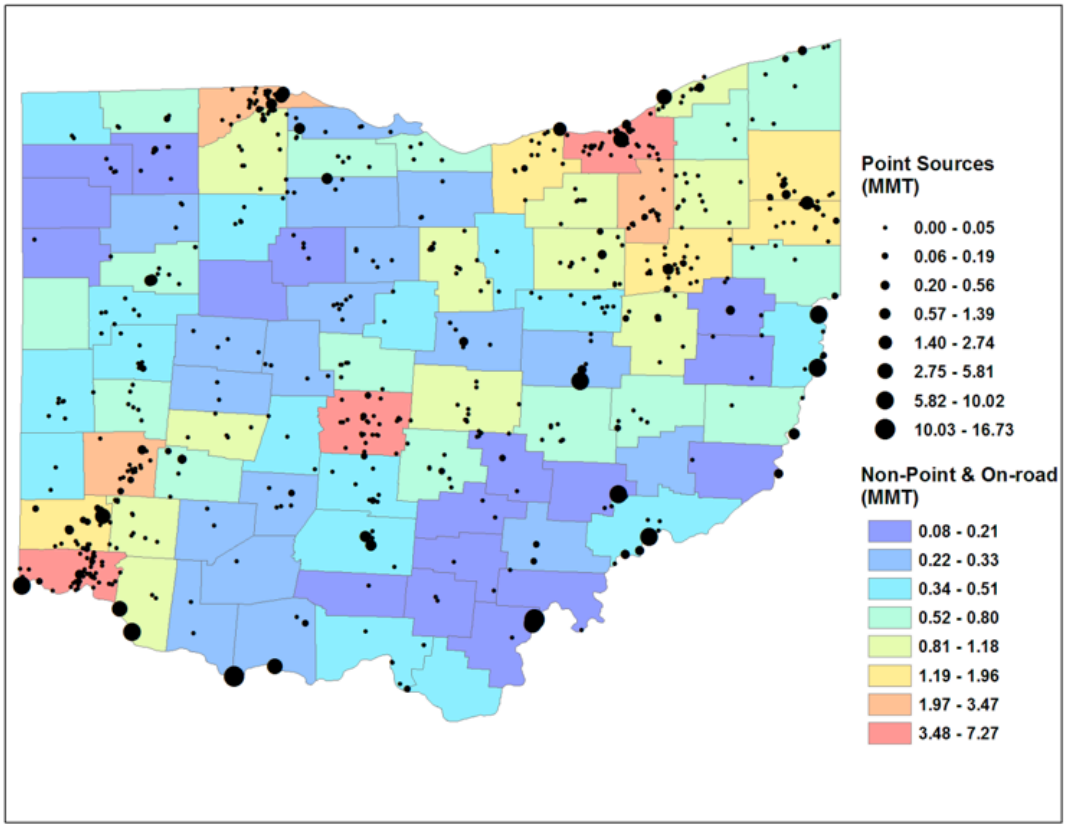


Table 2. GHG Emissions by IPCC Categories

IPCC code	Level 1	Level 2	Level 3	CO_2e (MMT)
1A1	Energy	Fuel Combustion Activities	Energy Industries	117.63
1A2		Fuel Combustion Activities	Manufacturing Industries and Construction	20.30
1A3		Fuel Combustion Activities	Transportation	65.74
1A4		Fuel Combustion Activities	Commercial	13.90
1A4		Fuel Combustion Activities	Residential	19.01
1B2		Fugitive Emissions from Fuels	Oil and Natural Gas	1.67
2A1	Industrial processes	Mineral Industry	Cement Production	0.26
2A2		Mineral Industry	Lime Production	2.32
2A3		Mineral Industry	Glass Production	0.18
2A4		Mineral Industry	Other Process Uses of Carbonates	0.31
2B1		Chemical Industry	Ammonia Production	0.71
2B2		Chemical Industry	Nitric Acid Production	0.62
2B8		Chemical Industry	Petrochemical & Carbon Black Production	0.33
2C1		Metal Industry	Iron and Steel Production	5.78
2C2		Metal Industry	Ferroalloys Production	0.23
2C3		Metal Industry	Aluminum Production	0.35
3A1	Agriculture	Livestock	Enteric Fermentation	2.67
3A2		Livestock	Manure Management	1.43
4A1	Waste	Solid Waste Disposal	Managed Waste Disposal (Landfills)	0.29
4C1		Incineration & Open Burning of Waste	Waste Incineration	0.88
4C2		Incineration & Open Burning of Waste	Open Burning of Waste	0.22

Figure 2. GHG Emissions (CO_2e) in Million Metric Tons (MMT) from Point Sources (Facilities) and County-Level Area Sources Including Non-Point and On-Road Transportation



The source distribution and total county GHG emissions are provided for the five Ohio regions in Figures 3-7. Being a metropolitan area, Franklin County (Central Ohio) had high emissions from road transportation, commercial and residential sectors. Cuyahoga County (Northeast Ohio) resides in the Cleveland-Akron metropolitan area and therefore experienced elevated levels of GHG emissions from transportation, commercial and residential sectors. In addition, heavy industrialization in Cuyahoga County has contributed significant emissions, such as those from ArcelorMittal Cleveland, Inc. Power plants and industries also released high GHG emissions in Jefferson County (Northeast Ohio). In Northwest Ohio, Lucas County observed large GHG emissions with contributions from commercial and residential areas, transportation and electricity generation. Soaring levels of GHG were emitted from power plants in Southeast Ohio, with Gallia County observing the highest in Ohio.

Figure 3. County-Level Distribution by Source Categories (top) and County Total (bottom) for GHG Emissions (CO_2e) in Central Ohio

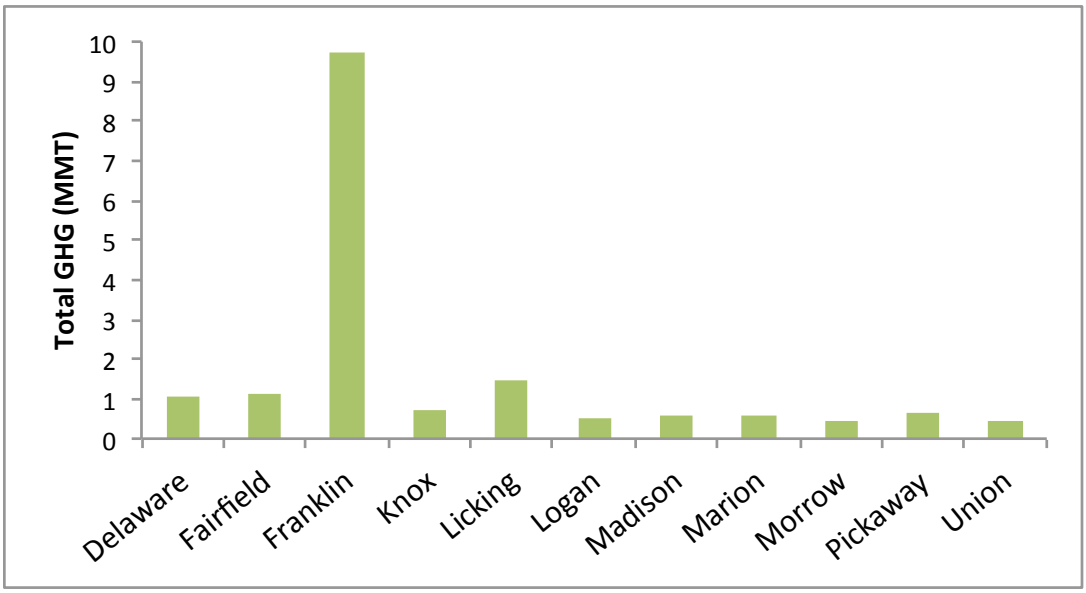
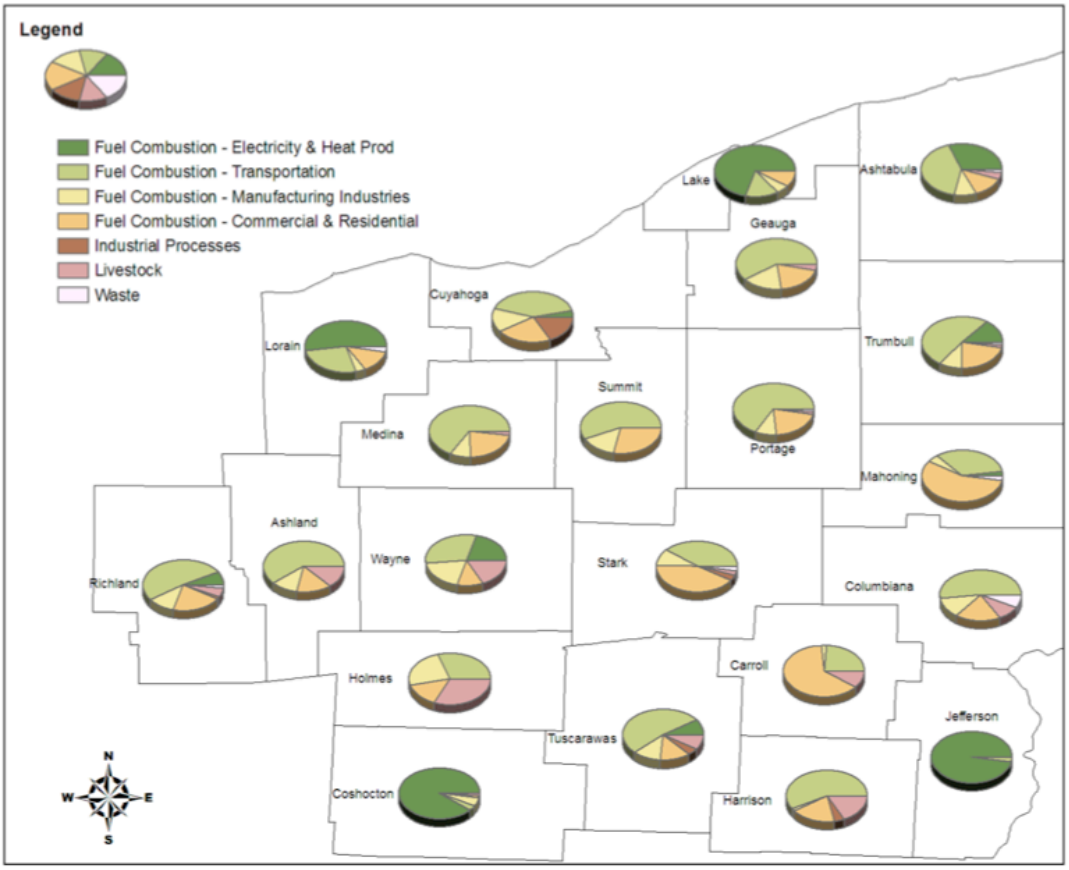


Figure 4. County-Level Distribution by Source Categories (top) and County Total (bottom) for GHG Emissions (CO_2e) in Northeast Ohio



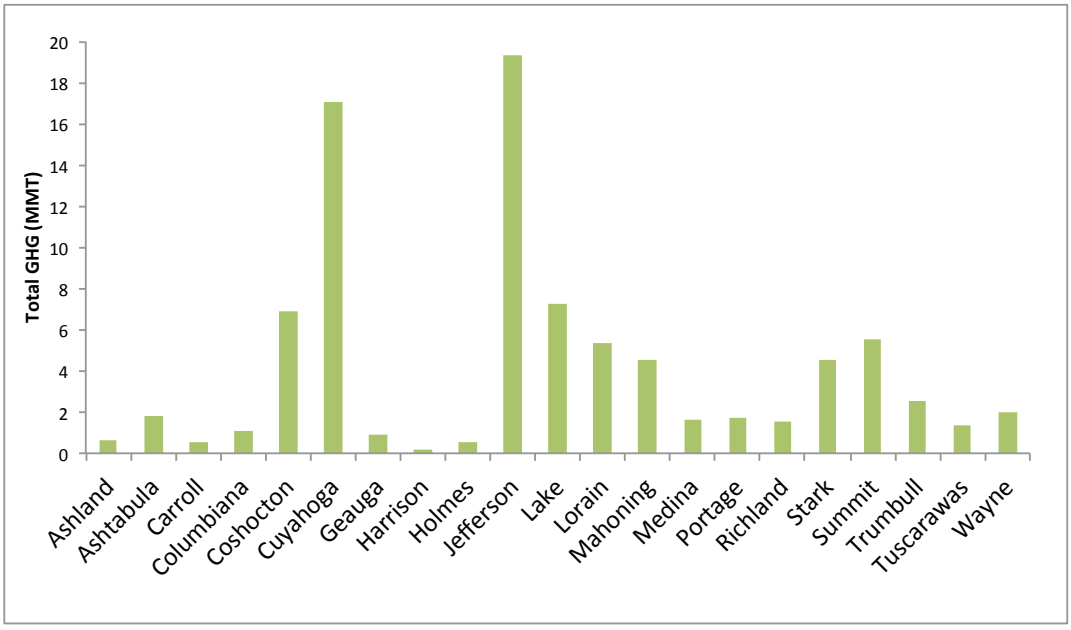
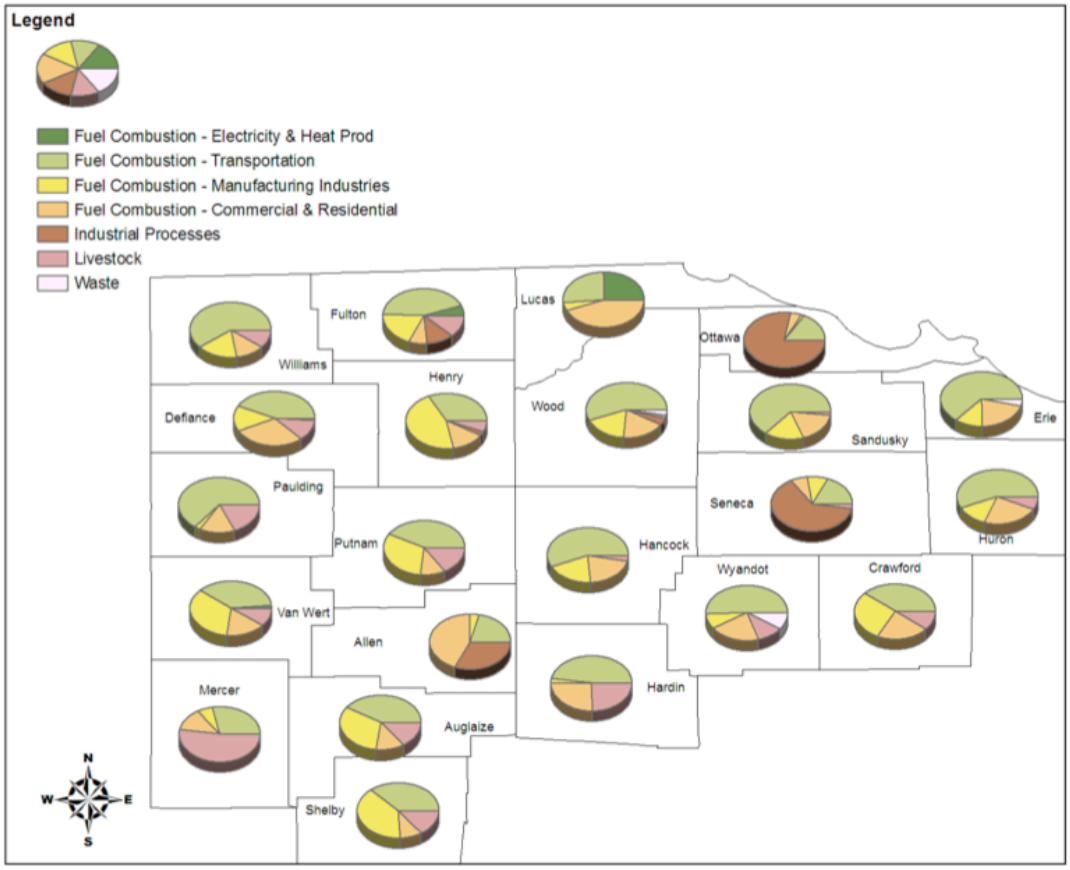


Figure 5. County-Level Distribution by Source Categories (top) and County Total (bottom) for GHG Emissions (CO_2e) in Northwest Ohio



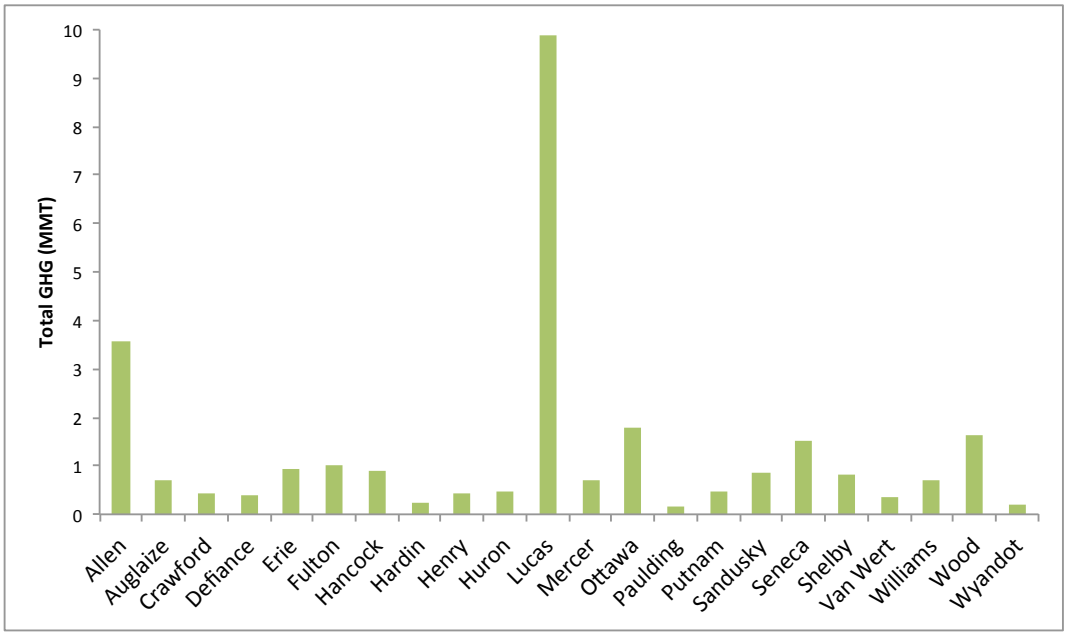
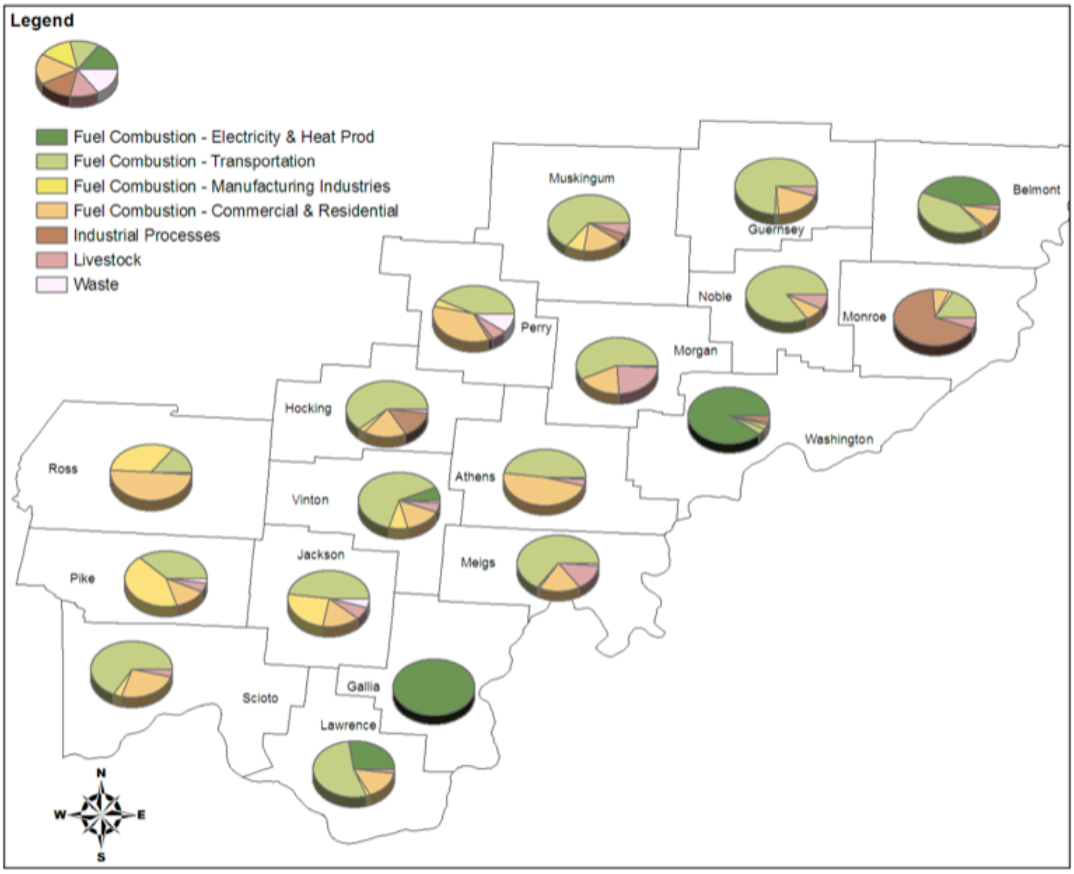


Figure 6. County-Level Distribution by Source Categories (top) and County Total (bottom) for GHG Emissions (CO_2e) in Southeast Ohio



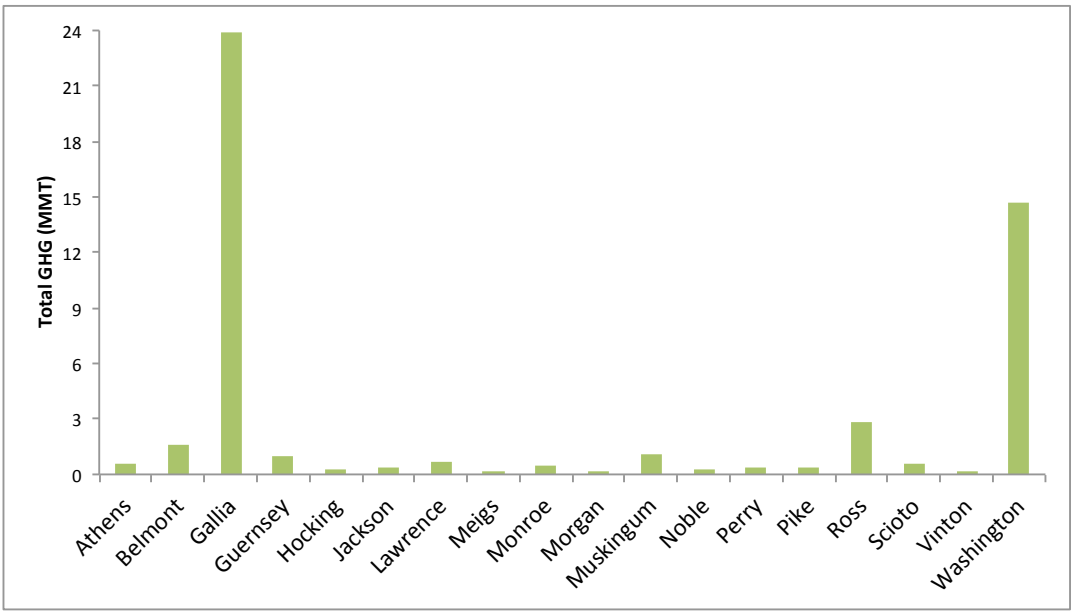
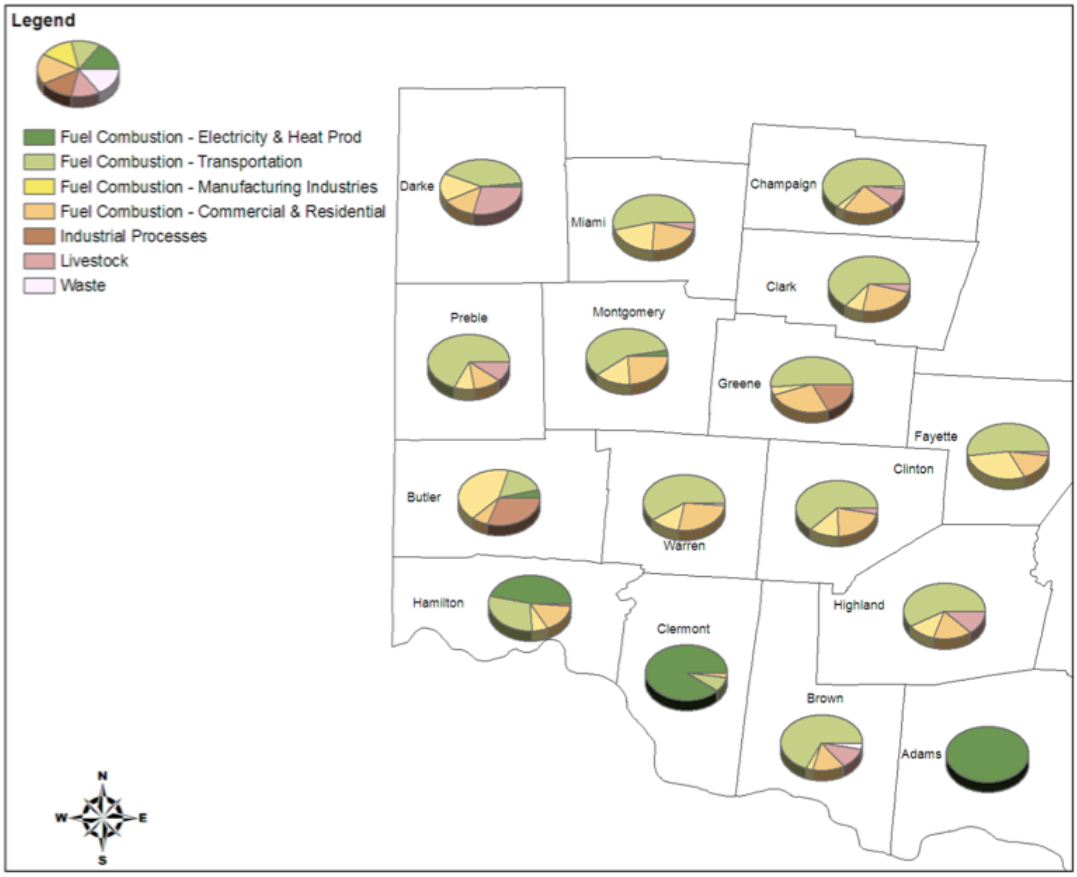
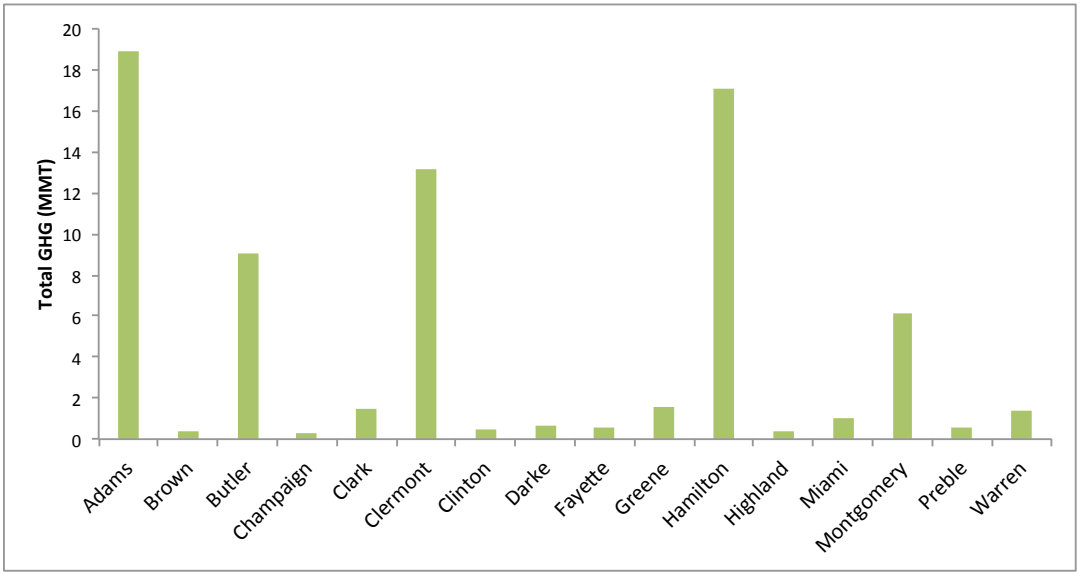


Figure 7. County-Level Distribution by Source Categories (top) and County Total (bottom) for GHG Emissions (CO_2e) in Southwest Ohio





IV. WEB-BASED DATA MANAGEMENT SYSTEM

A comprehensive Web-based retrieval system was designed to assist the various collaborating researchers, project sponsors, stakeholders and interested parties in eveluating Ohio's baseline for decision making. This information in conjunction with the policy scenario modeling and policy considerations provided in this report, will help to inform Ohio's emission mitigation strategies moving forward.

The inventory database query system was populated in Microsoft Sequential Query Language (MSSQL). An internal database structure was designed with a detailed logical database table. The database table illustrates the standardized codes to identify different fields or parameters in the inventory. The relational database was populated between different emission categories utilizing category code, county code and source type.

A GIS emissions map was superimposed on Google maps. Querying a database sometimes referred to as "data mining," permits user-defined access and review of the data. The retrieval system provides users with a series of drill-down queries to develop a concise data output file for viewing, online analysis, and/or downloading directly to their computers. In the current system, users can query GHG data by different levels of source description (e.g., Energy →Fuel combustion → Electric generation →Coal), spatial resolution (e.g., State → County → Point) and GHG gases (CO_2, CH_4, N_2O or Total CO_2e). The Web-based system also provides extensive data analysis tools such as pie charts and bar graphs. These tools help users to quickly view the percentage GHG contribution of different sectors or fuel types.

APPENDIX 8-1:
GHG EMISSION FACTORS FOR DIFFERENT FUELS

Table 1.A. Emission Factors for CO_2 Emissions by Fuel

Fuel Type	Material Units	Combustion Type	CO_2 EF (lb/unit)	EF Reference
Blast Furnace Gas	MILLION CUBIC FEET	Industrial	55639	IPCC 2006
Coal	TONS		4810	USEPA 2005
Coke Oven Gas	MILLION CUBIC FEET	Industrial	9501	IPCC 2006
Diesel	1000 GALLONS		22600	USEPA 2005
Digester Gas	MILLION CUBIC FEET	Internal Combustion	13500	OhioEPA 2010
		External Combustion	70900	OhioEPA 2010
Distillate Oil	THOUSAND GALLONS		22300	USEPA 2005
Dried Sludge	TONS	Incineration	3482	NCDAQ 2009
Gasoline	THOUSAND GALLONS	Internal Combustion	19500	USEPA 2005
Jet Fuel	THOUSAND GALLONS	Internal Combustion	183204	CARB 2010
Landfill Gas	MILLION CUBIC FEET	Internal Combustion	25000	OhioEPA 2010
		External Combustion	57681	NCDAQ 2009#
Liquid Waste	THOUSAND GALLONS	Industrial	22000	EIA 2011$
Liquefied Petroleum Gas	THOUSAND GALLONS	Industrial	12500	USEPA 2008
Medical Waste	TONS	Incineration	9150	OhioEPA2010
Natural Gas	MILLION CUBIC FEET	External Combustion	120000	USEPA 2005
		Internal Combustion	110000	USEPA 2005
Petroleum Coke	TONS	Electricity Generation	5948	CARB 2010
Refinery Gas	MILLION CUBIC FEET	Industrial	176811	CARB 2010
Residual Oil	THOUSAND GALLONS		25000	USEPA 2005
Waste	TONS	Incineration	1999	EIA 2011
Wood	TONS		2028	USEPA 2005

Recommends 50% CO_2 and 50% CH_4 composition $ Assumed as waste oil

Sources:

California Air Resources Board. (2010). *Documentation of California's 2000-2008 GHG Inventory*. Sacramento, California. Retrieved from http://www.arb.ca.gov/cc/inventory/doc/doc_index.php

U.S. Energy Information Administration. (2011). *Voluntary Reporting of Greenhouse Gases Program, Fuel Emission Coefficients*. Washington, D.C. Retrieved from http://www.eia.doe.gov/oiaf/1605/coefficients.html

Inter-Governmental Panel on Climate Change. (2006). 2006 *IPCC Guidelines for National Greenhouse Inventories*. Geneva, Switzerland. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

North Carolina Division of Air Quality. (2009). *Greenhouse Gas Emission Guidelines: Stationary Combustion Sources*. Raleigh, NC.

T. Velalis, Ohio Environmental Protection Agency, Columbus, Ohio, personal communications, 2010.

U.S. Environmental Protection Agency. (2005). *Technology Transfer Network Clearinghouse for Inventories & Emissions Factor, WebFIRE*. Washington, D.C. Retrieved from http://cfpub.epa.gov/webfire/

Table 1.B. Emission Factors for CH_4 and N_2O Emissions by Fuel

Fuel Type	Material Units	Combustion Type	CH_4 EF (lb/unit)	N_2O EF (lb/unit)	EF Reference
Coal	TONS		0.0600	0.0400	USEPA 2005
Coke Oven Gas	MILLION CUBIC FEET	Industrial	0.2140	0.0214	IPCC 2006
Diesel	THOUSAND GALLONS		0.1110	0.2600	USEPA 2005
Digester Gas	MILLION CUBIC FEET	Internal Combustion	1.2130	0.1213	CARB 2010
Distillate Oil	THOUSAND GALLONS	Industrial	0.0520	0.2600	USEPA 2005
		Commercial	0.2160	0.2600	USEPA 2005
		Residential	0.2160	0.0500	USEPA 2005
		Electricity Generation	0.2800	0.2600	USEPA 2005
Dried Sludge	TONS	Incineration	0.5720	0.0764	CARB 2010*
Gasoline	THOUSAND GALLONS	Internal Combustion	1.8678	0.6084	CARB 2010
Jet Fuel	THOUSAND GALLONS	Internal Combustion	0.5754	0.1587	CARB 2010
Landfill Gas	MILLION CUBIC FEET		0.9970	0.1108	NCDAQ 2009
Liquefied Petroleum Gas	THOUSAND GALLONS	Industrial	0.2000	0.0220	USEPA 2008
Medical Waste	TONS	Incineration	0.7758	0.1034	CARB 2010*
Natural Gas	MILLION CUBIC FEET	Internal Combustion	2.3000	2.2000	USEPA 2005
Petroleum Coke	TONS		0.1748	0.0350	CARB 2010
Refinery Gas	MILLION CUBIC FEET	Industrial	2.7558	0.2756	CARB 2010
Residual Oil	THOUSAND GALLONS		0.4750	0.5300	USEPA 2005
Waste	TONS	Incineration	0.7758	0.1034	CARB 2010
Wood	TONS		0.1000	0.2081	USEPA 2005
Wood (Dry)	TONS		0.3280	0.2081	USEPA 2005
Wood (Wet)	TONS		0.1845	0.1171	USEPA 2005

*Emission factor assumed for municipal solid waste

Source:
U.S. Environmental Protection Agency. (2008). *AP 42, Fifth Edition, Volume I Chapter 1: External Combustion Sources, Liquefied Petroleum Gas*. Washington, D.C. Retrieved from http://www.epa.gov/ttn/chief/ap42/ch01/index.html

APPENDIX 8-2:

METHODOLOGY FOR COMPUTATION OF REVISED CO_2 EMISSION FACTOR FOR COAL BURNING IN POWER PLANTS

The COALQUAL database[10] was used to retrieve carbon content in coal samples from all over the country. Carbon content was averaged for all samples in a county and thus origin county-specific average carbon content was generated. EIA 923 data[11] provides the plant-specific coal supply's origin county for the 12 months during 2009. The county averaged carbon content derived from COALQUAL database was mapped to these 25 plants. Each plant has a different coal origin and different quantities supplied. A supply quantity based on weighted carbon content was computed for the whole year of 2009. Then CO_2 EF was calculated as:

$$CO_{2EF} = CC\% \times {}^{44}/_{12} \times 0.99 \times 1/100 \times 2000 \ {}^{lb}/_{tons}$$

Where,

CC% = Weighted carbon content in percentage

44/12 = Stoichiometric conversion factor from carbon to CO_2

0.99 = 99% oxidation factor of carbon as per IPCC

The computed emission factors for 25 power plants are provided in Table 2.A.

[10] U.S. Geological Survey. (1997). *Coal Quality Database*. Reston, Virginia. Retrieved from http://energy.er.usgs.gov/products/databases/CoalQual/intro.htm

[11] U.S. Energy Information Administration. (2009). *EIA-923 (Schedule 2) - Monthly Utility and Nonutility Fuel Receipts and Fuel Quality Data, 2008 and Beyond*. Washington, DC. Retrieved from www.eia.doe.gov/cneaf/electricity/page/eia423.html

Table 2.A. Plant-Specific CO_2 Emission Factors 25 Facilities Combusting Coal

Facility	City	County	CO_2 EF (lb/unit)
Picway Power Plant	Lockbourne	Pickaway	4551.15
FirstEnergy Generation Corp., Ashtabula Plant	Ashtabula	Ashtabula	4067.97
Painesvile Municipal Electric Plant	Painesville	Lake	4920.44
Eastlake Plant	Eastlake	Lake	4103.50
Avon Lake Power Plant	Avon Lake	Lorain	4847.25
Niles Plant	Niles	Trumbull	4862.77
Department of Public Utilities, City of Orrville, Ohio	Orrville	Wayne	4920.44
Toledo Edison Co., Bay Shore Plant	Oregon	Lucas	3318.81
R.E. Burger Plant	Shadyside	Belmont	4800.55
Conesville Power Plant	Conesville	Coshocton	4843.50
Ohio Valley Electric Corp., Kyger Creek Station	Cheshire	Gallia	4183.39
General James M. Gavin Power Plant	Cheshire	Gallia	4478.81
Cardinal Power Plant	Brilliant	Jefferson	4934.39
W.H. Sammis Plant	Stratton	Jefferson	4480.88
P. H. Glatfelter Company - Chillicothe Facility	Chillicothe	Ross	4557.73
Muskingum River Power Plant	Waterford	Washington	5284.04
R. H. Gorsuch Station	Marietta	Washington	4745.93
DP&L, J.M. Stuart Generating Station	Aberdeen	Adams	4682.97
DP&L, Killen Generating Station	Manchester	Adams	4873.77
DP&L, O.H. Hutchings Generating Station	Miamisburg	Montgomery	5173.64
Cleveland Electric Illuminating Co., Lake Shore Plant	Cleveland	Cuyahoga	3454.29
City of Hamilton Department of Public Utilities	Hamilton	Butler	5054.33
Duke Energy Ohio, W.H. Zimmer Station	Moscow	Clermont	4754.77
Duke Energy Ohio, W.C. Beckjord Station	New Richmond	Clermont	4876.95
Duke Energy Ohio, Miami Fort Station	North Bend	Hamilton	4740.03

APPENDIX 8-3:
GHG EMISSION FACTORS FOR DIFFERENT INDUSTRIAL PROCESSES

Table 3.A. Emission Factors for CO_2 Emissions by Industrial Process Type

Industry Type	Process Type	Material Description	Material Units	CO_2 EF (lb/unit)	EF Reference
Chemical Manufacturing	Ammonia Production - Primary Reformer	Ammonia	TONS	6.80	USEPA 1993
Chemical Manufacturing	Ammonia Production - CO2 Regenerator	Ammonia	TONS	2440.00	USEPA 1993
Chemical Manufacturing	Carbon Black Production	Carbon Black	TONS	10500.00	IPCC 2006
Mineral Products	Asphalt Concrete - Drum Mix Plant	Hot Mix Asphalt	TONS	33.00	USEPA 2004
Mineral Products	Asphalt Concrete - Batch Mix Plant	Hot Mix Asphalt	TONS	37.00	USEPA 2004
Mineral Products	Brick Manufacture-Kilns	Brick	TONS	400.00	USEPA 1997
Mineral Products	Brick Manufacture-Dryer	Brick	TONS	71.00	USEPA 1997
Mineral Products	Ceramic Clay/Tile Manufacture - Kiln	Clay	TONS	780.00	USEPA 1996
Mineral Products	Castable Refractory - Rotary Calciner	Clay	TONS	600.00	USEPA 1995a
Mineral Products	Glass Manufacture - Melting Furnace	Glass	TONS	400.00	IPCC 2006
Mineral Products	Cement Manufacturing – Dry Kiln	Clinker	TONS	1800.00	USEPA1995b
Mineral Products	Lime Manufacturing - Calcimatic Kiln	Lime	TONS	2700.00	USEPA 1998
Mineral Products	Lime Manufacturing - Rotary Kiln	Lime	TONS	3200.00	USEPA 1998
Petroleum Industry	Fluid Catalytic Cracking Units	Refinery Feed	1000 BARRELS	47595.69	API 2004
Petroleum Industry	Hydrogen Generation Unit	Refinery Feed	1000 BARRELS	14447.83	API 2004
Petroleum Industry	Asphalt Blowing	Asphalt	TONS	13.38	API 2004
Primary Metal Production	Aluminum Ore - Electro-reduction	Molten Aluminum	TONS	3200.00	IPCC 2006
Primary Metal Production	Ferroalloy - Open Furnace	Silicomanganese	TONS	2800.00	IPCC 2006
Primary Metal Production	Ferroalloy - Open Furnace	Ferromanganese	TONS	2600.00	IPCC 2006
Primary Metal Production	By-product Coke Manufacturing	Coke	TONS	1120.00	IPCC 2006
Primary Metal Production	Iron Production	Iron	TONS	2700.00	IPCC 2006
Primary Metal Production	Steel Manufacturing - Electric Arc Furnace	Steel	TONS	160.00	IPCC 2006
Primary Metal Production	Steel Manufacturing - Basic Oxygen Furnace	Steel	TONS	220.00	IPCC 2006

Table 3.B. Emission Factors for CH_4 and N_2O Emissions by Industrial Process

Industry Type	Process Type	Material Description	Material Units	CH_4 EF (lb/unit)	N_2O EF (lb/unit)	EF Reference
Chemical Manufacturing	Ammonia Production - CO_2 Regenerator	TONS	Ammonia	2.0260	0.0203	USEPA 1993
Chemical Manufacturing	Carbon Black Production	TONS	Carbon Black	22.0000		IPCC 2006
Chemical Manufacturing	Nitric Acid	TONS	Pure Acid		18.0000	IPCC 2006
Chemical Manufacturing	Nitriles, Acrylonitrile Production	TONS	Acrylonitrile		0.3600	IPCC 2006
Mineral Products	Asphalt Concrete - Drum Mix Plant	TONS	Hot Mix Asphalt	0.0120		USEPA 2004
Mineral Products	Asphalt Concrete - Batch Mix Plant	TONS	Hot Mix Asphalt	0.0074		USEPA 2004
Mineral Products	Brick Manufacture-Kilns	TONS	Brick	0.0370		USEPA 1997
Mineral Products	Brick Manufacture-Dryer	TONS	Brick	0.1100		USEPA 1997
Petroleum Industry	Asphalt Blowing	TONS	Asphalt	7.0200		USEPA 2008
Primary Metal Production	By-product Coke Manufacturing	TONS	Coke	0.0002		IPCC 2006
Primary Metal Production	Iron Production	TONS	Iron	1.8000		IPCC 2006

Sources:

American Petroleum Institute. (2004). *Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry.* Washington, D.C.

Inter-Governmental Panel on Climate Change. (2006). *2006 IPCC Guidelines for National Greenhouse Inventories.* Geneva, Switzerland. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

U.S. Environmental Protection Agency. (1993). *AP 42, Fifth Edition, Volume I Chapter 8: Inorganic Chemical Industry, Synthetic Ammonia.* Washington, D.C. Retrieved from http://www.epa.gov/ttn/chief/ap42/ch08/index.html

U.S. Environmental Protection Agency. (1995a). *AP 42, Fifth Edition, Volume I Chapter 11: Refractory Manufacturing.* U.S. Environmental Protection Agency, Washington, D.C. Retrieved from http://www.epa.gov/ttn/chief/ap42/ch011/index.html

U.S. Environmental Protection Agency. (1995b). *AP 42, Fifth Edition, Volume I Chapter 11: Portland Cement Manufacturing.* Washington, D.C.

U.S. Environmental Protection Agency. (1996). *AP 42, Fifth Edition, Volume I Chapter 11: Ceramic Clay Manufacturing*. Washington, D.C.

U.S. Environmental Protection Agency. (1997). *AP 42, Fifth Edition, Volume I Chapter 11: Brick and Related Clay Products*. Washington, D.C.

U.S. Environmental Protection Agency. (1998). *AP 42, Fifth Edition, Volume I Chapter 11: Lime Manufacturing*. Washington, D.C.

U.S. Environmental Protection Agency. (2004). *AP 42, Fifth Edition, Volume I Chapter 11: Hot Mix Asphalt Plants*. Washington, D.C.

U.S. Environmental Protection Agency. (2008). *Technical Support Document for the Petroleum Refining Sector*. Washington, D.C.

APPENDIX 8-4:

METHODOLOGY FOR ESTIMATING GHG EMISSIONS FROM ENTERIC FERMENTATION IN LIVESTOCK MANAGEMENT

To estimate ammonia emissions from livestock, PECHAN compiled livestock population for each county from USDA.[12] The Air Quality Center project team utilized the livestock activity from PECHAN and computed the methane emissions from enteric fermentation at the county level in Ohio.

U.S. EPA distributed cattle population among replacement, stocker, feedlot, and mature animals using a cattle transition matrix found in the Cattle Enteric Fermentation Model (CEFM) as shown in Table 4.A. Because of a lack of data on cattle categorization, the PECHAN county cattle population was assumed to be distributed as for the entire nation. Therefore, specific cattle population ratios in the U.S. EPA inventory were used to compute the county animal numbers to facilitate methane estimation from enteric fermentation in Ohio.

Table 4.A. U.S. Cattle Population by Animal Type in 2007

Livestock Type	2007 Livestock Population (1000 Heads)
Dairy	
Dairy Cows	9145
Dairy Replacements 7-11 months	1299
Dairy Replacements 12-23 months	3043
Beef	
Bulls	2214
Beef Cows	32644
Beef Replacements 7-11 months	1349
Beef Replacements 12-23 months	3276
Steer Stockers	8302
Heifer Stockers	4966
Feedlot Cattle	13404

The CH_4 emission factors per head by animal type were computed in CEFM

[12] U.S. Department of Agriculture. (2009). *2007 Census of Agriculture Report*. Washington, D.C. Retrieved from http://www.agcensus.usda.gov/

model by U.S. EPA and are shown in Table 4.B. for cattle and Table 4.C. for other livestock.

Table 4.B. National Emission Factors for Cattle Population

Livestock Type	Emission Factors (kg CH4/head/year)
Dairy	
Dairy Cows	141
Dairy Replacements 7-11 months	46
Dairy Replacements 12-23 months	69
Beef	
Bulls	53
Beef Cows	94
Beef Replacements 7-11 months	60
Beef Replacements 12-23 months	69
Steer Stockers	57
Heifer Stockers	59
Feedlot Cattle	42

Table 4.C.: National Emission CH_4 Factors for Livestock

Livestock Type	Emission factor
Sheep	8
Goats	5
Horses	18
Swine	1.5

APPENDIX 8-5:

METHODOLOGY FOR ESTIMATING GHG EMISSIONS FROM LIVESTOCK MANURE MANAGEMENT

The estimation methodology for GHG emissions from livestock manure management in Ohio was derived from the U.S. EPA as discussed below.

CH_4 and N_2O emissions are computed from the following animal characteristics for each animal category:

- Volatile solids (VS) excretion rate
- Maximum methane producing capacity (B_o) for U.S. animal waste
- Total Kjeldahl nitrogen excretion rate (N_{ex})
- Typical animal mass (TAM)

These animal characteristics vary by animal type, age and feedlot placement. U.S. EPA estimated national animal population, categorized by the animal age and operations, from USDA data. The population distribution is shown in Table 5.A. Similar to enteric fermentation, the research team distributed the PECHAN computed county population according to the U.S. EPA categories. Thus, it was assumed that each animal population (county level) is distributed by its type, age and feedlot placement in the same way as in national level.

Table 5.A. U.S. Livestock Population

Animal Type	2007 Livestock Population (1000 Heads)
Dairy Cattle	**13487**
Cows	9145
Heifer	4343
Beef Cattle	**88062**
Feedlot Steers	8674
Feedlot Heifers	4730
NOF Bulls	2214
NOF Calves	21906
NOF Heifers	9592
NOF Steers	8302
NOF Cows	32644
Swine	**65417**
Market <60 lb	21812
Market 60-119 lb	14557
Market 120-179 lb	12185
Market >180 lb	10673
Breeding	6190
Sheep	**6120**
Sheep on Feed	3000
Sheep NOF	3120
Goats	**2530**
Poultry	**2166936**
Hens > 1yr	346613
Pullets	103816
Chickens	8164
Broilers	1619400
Turkeys	88943
Horses	**9500**

The typical animal waste characteristics for the livestock categories were compiled and provided in U.S. EPA's 2008 information. State-specific values for VS and N_{ex} were derived for Ohio. Table 5.B. illustrates the waste characteristics by different livestock population.

Table 5.B. Waste Characteristics Data

Livestock Group	TAM (kg)	N_{ex} (kg/day-1000 kg mass)	B_0 (m^3 CH_4/kg VS added)	VS (kg/day per 1,000 kg mass)
Dairy Cows	604	0.52	0.24	9.01
Dairy Heifers	476	0.46	0.17	8.35
Feedlot Steers	420	0.33	0.33	3.96
Feedlot Heifers	420	0.34	0.33	4.33
NOF Bulls	750	0.31	0.17	6.04
NOF Calves	118	0.30	0.17	6.41
NOF Heifers	420	0.35	0.17	7.93
NOF Steers	318	0.34	0.17	8.07
NOF Cows	533	0.30	0.17	6.91
Market <60 lb	16	0.60	0.48	8.80
Market 60-119 lb	41	0.42	0.48	5.40
Market 120-179 lb	68	0.42	0.48	5.40
Market >180 lb	91	0.42	0.48	5.40
Breeding	198	0.24	0.48	2.60
Sheep on Feed	25	0.42	0.36	9.20
Sheep NOF	80	0.42	0.19	9.20
Goats	64	0.45	0.17	9.50
Horses	450	0.30	0.33	10.00
Hens > 1yr	1.8	0.83	0.39	10.80
Pullets	1.8	0.62	0.39	9.70
Chickens	1.8	0.83	0.39	10.80
Broilers	0.9	1.10	0.36	15.00
Turkeys	6.8	0.74	0.36	9.70

The following equations for animal-GHG relationships in manure management systems were employed.

$$VS\ excreted_{Animal,WMS} = Population_{Animal} \times {}^{TAM}/_{1000} \times VS \times WMS \times 365.25$$

Where,

$VS\ excreted_{Animal,WMS}$ ➜ Volatile solids excreted in manure managed in each waste management system (WMS) for each livestock animal type (kg/year)

$Population_{Animal}$ ➜Livestock population in county by animal type (head)

TAM ➜Typical animal mass (kg)

VS ➜Volatile solids production rate (kg VS/ 1000 kg animal mass/ day)

WMS ➜Distribution of manure by WMS for each animal type in a state (percent)

365.25 ➜Days per year

$$N\ excreted_{Animal,WMS} = Population_{Animal} \times {}^{TAM}/_{1000} \times N_{ex} \times WMS \times 365.25$$

Where,

$N\ excreted_{Animal,WMS}$ ➜Total nitrogen excreted in each WMS for each animal type (kg/year)

N_{ex} ➜Kjeldahl nitrogen excretion rate (kg N/1000 kg animal mass/day)

Manure distribution among different WMS at beef feedlots, dairies, dairy heifer facilities and swine, layer, broiler and turkey operations were provided in U.S. EPA's 2008 data for Ohio as given in Table 5.C. Manure from remaining livestock categories, namely beef cattle (not on feed), sheep, horses and goats are managed in dry systems. Therefore, manure from these groups was assumed to be managed in pasture.

Table 5.C. Manure Distribution among Waste Management Systems by Operation (Percent)

Animal Operations / WMS	Dry Lot	Daily Spread	Solid Storage	Pasture	Liquid Slurry	Deep Pit	Anaerobic Lagoon	Poultry without Litter	Poultry with Litter
Beef Feedlots	100	-	-	-	0.6	-	-	-	-
Dairies	-	14	41	8	23	4	11	-	-
Dairy Heifer	78	14	-	8	0	-	-	-	-
Swine	-	-	4	7	27	47	15	-	-
Layers	-	-	-	-	-	0	100	100	-
Broiler & Turkey	-	-	-	1	-	-	-	-	99

$$CH_4 = \sum_{Animal,WMS} VS\ excreted_{Animal,WMS} \times B_0 \times MCF_{animal,\ WMS} \times 0.662$$

Where,

CH_4 ➜ Methane emissions from manure management (kg CH_4/year)

B_0 ➜ MaximumCH_4 producing capacity (m^3 CH_4/kg VS)

$MCF_{animal,WMS}$ ➜ Methane conversion factor for each animal and WMS (percent)

0.662 ➜ Methane density at 25° C (kg CH_4/m^3 CH_4)

Methane conversion factors (MCF) for dry systems in temperate climate were again derived from U.S. EPA's 2008 report that are based on IPCC default factors and listed in Table 5.D. U.S. EPA estimated the MCFs for lagoon and liquid systems based on van't Hoff-Arrhenius. MCFs for liquid systems in Ohio are shown in Table 5.E.

Table 5.D. Methane Conversion Factors (percent) for Dry Systems

Waste Management System	Temperate Climate MCF
Daily spread	0.005
Dry lot	0.015
Pasture	0.015
Poultry with & without bedding	0.015
Solid storage	0.040

Table 5.E. Methane Conversion Factors by State for Liquid Systems for 2008 (percent)

Animal Type	Anaerobic Lagoon	Liquid Slurry & Deep Pit
Dairy	0.69	0.26
Swine	0.70	0.27
Beef	-	0.26
Poultry	0.70	-

$$Direct\ N_2O = \sum_{animal,WMS} N\ excreted_{Animal,WMS} \times EF_{WMS} \times {}^{44}/_{28}$$

Where,

Direct N_2O ➜ Direct N_2O emissions in manure management systems (kg N_2O/ year)

EF_{WMS} ➜ Direct N_2O emission factor (kg N_2O-N/ kg N)

44/28 ➜ Conversion factor of N_2O-N to N_2O

IPCC default emission factors for direct N_2O emissions from manure management systems are listed in Table 5.F.

Table 5.F. Direct Nitrous Oxide Emission Factors for 2008 (kg N_2O-N/kg

Waste Management System	Direct N_2O EF
Anaerobic lagoon	0
Daily spread	0
Deep pit	0.002
Dry lot	0.020
Liquid slurry	0.005
Pasture	0
Poultry with & without bedding	0.001
Solid storage	0.005

$$Indirect\ N_2O = \sum_{Animal,\ WMS}\left(\left[N\ excreted_{Animal,WMS} \times Frac_{gas,WMS}/100 \times EF_{volatilization} \times 44/28\right] + \left[N\ excreted_{Animal,WMS} \times Frac_{runoff,WMS}/100 \times EFrunoff \times 44/28\right]\right)$$

Where,

Indirect N_2O ➜Indirect N_2O emissions in manure management systems (kg N_2O/ year)

$Frac_{gas,WMS}$ ➜ Nitrogen lost through volatilization in each WMS

$Frac_{runoff,WMS}$ ➜ Nitrogen lost through runoff and leaching in each WMS

$EF_{volatilization}$ ➜ Emission factor for volatilization (0.01 kg N_2O-N/ kg N)

EF_{runoff} ➜Emission factor for runoff (0.0075 kg N_2O-N/ kg N)

U.S. EPA estimated indirect N_2O loss factors were utilized to compute indirect emissions and are listed in Table 5.G. The project team used runoff nitrogen loss factors estimated for Midwest region.

Table 5.G. Indirect Nitrous Oxide Loss Factors (percent)

Animal Type	Waste Management System	Volatilization Nitrogen Loss	Runoff Nitrogen Loss
Beef Cattle	Dry Lot	23	1.9
	Liquid Slurry	26	0
	Pasture	0	0
Dairy Cattle	Anaerobic Lagoon	43	0.4
	Daily Spread	10	0
	Deep Pit	24	0
	Dry Lot	15	0.9
	Liquid Slurry	26	0.4
	Pasture	0	0
	Solid Storage	27	0
Goats	Dry Lot	23	1.9
	Pasture	0	0
Horses	Dry Lot	23	0
	Pasture	0	0
Poultry	Anaerobic Lagoon	54	0.4
	Liquid Slurry	26	0.4
	Pasture	0	0
	Poultry with bedding	26	0
	Poultry without bedding	34	0
	Solid Storage	8	0
Sheep	Dry Lot	23	1.9
	Pasture	0	0
Swine	Anaerobic Lagoon	58	0.4
	Deep Pit	34	0
	Liquid Slurry	26	0.4
	Pasture	0	0
	Solid Storage	45	0