2020 National Emissions Inventory Technical Support Document: Agriculture – Livestock Waste

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2020 National Emissions Inventory Technical Support Document: Agriculture – Livestock Waste

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10 Agriculture – Livestock Waste

10.1 Sector Descriptions and Overview

The emissions from this category are primarily from domesticated animals intentionally reared for the production of food, fiber, or other goods or for the use of their labor. The livestock included in the EPA–estimated emissions include beef cattle, dairy cattle, goats, ponies, horses, poultry (layers and broilers), sheep, turkeys and swine. We use the Farm Emissions Model (FEM) developed by Carnegie Mellon University (CMU) to estimate the EFs from swine, layers, broilers, beef cattle and dairy cattle. For the other animals estimated by EPA methods, we employ a nationwide average EF multiplied by appropriate activity data. A few S/L/T agencies report data from a few other categories in this sector such as domestic and wild animal waste, though these emissions are very small compared to the livestock listed above. The domestic and wild animal waste emissions are not included for every state and not estimated by the EPA. The pollutants that EPA reports using its methods for this sector are NH3, VOC, and some VOC-HAPs by animal type as described further below.

The SCCs shown in Table 10-1 represent those for which EPA provides nationwide estimates, and in grey highlight are the SCCs for which we use the FEM model; SCC level 1 are “Miscellaneous Area Sources” and SCC level 2 are “Agricultural Production – Livestock” for all SCCs.

Table 10-1: Livestock Waste SCCs that are estimated by EPA methods for 2020 NEI

SCC	SCC Level 3	SCC Level 4
2805002000	Beef cattle production composite	Not Elsewhere Classified
2805018000	Dairy cattle composite	Not Elsewhere Classified
2805025000	Swine production composite	Not Elsewhere Classified
2805007100	Poultry production - layers with dry manure management systems	Confinement
2805009100	Poultry production - broilers	Confinement
2805010100	Poultry production - turkeys	Confinement
2805045000	Goats Waste Emissions	Not Elsewhere Classified
2805035000	Horses/ Ponies Waste Emissions	Not Elsewhere Classified
2805040000	Sheep and Lambs Waste Emissions	Total

It should be noted that there are other SCCs that make up this sector in the NEI, and SLTs can report to them. However, they will be minor contributors to the overall emission levels from this sector and many of those data are removed via our “tagging” process and are reviewed carefully via our QA process so there is no double counting with emissions the EPA estimates and reports to the NEI.

10.2 Sources of data

The agencies listed in Table 10-2 submitted emissions for this sector; agencies not listed used EPA estimates for the entire sector. Some agencies submitted emissions for the entire sector (100%), while others submitted only a portion of the sector (totals less than 100%). In cases where a full submittal was not made, EPA data was used to backfill according to the information provided in the nonpoint survey for this sector. Some states submitted to SCCs that EPA does not estimate via the CMU model (more details provided later), but those emissions will all be small, and care was taken in assembling the final data for this sector not to double count emissions across state submitted emissions and EPA developed emissions.

Table 10-2: Agencies that submitted Ag Livestock Waste emissions to the 2020 NEI

Region	Agency	S/L/T
3	Delaware Department of Natural Resources and Environmental Control	State
9	Arizona Division of Air Quality	State
8	Utah Division of Air Quality	State
9	California Air Resources Board	State
10	Coeur d'Alene Tribe	Tribe
10	Idaho Department of Environmental Quality	State
10	Kootenai Tribe of Idaho	Tribe
10	Nez Perce Tribe	Tribe
10	Shoshone-Bannock Tribes of the Fort Hall Reservation of Idaho	Tribe

Through the rigorous 2020 NEI nonpoint QA Process, we tagged out all the emission submitted by California, Delaware, and Idaho (with agreement from each of those states) and used EPA's estimates instead across the board. The only SLT emissions remaining in this sector are from Utah, Arizona, and the tribes.

It should be noted that there are a couple of "Industrial Processes" point source SCCs for this sector. CA is the only state in the 2020 NEI to submit to point source ammonia for this sector, and only a very negligible amount of emissions. Some other states have submitted small amounts of PM, which is not an expected EPA pollutant for this sector. EPA thus "tags out" all PM from this sector. In general, point source emissions from this sector are negligible, particularly for NH_3, compared to the nonpoint emissions (many orders of magnitude lower). Generally, these emissions are ignored in the Nonpoint NH3 emissions accounting process. All point source emission totals and will be ignored in all subsequent discussions here and will not be included in the totals in other parts of this document for this sector. No point source subtraction is deemed necessary for this sector.

10.3 EPA-developed emissions

The general approach to calculating NH_3 emissions due to livestock is to multiply the emission factor (in kg per year per animal) by the number of animals in the county. The county-level NH_3 emissions factors are estimated using the FEM and county-level daily average meteorology (ambient temperature, wind speed, and precipitation) [ref 1, 2]. Once the FEM estimates NH_3 emission factors by animal type, the county-level NH_3 emission factors ($EF_{c,a}$) will be multiplied with the latest NEI animal population ($A_{c,a}$) to compute the county-level NH_3 emissions ($E_{c,a}$) for all animal types.

$$E_{c,a} = EF_{c,a} \times A_{c,a} \times 2.2/2000 \quad (1)$$

Where:

$E_{c,a,}$ = NH_3 emissions for animal type *a* and county c (short ton)
$EF_{c,a,}$ = NH_3 emissions factor from the FEM model for animal type *a* and county *c* (kg/head)
$A_{c,a}$ = animal count for animal type *a* and county c (head)
2.2/2000 = conversion factor from kg to short tons

VOC emissions were estimated by multiplying a constant national VOC/NH_3 emissions ratio of 0.08 to county-level NH_3 emissions. Hazardous air pollutants (HAP) emissions were estimated by multiplying the county-level VOC emissions by HAP/VOC ratios, which are obtained from the literature and can vary by animal type. The VOC emissions ($E_{VOC,c,a}$) are calculated using the ratio of VOC to NH_3 emissions from livestock. That ratio is 0.08 kg of VOC for every kg of NH_3. HAP emissions were estimated by multiplying the county-level VOC emissions by HAP/VOC ratios.

$$E_{VOC,c,a} = VOC/NH_3 \times E_{c,a} \quad (2)$$

Where:

VOC/NH_3 = 0.08 (Ratio of VOC/NH_3)
$E_{VOC,c,a}$ = VOC emissions for animal type *a* and county *c* (ton)
$E_{c,a}$ = NH_3 emissions for animal type *a* and county *c* (ton)

10.3.1 Activity data

The activity data for this source category is based on livestock counts (average annual number of standing heads) and population information by state and county used to develop U.S. EPA's Greenhouse Gas (GHG) Inventory [ref 3]. This data set is derived from multiple data sets from the United States Department of Agriculture (USDA), particularly the National Agricultural Statistics Service (NASS) survey and census [ref 4]. The USDA NASS survey dataset, which represents the latest available, 2020 national livestock data, is used to obtain the livestock counts for as many counties as possible across the United States. For a full description of the GHG livestock population estimation methodology, the reader should refer to the referenced citation for the EPA's GHG inventory document [ref 3].

Generally, counties not specifically included in the NASS survey data set (e.g., due to business confidentially reasons) are known as "D counties". They were gap-filled based on the difference in the reported state total animal counts, and the sum of all county-level reported animal counts. State-level data on animal counts from the GHG inventory were distributed to counties based on the proportion of animal counts in those counties from the 2020 NASS census. The general methods to allocate animal populations from state to county, based on lack of data at the county level, can be found in the EPA's GHG Inventory document [ref 3]. Equation (1) is used to allocate animal population to county, as needed:

$$P_{a,c} = P_{a,s} \times r_{a,c} \quad (1)$$

Where:

$P_{a,c,2020}$ = Estimated population of animal type *a* in county *c*

$P_{a,s,2020}$ = NASS survey reported state-level population of animal type *a* in state *s*

$r_{a,c,2020}$ = Ratio of animal county- to state-level animal counts from the NASS census for animal type *a* in county *c*

When we come across any "D counties", the county-level methodology relies on evenly distributing the 'available' population (the difference between the state population and the sum of the "non-D counties") to each D county in the state. So, for example, if Broward, Orange, and Polk counties in Florida are "D" and the sum of the non-D counties is 6,000 compared to a reported 9,000 population for a given animal in FL, each of those counties each get 1,000 head. The point of determining the county population is to get a ratio for each county/year/animal. That ratio is multiplied by the NASS population (the goal is to always match the NASS data). That resulting value is then the estimated county-level population. This procedure is very similar to how we handled these data in the 2017 NEI.

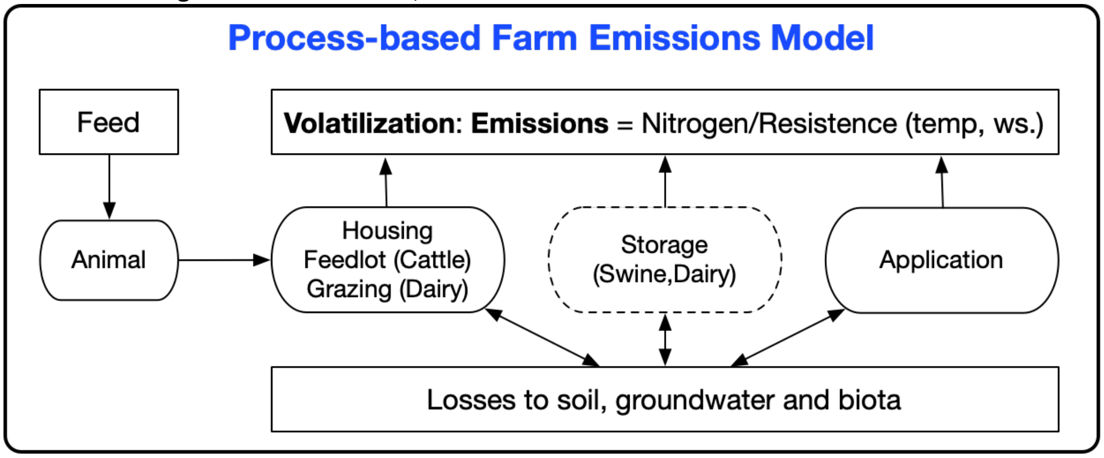
Please note that as with other sectors that rely on animal counts for activity, we allow SLTs to submit activity information. Those SLT-submitted activity data are quality assured and used over EPA estimates as appropriate. Please consult other parts of this document for the SLT data that were used over EPA's for animal count activity. The final animal count data used in the 2020 NEI data for the CMU FEM model animals are shown in Table 10-8. Only dairy cattle showed a bit of a growth in going from 2017 to 2020.

10.3.2 Methodology overview

Many of the methods and data described for this sector mirror exactly what was done in the 2017 NEI, except that 2020 information was used and the CMU FEM model was run for 2020. Thus, throughout this section the reader should refer to the 2017 NEI TSD (section 4.5) for any further details above and beyond what's provided in this document.

Before discussing the process used for the 2020 NEI, a brief discussion of EPA methods used in 2014 and 2017 NEI is beneficial. In 2004, Carnegie Mellon University (CMU) developed the FEM (Farm Emissions Model) to first estimate NH_3 emissions from only dairy farms [ref 5, 6, 7]. Over time, this model was modified to include all major animal types, such as swine, dairy cattle, beef cattle, poultry layers, and poultry broilers [ref 1, 2]. In the 2014 NEI, EPA implemented the FEM which is a semi-empirical process-based emissions model, as the model is based on a nitrogen mass balance with inputs of meteorological parameters and management practices to obtain the desired output of ammonia emissions as a function of time but also be constrained through the use of tuned parameters to ensure agreement with previously reported ammonia emission factors (see general diagram Figure 10-1 below and references [ref 1, 2] for more details). The semi-empirical process-based emission modeling approach allows us to evaluate the model for consistency with measured emission factors, maintain consistency by tracking the actual nitrogen available for emission (and also estimate uncertainty in our model's estimates of ammonia emissions, producing daily (and seasonally) variable EFs by animal type. Note that for the NEI, we aggregate emissions to the county level on annual basis as required by the nonpoint sector.

Figure 10-1: Nitrogen flow in the FEM, used to estimate livestock waste NH3 emissions in 2020 NEI



In the 2014 NEI, our estimates were developed by a graduate student working CMU. While she passed on the code and input files to EPA, when we attempted to use these in the 2017 NEI, we were not successful in reproducing some of her estimates; thus, we went to a simple ratioing technique (using meteorology changes from 2014 to 2017) to estimate emissions for this sector in the 2017 NEI. For the 2020 NEI, we were able to better reproduce the 2014 results and used the original FEM code provided by CMU with some improvements to estimate NH3 emissions for this sector. In this TSD, we summarize the 2020 NEI Process, leaving out a lot of the details which can be found in the 2017 NEI TSD, since they are unchanged. The 2020 NEI improvements section (Section 10.4.1) details new items that were added in the 2020 cycle.

In the 2020 NEI, the EPA methodology for ammonia emissions that results from the use of the CMU model, includes all processes from the housing/grazing, storage and application of manure from beef cattle, dairy cattle, swine, broiler chicken, and layer chicken production, and these are assigned to the "EPA" SCCs listed in Table 10-1. It is assumed the EFs used also account for, on average, all the management practices that are used in waste treatment for each of those animals.

10.3.3 Emissions factor development

CMU developed a model to estimate NH_3 emissions from livestock [ref 1-6]. This model produces daily-resolved, climate level emissions factors for a particular distribution of management practices for each county and animal type (for dairy cows, beef cattle, swine, poultry layers, and poultry broilers only), as expressed as emissions/animal. These county level emissions factors are then combined together to create a state level emissions factor for each animal type. Thus, the CMU model provides a state specific emission factor for each animal type (NH_3 emissions/head). For the non-CMU model animals that EPA estimates emissions for, we are reliant on use of population counts that come from the same source as described above combined with one national EF for each animal type (horses, goats, turkeys, and sheep) [ref 8]. VOC emissions are always a constant 8% of NH3 emissions.

To develop emissions factors for the 2020 NEI for the CMU-based animals, the CMU model was modified to use hourly meteorological data. HAP emissions were estimated by multiplying county-specific VOC emissions by speciation factors that are animal-specific as shown in Table 10-3 below. The HAP emissions are animal-specific and come from the SPECIATE database, as described in the 2017 NEI TSD for this sector. The HAP fractions found in SPECIATE are multiplied by the VOC estimates, record-by-record, to estimate HAPs for this sector.

Table 10-3: Animal-specific VOC fractions used to estimate HAPs for cattle, layers, broilers, and swine

SCC	Animal Type	HAP	Fraction of VOC	SPECIATE Profile Number
2805002000	Beef Cattle	1, 184-Dichlorobenzene	0.0013	95240
2805002000	Beef Cattle	Methyl isobutyl Ketone	0.0008	
2805002000	Beef Cattle	Toluene	0.0110	
2805002000	Beef Cattle	Chlorobenzene	0.0001	
2805002000	Beef Cattle	Phenol	0.0006	
2805002000	Beef Cattle	Benzene	0.0001	
2805007100	Poultry---Layers	Methyl isobutyl ketone	0.0169	95223
2805007100	Poultry---Layers	Toluene	0.0018	
2805007100	Poultry---Layers	Phenol	0.0024	
2805007100	Poultry---Layers	N-hexane	0.0111	
2805007100	Poultry---Layers	Chloroform	0.0025	
2805007100	Poultry---Layers	Cresol/Cresylic Acid (mixed isomers)	0.0048	
2805007100	Poultry---Layers	Acetamide	0.0075	
2805007100	Poultry---Layers	Methanol	0.0608	
2805007100	Poultry---Layers	Benzene	0.0052	
2805007100	Poultry---Layers	Ethyl Chloride	0.0031	
2805007100	Poultry---Layers	Acetonitrile	0.0088	
2805007100	Poultry---Layers	Dichloromethane	0.0002	
2805007100	Poultry---Layers	Carbon Disulfide	0.0034	
2805007100	Poultry---Layers	2-Methyl Naphthalene	0.0006	
2805009100	Poultry-Broilers	Methyl isobutyl ketone	0.0169	95223
2805009100	Poultry-Broilers	Toluene	0.0018	
2805009100	Poultry-Broilers	Phenol	0.0024	
2805009100	Poultry-Broilers	N-hexane	0.0111	
2805009100	Poultry-Broilers	Chloroform	0.0025	
2805009100	Poultry-Broilers	Cresol/Cresylic Acid (mixed isomers)	0.0048	
2805009100	Poultry-Broilers	Acetamide	0.0075	
2805009100	Poultry-Broilers	Methanol	0.0608	
2805009100	Poultry-Broilers	Benzene	0.0052	
2805009100	Poultry-Broilers	Ethyl Chloride	0.0031	
2805009100	Poultry-Broilers	Acetonitrile	0.0088	
2805009100	Poultry-Broilers	Dichloromethane	0.0002	
2805009100	Poultry-Broilers	Carbon Disulfide	0.0034	

SCC	Animal Type	HAP	Fraction of VOC	SPECIATE Profile Number
2805009100	Poultry-Broilers	2-Methyl Naphthalene	0.0006	
2805018000	Dairy Cattle	Toluene	0.0018	8897
2805018000	Dairy Cattle	Cresol/Cresylic Acid (mixed isomers)	0.0276	
2805018000	Dairy Cattle	Xylenes (mixed isomers)	0.0046	
2805018000	Dairy Cattle	Methanol	0.3542	
2805018000	Dairy Cattle	Acetaldehyde	0.0141	
2805025000	Swine	Toluene	0.0047	95241
2805025000	Swine	Phenol (Carbolic Acid)	0.0179	
2805025000	Swine	Benzene	0.0035	
2805025000	Swine	Acetaldehyde	0.0155	

For the non-FEM animals (goats, sheep, horses/ponies, and turkeys), animal-specific HAP speciation profiles were not available in the literature, so the assignments in Table 10-4 were made.

Table 10-4: VOC HAP Profiles used for sheep, goats, turkeys, and horses/ponies

Animal Type	VOC HAP Profiles Used
Sheep and Goats	Same HAP fractions as Dairy Cattle
Turkeys	Same HAP fractions as Chicken-Broilers
Horses/Ponies	Same HAP fractions as Beef Cattle

10.3.4 Process for estimating emissions

From a modeling perspective, the 2020 NEI process shadows what was done in the 2014 NEI, as described in the 2017 NEI TSD, with some built in improvements to the 2020 NEI as discussed in the next section.

However, unlike the 2017 NEI process, 2020 NEI for livestock waste emissions were estimated using actual FEM simulations with the latest USDA animal population representing the year 2020, enhanced county-level daily 2020 meteorology, after first calibrating the model with 2014 estimates developed earlier by CMU researchers.

The remainder of this section details high-level procedures used to arrive at the 2020 NEI estimates as well as presenting a summary of the model parameters derived for the 2020 process.

The basic steps in developing the 2020 inventory involved these basic steps:

- Develop county-specific daily meteorology inputs based on the MCIP meteorology over the US domain
- Run FEM to produce daily NH3 emission factors with county-specific meteorology and farm management practices, and animal-specific model parameters
    - Repeat for all farm processes (housing, storage, application, and/or grazing)
    - Compute a county composite process-specific EF as a weighted average across all manure management practices in that county.

    - Repeat for all animal types

- County-based Emissions = (Emissions Factor from CMU model) x (Animal Population)
    - Resulting data has structure of emissions = f(county, day, livestock type, “practice”) where “practice” ” is shorthand for the different housing/storage/application configurations that prevail in a county.
- Result is ammonia emissions with:
    - Daily temporal resolution
    - County spatial resolution
    - By livestock type and management practice

In the overall process described above, note that the FEM gets seasonal/daily variability due to the resistance parameters in each sub model (see 2017 NEI TSD) being dependent on meteorology. The model gets variability due to management practices because there is a separate resistance sub-model for each livestock type, by manure management stage (housing, storage, etc.), and by major practice (how often there are cleanouts). Regional variation comes from both meteorology effects and from differences in practices across the country. It should be noted that 3 meteorological variables that matter the most include: temperature, wind speed and precipitation.

Note that the FEM model does not cover Alaska, Hawaii, Virgin Islands, or Puerto Rico (only the lower 48 states) due to the lack of meteorology, we would thus be reliant on SLT submissions to cover this sector for those states.

10.3.4.1 *Meteorology*

The source code provided to EPA for FEM model contained weather data for 2014. It did not use standard identifiers (WBAN ID) and was limited to a small number of observations with an unknown source. The FEM weather data used a single monthly value for wind, temperature, and precipitation. FEM interpolated this data to hourly using different techniques. For temperature, a standard deviation was used to raise and lower the mean temperature in the month. For wind speed, the average monthly value was used for all hours. For precipitation, monthly amounts were divided into days (an hours) based upon a parameter defining the frequency of rain in a month. These were all upgraded in the 2020 modeling process as described in the next section.

10.3.4.2 *Animal practice documentation*

The animal practice documentation used here is a summary of the information provided in A. McQulling’s dissertation entitled, “Ammonia emissions from livestock in the United States: from farm-level models to a new national inventory.” The reader should consult those references [ref 1, 2] for further information.

Ammonia emissions from livestock depend on two major factors—the management practices employed by the producers (i.e., what housing, storage and application methods are used) and the environmental conditions of location where the farm is situated (i.e., temperatures, wind speeds, precipitation). All these factors have significant impacts on the conditions of the manure and waste (e.g., water content, total ammoniacal nitrogen concentration) and as a result can enhance or reduce the emissions of ammonia from these sources. The CMU model requires farm-type inputs which describe the type of animal housing, manure storage and application methods used for a particular location. Each location is expected to have some combination of practices; for example, in a single county, some of the swine farms may use deep-pit housing, lagoon storage, and irrigation application while other farms use shallow-pit housing with lagoon storage and injection application.

In order to understand the differences in regional preferences for particular manure management strategies, information was extracted from the most recent National Animal Health Monitoring Surveys done by the USDA [ref 1, 2, 9-29]. The beef cattle NAHMS was completed in 2007 and feedlot beef in 2011; dairy cattle data was from 2002 and 2007; swine data were collected for 2006 and 2012, and the most recent poultry NAHMS was completed for 2010. The most recent data available had limited spatial resolution and so the model is only able to resolve large-scale regional differences in practices. For beef cow calf systems, the United States was divided into four regions, but only two regions for beef housed on feedlots. For swine, the country was divided into three regions—Midwest, East, and South, and for layers, there were four regions—Northeast, Southeast, Central and West. An additional limitation in the data available for the characterization of the farm practices was that for some of the questions asked by the study, results were only reported in terms of percent of operations which used a particular practice. This may give too much weight to the practices used on smaller farms which have a relatively small contribution to the overall level of ammonia emissions from a particular livestock type or practice. Thus, some uncertainty is expected as a result of the limited quantity of data available regarding manure management practices throughout the country. As was previously discussed by Pinder et al. [ref 5-7], one of the main factors most limiting to the FEM's skill is the lack of information about manure management practices throughout the country. It is unclear whether these uncertainties result in the overprediction or underprediction of total ammonia emissions from livestock in the United States. For more detail on the NAHMS by animal type, the reader is referred to the 2017 NEI TSD, as that information has not changed in going from 2017 to 2020 NEIs.

10.3.4.3 *Model parameters*

The FEM is a tuned model that applies adjustments to approximate observed data. However, the model evaluation does not reflect the ability of the FEM to predict completely independent measurements but the ability of a relatively simple process-based model, with a single set of mass transfer parameters for each manure management practice, to describe the full range of observed variability.

The National Air Emissions Monitoring Study (NAEMS) data [ref 30] and literature data are used to both tune the mass balances for different types of animal management practices as well as help set the parameters the model needs to conduct the mass balance and estimate ammonia. The NAEMS information is clearly outlined in the 2017 NEI TSD, the reader is referred to that document. It should be noted that literature data beyond the NAEMS data is required, because the NAEMS dataset does not cover emissions measurements for beef cattle operations, nor does it cover several specific animal manure management practices for some animals. Please refer to the 2017 NEI TSD for more details and for references on this part of the process.

10.3.4.4 *Manure Characteristics*

Manure characteristics are important input parameters to the model because they govern the amount of nitrogen available for emission, whether or not the nitrogen present is likely to be volatilized, and how well the waste can infiltrate into the soil during manure application. These parameters have been selected based on information extracted from published literature as well as reports from the NAEMS study. Table 10-5 describes the types of parameters and inputs critical to the model and Table 10-6 presents information about manure volume, nitrogen concentration and pH levels in the waste from each type of animal included in the model. Please consult Table 4-38 in the 2017 NEI TSD for references for the values shown in Table 10-6 below. The differences between Table 10-6 and what's shown in Table 4-38 of the 2017 NEI TSD result from tuning of the model under 2020 conditions, as described later in this document.

Table 10-5: Description and sources of model inputs and parameters

Data Type	Description	Source of input or parameter	Input or Tuned Parameter?
Meteorology	Temperature (°C) Wind speed (m/s) Precipitation	From National Climate Data Center, based on farm location	Input value (monthly average for seasonal emissions, daily values for daily model run)
Manure Management Practice	Type of housing, storage, or application	Unique to each farm type; farm types have a unique set of inputs	Input value
Resistance Parameters	Surface mass transfer resistance from manure to atmosphere	Tuned based on literature and NAEMS observations to agree with previous work; constant for a particular management practice (for a particular animal type)	Tuned Parameters

Table 10-6: Model Input parameters related to manure characteristics

Parameter Name	Animal Type	Value Used in Model	Units
Manure Volume	Beef Cattle	8.0	animal^{-1} day^{-1}
	Dairy Cattle	6.0	animal^{-1} day^{-1}
	Swine	6.0	animal^{-1} day^{-1}
	Poultry-Layer	0.07	animal^{-1} day^{-1}
	Poultry-Broiler	0.6	finished animal^{-1}
Manure Urea Concentration	Beef Cattle	10.0	kg N animal^{-1} year^{-1}
	Dairy Cattle	14.0	kg N animal^{-1} year^{-1}
	Swine	19.0	kg N animal^{-1} year^{-1}
	Poultry-Layer	0.5	kg N animal^{-1} year^{-1}
	Poultry-Broiler	0.05	kg N finished animal^{-1}
Housing pH	Beef Cattle	7.0	Dimensionless
	Dairy Cattle	7.7	Dimensionless
	Swine	7.0	Dimensionless
	Poultry-Layer	7.3	Dimensionless
	Poultry-Broiler	7.3	Dimensionless
Storage pH	Dairy Cattle	7.3	Dimensionless
	Swine	7.7	Dimensionless
Application pH	Beef Cattle	7.8	Dimensionless
	Dairy Cattle	7.5	Dimensionless
	Swine	7.8	Dimensionless

Parameter Name	Animal Type	Value Used in Model	Units
Storage pH	Poultry-Layer	7.2	Dimensionless
	Poultry-Broiler	7.3	Dimensionless
	Beef Cattle	7.7	Dimensionless
	Dairy Cattle	7.7	Dimensionless

There are only a very limited number of studies which describe the manure nitrogen and manure pH for each animal type. As a result, there is considerable uncertainty in these input values which can result in significant uncertainty in predicted emissions from the model.

10.3.4.5 *Tunable Parameters*

The FEM is a balance between an empirical approach and first-principles process-based model. A nitrogen mass balance and a process description of ammonia losses are used, but the FEM model parameters are tuned to reproduce measured emissions factors. Model complexity is limited to the most important emissions processes and to inputs that are typically available. The strategy pursued for developing process-based models is guided by the need to build emissions inventories, and the requirements and data limitations associated with this application. Previous measurement campaigns also often sampled emissions from a single part of the production process. This means that information about the emissions process from the start to end of production might be lacking, making nitrogen mass balance in the system difficult. The lack of whole-farm measurements is one gap in much of the literature available and a benefit of the estimates of ammonia emissions produced by the FEM.

There are 2-3 tunable parameters associated with each sub-model in the farm emissions model. These tunable parameters allow adjustment of model-predicted emissions and to correct for the unknowns and uncertainties of the input parameters and to ensure that the model-predicted values are consistent with those that have been reported in the literature and in the National Air Emissions monitoring study; they are constant for a particular farm type—tuning is not done for a particular farm—and as a result, there can be significant disagreement between model predictions and the measured emissions for a single farm. The goal of the FEM is not necessarily to capture the emissions of single farms perfectly, but rather to capture the effects of various parameters on emissions on a farm typical of a certain set of practices.

In the FEM, as previously described [ref 1], ammonia emissions are estimated as a function of the nitrogen present in the waste and the mass transfer resistance. This resistance is made up of the following three parts: the aerodynamic (r_a), quasi-laminar (r_b), and surface resistances (r_s) [ref 33]. Aerodynamic and quasi-laminar resistances are used to describe the resistance to transport in the gaseous layer above the animal wastes [ref 31, 34, 35]. These parameters are based on widely used theoretical formulas and are not tuned. The third part of the resistance is the surface resistance from diffusion closest to the gas-liquid (manure) interface. Here, the surface resistance is a function of tuned parameters as well as temperature which ensures the modeled ammonia emission factors are consistent with observations; Table 10-7 lists which tunable parameters are used for each animal and each sub-model.

These values are specific to a particular practice for a particular animal type. This means that a free stall dairy with lagoon storage and injection application would employ the same tuned parameters whether it was located in New York or California. Conversely, two farms in the same location but utilizing different manure management practices would have different tuned parameters in their sub-models. The values that have been used for each of these parameters can be found in Table 10-8 [ref 1, 2]. The 2017 NEI TSD provides further references for the values discussed in Table 10-7 and shown in Table 10-7.

Table 10-7: Tuned model parameters for beef, swine, and poultry

Sub-model	Animal Type	Description
Housing	Cattle: Beef & Dairy Swine Poultry: Broiler & Layer	Resistance parameters H_1, H_2
Storage	Dairy Cattle Swine	Resistance parameters S_1, S_2
Application	Cattle: Beef & Dairy Swine Poultry: Broiler & Layer	Resistance parameters A_1, A_2, A_3
Grazing	Cattle: Dairy & Beef	Resistance parameters G_1, G_2

Table 10-8: Tuned Parameter Values by practice and animal type for the 2020 NEI

Sub-model	Description	Animal Type	Tuning/Evaluation Sources
Housing	Resistance parameters H_1, H_2	Dairy Cattle Swine Poultry-Broiler Poultry-Layer	H,=0.1 (s•m^{-1}•°C^{-1}), H_2=-0.015 (s^{2}m^{-2}) H,=0.1 (s•m^{-1}•°C^{-1}), H_2=-0.08 (s^{2}m^{-2}) H,=0.15 (s•m^{-1}•°C^{-1}), H_2=-0.0035 (s^{2}m^{-2}) H,=0.1 (s•m^{-1}•°C^{-1}), H_2=-0.001 (s^{2}m^{-2})
Storage	Resistance parameters S_1, S_2	Dairy Cattle Swine	S_1=0.1(s•m^{-1}), S_2=1.00(s•m^{-1}•°C^{-1}) S_1=0.2(s•m^{-1}), S_2=4.00(s•m^{-1}•°C^{-1})
Application	Resistance parameters A_1, A_2, A_3	Dairy Cattle Swine Poultry	A,=0.0004(s•m^{-1}), A_2 =8.8, A_3=1.4 A,=0.001(s•m^{-1}), A_2 =-10, A_3=20 A,=0.001(s•m^{-1}), A_2 =-0.01, A_3=0.2
Grazing	Resistance parameters G_1, G_2	Dairy Cattle Beef Cattle	G,= 0.12(s•m^{-1}), G_2=5.4

There are no controls assumed for this source category. Example calculations based on the sequence of steps listed in the “2020 Process for estimating emissions” section shown above can be very involved, but the 2017 NEI TSD section 4.5 shows an example of how these calculations are made. The program that contains the FEM code will be made available to the public once we have finished all the documentation and some specific QA steps associated with the code.

10.3.4.6 *Sheep/lambs, goats, turkeys, and horses/ponies*

In addition to the emissions from the large NH3-emitting from beef cattle, dairy cattle, swine, poultry layers and broilers estimated via the CMU FEM model described above, the EPA also estimates emissions from a set of smaller NH3-emitting animals, which include sheep/lambs, goats, horses/ponies, and turkeys. These emissions are not estimated via the FEM model, but rather estimated with the simple approach of [Emission factors*activity], where the activity is a county-based animal count based on USDA data referenced earlier in this section. These default animal counts are reviewed by the SLTs and replaced with better local counts as appropriate. The EFs are constant for every county in the US and come from an earlier EPA report by Battye et al. [ref 37]. VOC speciation for these non-FEM animal types is applied according to the information provided earlier in this section. Nationwide animal counts, emission factors, and 2020 NEI NH_3totals are shown for each of these animal type combinations below in Table 10-9. VOC is estimated at 8% of NH3 as with the other animal types. And all other assumptions are as stated for the CMU animal emission estimates discussed earlier.

Table 10-9: Animal counts, emission factors, and total NH3 emission estimates in 2020 NEI for goats/sheep and lambs/horses, goats, and ponies/turkeys

Animal Type	National average EF (Tons of NH3/head of animal)	Total Animal Count (Number of Animals)	Estimated Emissions (Tons)
Goats	0.007055	2,744,909	19,365
Sheep/Lambs	0.003714	5,200,000	19,311
Horses/Ponies	0.013448	2,382,854	32,045
Turkeys	0.001112	74,666,661	83,000

10.4 Emissions Summaries

Table 10-10 below shows the comparison of animal population and national NH_3 emissions total between NEI 2014, 2017, and 2020. The average national ammonia emissions changes (tons/year) between 2017 and 2020 NEIs range from 1% (Swine), +10% (Beef Cattle), +15% (Broiler), +17% (Layer) to +22% (Dairy). These increases in emissions result from a combination of differences in meteorology, increased animal counts, and some updated manure management practice information. Please note that these numbers represent only EPA estimates, but a noted in the earlier section, there were only a few emission submissions made the SLTs to this sector and most states accepted our estimates. So, the 2020 numbers shown here should be reflective of actual 2020 NEI emissions at the national level.

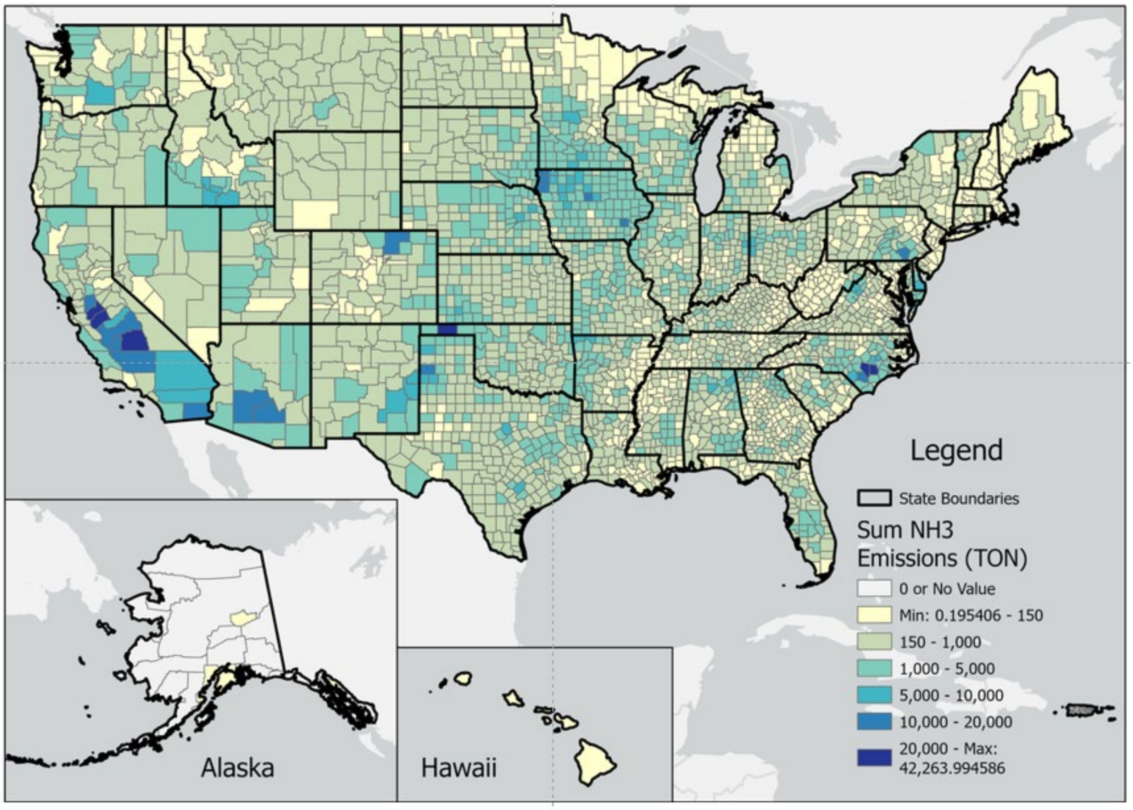
Table 10-10: Animal population and national NH_3 total emissions from: 2014, 2017, and 2020 NEIs

Animal	Animal Population (Number of animals*1000)			Total Emissions (tons/year)		
	NEI2014	NEI2017	NEI2020	NEI2014	NEI2017	NEI2020
Beef	79,367	81,414	80,658	590,424	634,695	698,170
Dairy	9,035	18,888	18,802	225,919	475,573	580,858
Swine	67,766	72,145	77,255	722,622	834,314	845,306
Layer	362,319	497,254	509,914	73,492	109,404	127,548
Broiler	1,506,271	1,621,047	1,676,730	228,723	260,764	299,691

2020 NEI results are shown as total NH3 emissions by county in Figure 10-2. The hotspots are seen to be in the San Joaquin Valley in CA, parts of the Midwest and eastern NC. Beef and dairy cattle emissions drive the hotspots in California mostly. Poultry emissions dominate the southeastern US hotspots, and swine emissions are very prevalent in NC. Turkeys (which are not estimated outside of the FEM model) are important in both NC and in MN areas of the country.

In general, there is seen to be about a 5% increase in ammonia emissions in going from 2017 to 2020 NEIs which manifest as increases or decreases by different animal types across the states.

Figure 10-2: Total NH3 emissions from livestock waste sector, 2020 NEI



10.4.1 Improvements/Changes in the 2020 NEI

A few improvements were made for this sector in going from the 2017 to 2020 NEI. These are highlighted below in summary fashion:

10.4.1.1 *Availability of working computer code to estimate NH3 emissions for 2020*

In the 2017 NEI, we could not develop a code to run the actual FEM model, because we were not confident in how the model reproduced 2014 estimates, so we used a simple ratio approach to estimate emissions based on meteorology changes. In the 2020 NEI cycle, we worked extensively with the code supplied during the 2014 NEI process to EPA and talked to several experts and were able to reproduce 2014 estimates to a certain degree of confidence, where we could use that as a calibration step and move forward to running the actual FEM code for 2020 conditions. We therefore now have a working program at EPA that can generate 2020 NEI emissions for this category using all the model parameters and processes detailed in this document. We expect to make the code publicly available after we are done thoroughly quality assuming it for the emissions it produces at all temporal resolutions (day specific EFs, for example, which is not needed for the NEI).

10.4.1.2 *Improvements to Meteorological Modeling*

One of the primary enhancements made to the FEM for the 2020 NEI is a re-design of the modeling system to accept spatially and temporally enhanced local meteorology. Earlier in this document, it was detailed that a limited number of meteorological observations without proper indexing and identification were used in previous FEM NEI simulations.

To improve this aspect in the 2020 NEI, one of the SMOKE-based (Spare Matrix Operator Kerner Emission) utility programs, called **GenTPro** (**Gen**erating **T**emporal **Pro**files) was updated to generate county-level daily average meteorological inputs for the FEM based on the gridded hourly meteorology data from Meteorology-Chemistry Interface Processor (MCIP) model simulations over the U.S. [ref 36]. The MCIP modeling process relies on hourly meteorological measurements across the US as well as other information to obtain meteorological parameters. The reader should consult the reference above for how these data are formatted and available for download and access. Utilizing the MCIP hourly meteorology for FEM simulations allows us to greatly enhance the spatial and temporal representations of meteorology on NH_3 emissions from the agricultural livestock sector. **GenTPro** can generate the spatially and temporally resolved county-level daily average meteorology inputs (e.g., temperatures, wind speed, and precipitation) for use in generating daily FEM EFs for over 3,100 counties in the U.S. The FEM code has also been enhanced to accommodate and read in these newly designed county-level daily average meteorological data.

10.4.1.3 *Farm Manure Management Practices Information Improvements*

In addition to local meteorology effects, NH_3 EFs from livestock waste is also a strong function of manure management practices employed by the producers *(i.e.*, what housing, storage and application methods are used). It can also significantly impact the conditions of the manure and waste (e.g., water content, total ammoniacal nitrogen concentration, pH) and as a result, it can increase or reduce the emissions of ammonia from these sources.

The FEM model requires county-level farm manure management inputs which describe the type of animal housing, manure storage, and application methods used for a particular location. Each location is expected to have some combination of practices; for example, in a single county, some of swine farms may employ deep-pit housing, lagoon storage, and irrigation application while other farms use shallow-pit housing with lagoon storage and injection application. In order to understand the differences in regional preferences for particular manure management strategies, information was extracted from the most recent National Animal Health Monitoring Surveys (NAHMS) from the U.S. Department of Agriculture (USDA) [ref 1,2, 9-29], as described earlier.

Though the basic NAHMS data we access for the 2020 NEI is the same as that accessed for earlier NEIs, we have tried in the 2020 process to help improve accounting for these farm management process and to enable easy review and edits by our stakeholders, by developing a Python-based Farm Practices Probability Tool (FP2). This tool will allows user to generate the FEM-ready county-level farm manure management practice configuration probability table based on a combination of manure management practices distribution within the county, state, or region from the USDA-based NAHMS [ref 9-29] reports. The format of farm configuration probability table is described in Table 10-11. For each county, the FP2 tool generates a default probability table that attempts to represent all types of manure management practices for that county based on NAHMS data. A farm configuration is a unique combination of manure management practices that describe the operation of the farm. Each farm configuration is executed by the FEM, and the county-level daily NH_3 emission factor is the average of all farm configuration FEM simulations, weighted by farm size and probability of occurrence. In future NEI cycles, EPA expects to update these farm configuration probability tables with the latest and most accurate animal manure management practices information from updated NAHMS data and/or inputs from SLTs as the tool is flexible enough to allow SLTs to enter values that would supercede the default values that have been established for all the operations shown in Table 10-11. A value of 1 indicates that configuration exists for a county, a value of 0 indicates it does not.

Table 10-11: FEM farm manure management practice configuration probability table.

FEM Submodel	Configuration	Value	Description
Grazing	Confined_summer	1 or 0	Seasonal summer Grazing
	Confined_winter	1 or 0	Seasonal Winter Grazing
	Pasture	1 or 0	Pasture resistance
	Drylot	1 or 0	Beef=Drylot, Poultry-Litter
Housing	Tiestall	1 or 0	Dairy=Tiestall, Swine=Deep-Pit, Poultry=High-Rise
	Freestall	1 or 0	Dairy=Freestall, Swine=Shallow-Pit, Poultry=Manure Belt
	Nohousing	1 or 0	No enclosed housing:
	Liquid	1 or 0	Liquid phase animal waste
	Solid	1 or 0	Dry phase animal waste
Storage	Lagoon	1 or 0	Lagoon storage
	Earthbasin	1 or 0	Earth basin storage
	Slurrytank	1 or 0	Slurry tank storage
Application	Irrigation	1 or 0	Irrigation application
	Injection	1 or 0	Injection application
	Trailinghose	1 or 0	Trailinghose application
	Broadcast	1 or 0	Broadcast application
	Summer_application	1 or 4	Summer: [1=daily, 2=weekly, 3=monthly, 4=seasonal]
	Winter_application	1 or 4	Winter: [1=daily, 2=weekly, 3=monthly, 4=seasonal]
Farm practice	Probability	Fraction	Probability of occurrence (e.g., 0.1, 0.2,,) (this represents the probability for any county that a particular type of farm practice exists. Using the "1" s in a county over the total number of "1"s for a practice across the nation.

10.4.1.4 *Continued use of National Air Emissions Monitoring Study (NAEMS) data to tune the models*

While this is not exactly an improvement in the 2020 NEI process, it's is important to point out how important this dataset is for developing emission estimates from the CMU FEM model. It is difficult to characterize NH_3 emission factors from agricultural livestock waste due to the many sources of emissions variability, such as local meteorology, farm management practices, and nutritional feed used in the farms, as well as difficulties in long-term monitoring of emissions from various processes (housing, storage, application and/or grazing) within a farm. Previously many evaluations and tuning of the FEM were performed based on short-term measurements mostly from the literature. In 2016, research at CMU expanded the applications of FEM [ref 1,2] to other animal types beyond dairy cattle (to beef cattle, broilers, layers, and swine) and helped develop the 2014 NEI livestock waste emission estimates for use in the NEI. In this 2014 NEI development, the FEM was first evaluated with the long-term NH_3 monitoring campaign study, National Air Emissions Monitoring Study (NAEMS), that robustly represents the seasonal and regional differences in emissions from livestock production in the United States [ref 30]. The NAEMS farms were selected to span a range of practices as well as locations and emission measurements were conducted from 2007 to 2010. The reader is referred to the references listed in this document and in the 2017 NEI TSD on the NAEMS measurement campaign, but Table 10-12 shows the list of all farms [ref 30] that participated in the NAEMS long-term monitoring campaign. Emissions measurements were taken at a total of 17 (2 livestock barn sites (5 swine, 5 dairy cattle, 4 layer, and 3 broiler barn sites) and 10 manure storage facility sites (5 swine lagoons, 1 swine basin, 1 dairy cow manure lagoon, 2 dairy basins, 1 dairy drylot) for anywhere from 1.5 to 2.5 years, beginning in late 2007 and continuing through early 2010. While the NAEMS monitoring locations covers most of the housing application it is limited in its coverage of storage processes within farms. Storage and application of poultry, as well as beef cattle were not a part of the NAEMS study and as a result those emission measurements had to be found elsewhere for use in the FEM modeling. As further improvements are made in assessing the NAEMS data via development of alternative emission estimation processes for farms, the NEI will continue to draw upon such analyses for its development and for QA.

Table 10-12: Description of farms in NAEMS including management practices by animal type.

Animal Type	State	Process	Management Practice
Broiler	California	Housing	Litter-based
	Kentucky (2)		Liter-based
Layer	California	Housing	High-Rise (HR)
	North Carolina		High-Rise (HR)
	Indiana		High-Rise (HR)
	Indiana		Manure-belt (MB)
Swine	Iowa	Housing	Deep Pit
	Indiana		Deep Pit
	North Carolina		Shallow Pit/Flush
	North Carolina		Shallow Pit/Flush
	Oklahoma		Shallow Pit/Flush
	Iowa	Storage	Manure Basin
	Indiana		Lagoon
	North Carolina		Lagoon
	North Carolina		Lagoon
	Oklahoma		Lagoon
	Oklahoma		Lagoon
Dairy	California	Housing	Free-stall Barn
	Indiana		Free-stall Barn

Animal Type	State	Process	Management Practice
	New York		Free-stall Barn
	Washington		Free-stall Barn
	Wisconsin		Free-stall Barn
	Indiana	Storage	Lagoon
	Texas		Feedlot (housing)
	Washington		Manure Basin
	Wisconsin		Manure Basin

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