March 7, 2019

SPECIFICATION SHEET: AG

Description: Nonpoint agricultural (ag) emissions, for simulating 2016 U.S. air quality

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1. EXECUTIVE SUMMARY

This document details the approach and data sources to be used for developing 2016 gridded nonpoint agriculture (ag) sector emissions for use in an air quality model. The ag sector includes NH3 and VOC emissions from livestock and fertilizer sources. 2016 livestock emissions consist of county-level projections of livestock emissions from the 2014NEIv2 based on U.S. Department of Agriculture (USDA) animal population projections. For livestock in which a data projection factor did not exist, emissions are held constant between 2014 and 2016. Fertilizer emissions for 2016 come from the FEST-C and EPIC model. The SMOKE program GenTPRO estimates the hourly temporalization of ag livestock and fertilizer emissions using hourly gridded meteorology data. Base year inventories were processed with the Sparse Matrix Operating Kernel Emissions (SMOKE) modeling system version 4.6. SMOKE creates emissions in a format that can be input into air quality models. National and state-level emission summaries for key pollutants are provided.

2. INTRODUCTION

The ag sector includes NH_3 emissions from fertilizer and emissions of all pollutants other than $PM_{2.5}$ from livestock in the nonpoint (county-level) data category of the 2014NEIv2. $PM_{2.5}$ from livestock are in the afdust sector. Combustion emissions from agricultural equipment, such as tractors, are located in the Nonroad sector. The sector now includes VOC and HAP VOC in additional to NH_3. The Beta platform uses a 2016-specific fertilizer inventory from the EPIC model combined with a 2016 USDA-based county-level projection of 2014NEIv2 livestock emissions. The SCCs included in the ag sector are shown in Table 1.

Table 1. 2016 beta platform SCCs for ag sector

SCC	Tier 1 description	Tier 2 description	Tier 3 description	Tier 4 description
2801700099	Miscellaneous Area Sources	Ag. Production - Crops	Fertilizer Application	Miscellaneous Fertilizers
2805001100	Miscellaneous Area Sources	Ag. Production - Livestock	Beef cattle - finishing operations on feedlots (drylots)	Confinement
2805001200	Miscellaneous Area Sources	Ag. Production - Livestock	Beef cattle - finishing operations on feedlots (drylots)	Manure handling and storage
2805001300	Miscellaneous Area Sources	Ag. Production - Livestock	Beef cattle - finishing operations on feedlots (drylots)	Land application of manure
2805002000	Miscellaneous Area Sources	Ag. Production - Livestock	Beef cattle production composite	Not Elsewhere Classified
2805003100	Miscellaneous Area Sources	Ag. Production - Livestock	Beef cattle - finishing operations on pasture/range	Confinement
2805007100	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry production - layers with dry manure management systems	Confinement
2805007300	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry production - layers with dry manure management systems	Land application of manure
2805008100	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry production - layers with wet manure management systems	Confinement
2805008200	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry production - layers with wet manure management systems	Manure handling and storage

SCC	Tier 1 description	Tier 2 description	Tier 3 description	Tier 4 description
2805008300	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry production - layers with wet manure management systems	Land application of manure
2805009100	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry production - broilers	Confinement
2805009200	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry production - broilers	Manure handling and storage
2805009300	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry production - broilers	Land application of manure
2805010100	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry production - turkeys	Confinement
2805010200	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry production - turkeys	Manure handling and storage
2805010300	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry production - turkeys	Land application of manure
2805018000	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle composite	Not Elsewhere Classified
2805019100	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle - flush dairy	Confinement
2805019200	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle - flush dairy	Manure handling and storage
2805019300	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle - flush dairy	Land application of manure
2805020002	Miscellaneous Area Sources	Ag. Production - Livestock	Cattle and Calves Waste Emissions	Beef Cows
2805021100	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle - scrape dairy	Confinement
2805021200	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle - scrape dairy	Manure handling and storage
2805021300	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle - scrape dairy	Land application of manure
2805022100	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle - deep pit dairy	Confinement
2805022200	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle - deep pit dairy	Manure handling and storage
2805022300	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle - deep pit dairy	Land application of manure
2805023100	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle - drylot/pasture dairy	Confinement

SCC	Tier 1 description	Tier 2 description	Tier 3 description	Tier 4 description
2805023200	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle - drylot/pasture dairy	Manure handling and storage
2805023300	Miscellaneous Area Sources	Ag. Production - Livestock	Dairy cattle - drylot/pasture dairy	Land application of manure
2805025000	Miscellaneous Area Sources	Ag. Production - Livestock	Swine production composite	Not Elsewhere Classified (see also 28-05-039, -047, -053)
2805030000	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry Waste Emissions	Not Elsewhere Classified (see also 28-05-007, -008, -009)
2805030007	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry Waste Emissions	Ducks
2805030008	Miscellaneous Area Sources	Ag. Production - Livestock	Poultry Waste Emissions	Geese
2805035000	Miscellaneous Area Sources	Ag. Production - Livestock	Horses and Ponies Waste Emissions	Not Elsewhere Classified
2805039100	Miscellaneous Area Sources	Ag. Production - Livestock	Swine production - operations with lagoons (unspecified animal age)	Confinement
2805039200	Miscellaneous Area Sources	Ag. Production - Livestock	Swine production - operations with lagoons (unspecified animal age)	Manure handling and storage
2805039300	Miscellaneous Area Sources	Ag. Production - Livestock	Swine production - operations with lagoons (unspecified animal age)	Land application of manure
2805040000	Miscellaneous Area Sources	Ag. Production - Livestock	Sheep and Lambs Waste Emissions	Total
2805045000	Miscellaneous Area Sources	Ag. Production - Livestock	Goats Waste Emissions	Not Elsewhere Classified
2805047100	Miscellaneous Area Sources	Ag. Production - Livestock	Swine production - deep-pit house operations (unspecified animal age)	Confinement
2805047300	Miscellaneous Area Sources	Ag. Production - Livestock	Swine production - deep-pit house	Land application of manure

SCC	Tier 1 description	Tier 2 description	Tier 3 description	Tier 4 description
			operations (unspecified animal age)	
2805053100	Miscellaneous Area Sources	Ag. Production - Livestock	Swine production - outdoor operations (unspecified animal age)	Confinement

For livestock, meteorologically-based temporal allocation (described in Section 4, Temporal Allocation) is used for month-to-day and day-to-hour temporal allocation. Monthly profiles are based on the daily data underlying the EPA estimates. Fertilizer uses different state-specific year-to-month profiles than livestock but uses the same meteorological-based month-to-hour profiles as livestock. These temporal profile methodologies have not changed from recent platforms.

3. Inventory Development Methods

Livestock

Beta platform livestock emissions consist of a projection of 2014NEIv2 livestock emissions to the year 2016 and include NH3 and VOC. The livestock waste emissions from 2014NEIv2 contain emissions for beef cattle, dairy cattle, ducks, geese, goats, horses, poultry, sheep, and swine. The data come from both state-submitted emissions and EPA-calculated emission estimates. Further information about the 2014NEIv2 emissions can be found in the 2014 National Emissions Inventory, version 2 Technical Support Document (https://www.epa.gov/sites/production/files/2018-07/documents/nei2014v2_tsd_05jul2018.pdf). Projection factors for 2016 emission estimates are based on animal population data from the USDA National Agriculture Statistics Service Quick Stats (https://www.nass.usda.gov/Quick_Stats/). These estimates are developed by data collected from annual agriculture surveys and the Census of Agriculture that is completed every five years. These data includes estimates for beef, layers, broilers, turkeys, dairy, swine, and sheep. Each SCC in the 2014NEIv2 livestock inventory was mapped to one of these USDA categories. Then, projection factors were calculated based on USDA animal populations for 2014 and 2016. Emissions for animal categories for which population data were not available (e.g. goats) were held constant in the projection.

Projection factors were calculated at the county level, but only where county-level data was available for a particular animal category. Data were not available for every animal category in every county. State-wide projection factors based on state total animal populations were

calculated and applied to counties where county-specific data was not available for a given animal category. However, data were also not always available for every animal category in every state; in cases of missing state-level data, a national projection factor was applied. Projection factors were not pollutant-specific and were applied to all pollutants. The national projection factors, which were only used when county or state data were not available, are shown in Table 2.

Table 2. National projection factors for livestock: 2014 to 2016

beef	+3.83%
swine	+6.40%
broilers	+5.56%
turkeys	+3.91%
layers	+2.76%
dairy	+0.53%
sheep	+1.48%

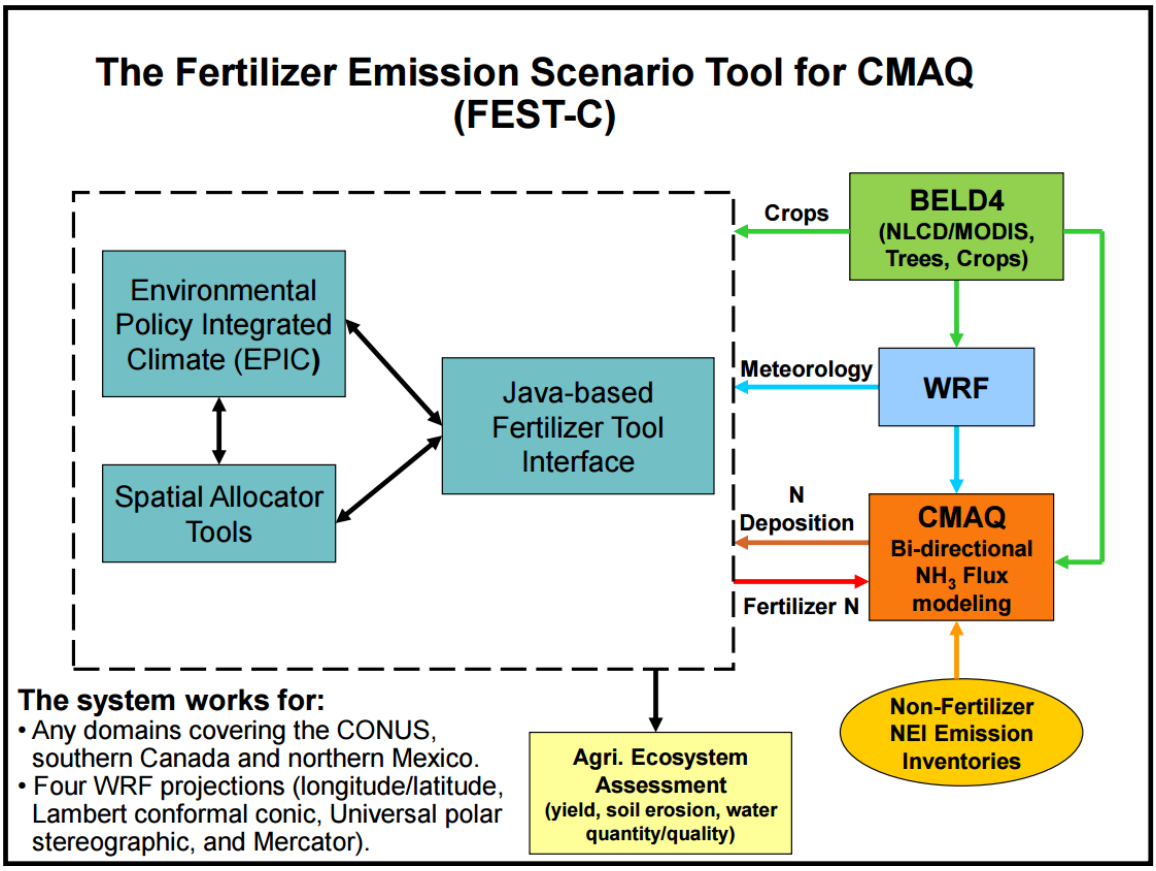
Fertilizer

Fertilizer emissions for 2016 are based on the FEST-C model (https://www.cmascenter.org/fest-c/). These emissions are unchanged from alpha platform. The bidirectional version of CMAQ (v5.3) and the Fertilizer Emissions Scenario Tool for CMAQ FEST-C (v1.3) were used to estimate ammonia (NH_3) emissions from agricultural soils. The approach to estimate year-specific fertilizer emissions consists of these steps:

- Run FEST-C and CMAQ model with bidirectional ("bidi") NH_3 exchange to produce nitrate (NO_3), Ammonium (NH4+, including Urea), and organic (manure) nitrogen (N) fertilizer usage estimates, and gaseous ammonia NH3 emission estimates respectively.
- Calculate county-level emission factors as the ratio of bidirectional CMAQ NH_3 fertilizer emissions to FEST-C total N fertilizer application.
- Assign the NH3 emissions to one SCC: "…Miscellaneous Fertilizers" (2801700099).

FEST-C is the software program that processes land use and agricultural activity data to develop inputs for the CMAQ model when run with bidirectional exchange. FEST-C reads land use data from the Biogenic Emissions Landuse Dataset (BELD), meteorological variables from the Weather Research and Forecasting model, and nitrogen deposition data from a previous or historical average CMAQ simulation. FEST-C, then uses the USDA's Environmental Policy Integrated Climate (EPIC) modeling system (https://epicapex.tamu.edu/epic/) to simulate the agricultural practices and soil biogeochemistry and provides information regarding fertilizer timing, composition, application method and amount.

Figure 1. "Bidi" modeling system used to compute 2016 Fertilizer Application emissions



Activity Data

The following activity parameters were input into the EPIC model:

- Grid cell meteorological variables from WRF (see Table 3)
- Initial soil profiles/soil selection
- Presence of 21 major crops: irrigated and rain fed hay, alfalfa, grass, barley, beans, grain corn, silage corn, cotton, oats, peanuts, potatoes, rice, rye, grain sorghum, silage sorghum, soybeans, spring wheat, winter wheat, canola, and other crops (e.g. lettuce, tomatoes, etc.)
- Fertilizer sales to establish the type/composition of nutrients applied
- Management scenarios for the 10 USDA production regions. These include irrigation, tile drainage, intervals between forage harvest, fertilizer application method (injected versus surface applied), and equipment commonly used in these production regions.

The WRF meteorological model was used to provide grid cell meteorological parameters for year 2016 using a national 12-km rectangular grid covering the continental U.S. The meteorological parameters in Table 3 were used as EPIC model inputs.

Table 3. Environment variables needed for an EPIC simulation

EPIC input variable	Variable Source
Daily Total Radiation (MJ m^2)	WRF
Daily Maximum 2-m Temperature (C)	WRF
Daily minimum 2-m temperature (C)	WRF
Daily Total Precipitation (mm)	WRF
Daily Average Relative Humidity (unitless)	WRF
Daily Average 10-m Wind Speed (m s^{-1})	WRF
Daily Total Wet Deposition Oxidized N (g/ha)	CMAQ
Daily Total Wet Deposition Reduced N (g/ha)	CMAQ
Daily Total Dry Deposition Oxidized N (g/ha)	CMAQ
Daily Total Dry Deposition Reduced N (g/ha)	CMAQ
Daily Total Wet Deposition Organic N (g/ha)	CMAQ

Initial soil nutrient and pH conditions in EPIC were based on the 1992 USDA Soil Conservation Service (CSC) Soils-5 survey. The EPIC model then was run for 25 years using current fertilization and agricultural cropping techniques to estimate soil nutrient content and pH for the 2016 EPIC/WRF/CMAQ simulation.

The presence of crops in each model grid cell was determined through the use of USDA Census of Agriculture data (2012) and USGS National Land Cover data (2011). These two data sources were used to compute the fraction of agricultural land in a model grid cell and the mix of crops grown on that land.

Fertilizer sales data and the 6-month period in which they were sold were extracted from the 2014 Association of American Plant Food Control Officials (AAPFCO, http://www.aapfco.org/publications.html). AAPFCO data were used to identify the composition (e.g. urea, nitrate, organic) of the fertilizer used, and the amount applied is estimated using the modeled crop demand. These data were useful in making a reasonable assignment of what kind of fertilizer is being applied to which crops.

Management activity data refers to data used to estimate representative crop management schemes. The USDA Agricultural Resource Management Survey (ARMS, https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Ag_Resource_Management/) was used to provide management activity data. These data cover 10 USDA production regions

and provide management schemes for irrigated and rain fed hay, alfalfa, grass, barley, beans, grain corn, silage corn, cotton, oats, peanuts, potatoes, rice, rye, grain sorghum, silage sorghum, soybeans, spring wheat, winter wheat, canola, and other crops (e.g. lettuce, tomatoes, etc.).

Emission Factors

The emission factors were derived from the 2016 CMAQ FEST-C outputs. Total fertilizer emission factors for each month and county were computed by taking the ratio of total fertilizer NH_3 emissions (short tons) to total nitrogen fertilizer application (short tons). 12 km by 12 km gridded NH_3 emissions were mapped to a county shape file polygon. The cell was assigned to a county if the grid centroid fell within the county boundary.

4. ANCILLARY DATA

Spatial Allocation

Spatial allocation of ag emissions to the national 36km and 12km domains used for air quality modeling is accomplished using spatial surrogates. Spatial surrogates map county polygons to the uniformly spaced grid cells of a modeling domain. The ag sector uses the NLCD Total Agriculture surrogate (310) for the entire sector.

Temporal Allocation

Both the livestock and fertilizer emissions inventories include monthly values. Livestock monthly values are based on SMOKE temporal profiles, pre-applied to the inventory. These livestock profiles, which are by state and separate for beef, layers, broilers, dairy, and swine, are based on daily ag emissions from 2014NEIv1 developed by CMU[1]. Fertilizer monthly emissions values come from the EPIC model.

Hour-of-month temporalization for all ag sources – both livestock and fertilizer, all pollutants – is based on meteorology, using the Bash algorithm applied by the SMOKE program GenTPRO (https://www.cmascenter.org/smoke/documentation/4.6/html/ch05s03s05.html). GenTPRO uses an equation derived by Jesse Bash of the EPA's ORD based on the Zhu, Henze, et al. (2013) empirical equation. This equation is based on observations from the TES satellite instrument with the GEOS-Chem model and its adjoint to estimate diurnal NH_3 emission variations from livestock as a function of ambient temperature, aerodynamic resistance, and wind speed. The equations are:

[1] McQuilling, A. M. & Adams, P. J. Semi-empirical process-based models for ammonia emissions from beef, swine, and poultry operations in the United States. Atmos. Environ. 120, 127–136 (2015).

$$E_{i,h} = [161500/T_{i,h} \times e^{(-1380/T_{i,h})}] \times AR_{i,h}$$

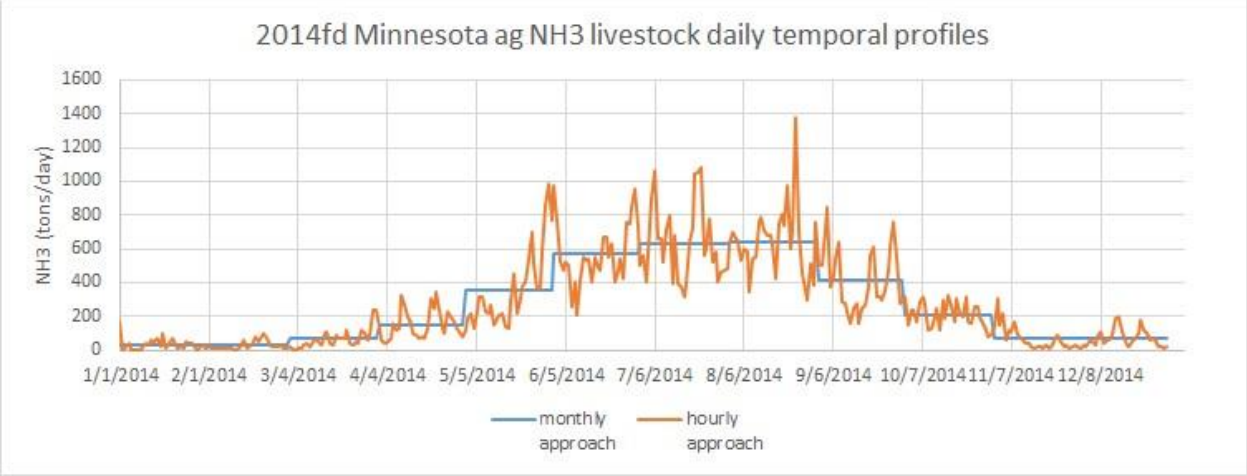
$$PE_{i,h} = E_{i,h} / Sum(E_{i,h})$$

where

- $PE_{i,h}$ = Percentage of emissions in county *i* on hour *h*
- $E_{i,h}$ = Emission rate in county *i* on hour *h*
- $T_{i,h}$ = Ambient temperature (Kelvin) in county *i* on hour *h*
- $V_{i,h}$ = Wind speed (meter/sec) in county *i* (minimum wind speed is 0.1 meter/sec)
- $AR_{i,h}$ = Aerodynamic resistance in county *i*

These hourly GenTPRO profiles were calculated at the county level based on hourly 12km meteorology and are applied on an hour-of-month basis, in combination with the monthly values in the emissions inventory. GenTPRO profiles based on 12km meteorology are used for all modeling domains and resolutions to ensure consistency between runs. An example plot showing daily emissions derived from applying this approach to Minnesota for calendar year 2014 is shown in Figure 2.

Figure 2. Example temporal profile of NH3 livestock emissions for Minnesota



Chemical Speciation

The ag sector includes speciation of NH3 and VOC emissions. For NH3, in support of optional bidirectional NH3 application within CMAQ, an extra species called NH3_FERT is generated. NH3_FERT = NH3 for fertilizer sources, and NH3_FERT = 0 for all other sources. The NH3_FERT species is created in addition to the normal NH3 species, which includes both fertilizer and livestock as always. Reports summarizing total VOC emissions according to VOC speciation profile were developed at the state and county level. VOC speciation employs the use of partial HAP integration.

5. EMISSIONS PROJECTION METHODS

Future year projections for the beta platform have not yet been finalized at the time this was written.

6. EMISSIONS PROCESSING REQUIREMENTS

Ag emissions were processed for air quality modeling using the Sparse Matrix Operator Kernel Emissions (SMOKE[2]) modeling system. Because the fertilizer and livestock inventories are monthly, the sector is processed through SMOKE as a monthly sector; i.e. Smkinven was run once per month with the appropriate SMKINVEN_MONTH setting (this is handled automatically by the platform scripts when using smk_ar_monthly_emf.csh). Spcmat, Grdmat, and Temporal are then also run once per month, followed by Smkmerge. The Temporal program uses the hourly temporal profile NetCDF file created by GenTPRO (ATPRO_HOURLY_NCF) to apply hourly temporalization. GenTPRO does not need to be run in addition to the standard SMOKE programs unless a new ATPRO_HOURLY_NCF file is desired. Because the hourly temporalization is different for every day of the year, separate emissions files are generated for every day, not just for representative days.

This is a 2-D sector in which all emissions were output to a single layer gridded emissions file.

7. EMISSIONS SUMMARIES

National and state totals by pollutant for the beta platform cases are provided here along with some example plots. Additional plots and maps are available online through the LADCO website[3] and the Intermountain West Data Warehouse[4]. The case descriptions are as follows:

2011en, 2023en, 2028el = Final 2011, 2023, and 2028 cases from the 2011v6.3 platform

2014fd = 2014NEIv2 and 2014 NATA

2016fe = 2016 alpha platform (grown from 2014NEIv2)

2016ff, 2023ff, and 2028ff = 2016, 2023, and 2028 cases from the 2016 beta platform

Table 4. Comparison of national total annual CAPS ag emissions (tons/yr)

Pollutant	2011en	2014fd	2016fe	2016ff	2023en	2028el
NH3	3,522,492	2,828,369	2,776,552	2,856,742	3,609,331	3,612,417
VOC		179,970	179,970	186,274		

[2] http://www.smoke-model.org/index.cfm

[3] https://www.ladco.org/technical/modeling-results/2016-inventory-collaborative/

[4] http://views.cira.colostate.edu/iwdw/eibrowser2016

Table 5. Comparison of state total annual NH3 ag emissions (tons/yr)

State	2011en	2014fd	2016fe	2016ff	2023en	2028el
Alabama	59,935	44,478	45,199	46,900	65,280	65,696
Arizona	33,247	28,031	26,929	27,100	33,459	33,426
Arkansas	117,710	58,981	58,436	60,223	123,270	123,676
California	203,203	364,703	273,648	270,635	202,026	200,089
Colorado	68,895	48,845	46,917	49,009	69,290	69,007
0Connecticut	2,458	1,557	1,649	1,685	2,519	2,498
Delaware	5,185	5,827	5,563	5,831	5,185	5,185
D.C.		0	0	0		
Florida	37,873	30,450	32,926	33,338	38,721	38,683
Georgia	90,890	61,890	62,822	65,515	98,220	98,850
Hawaii	6,898	3,804			6,902	6,891
Idaho	60,583	67,272	63,009	65,463	60,544	60,425
Illinois	106,874	107,521	70,723	72,957	109,745	110,333
Indiana	108,171	64,178	62,211	64,706	111,486	112,088
Iowa	280,766	273,253	280,014	294,160	294,765	297,346
Kansas	171,012	161,925	170,989	176,776	171,190	170,283
Kentucky	50,793	31,176	34,129	34,734	52,502	52,522
Louisiana	38,188	29,984	35,685	35,874	39,184	39,208
Maine	5,097	2,022	2,129	2,154	5,202	5,147
Maryland	22,714	12,190	12,412	12,798	22,714	22,714
Massachusetts	2,215	973	1,002	1,013	2,248	2,233
Michigan	54,955	31,779	33,748	34,918	55,898	56,045
Minnesota	188,766	129,605	138,954	144,526	192,612	193,472
Mississippi	55,781	52,170	53,177	55,026	60,303	60,688
Missouri	122,553	83,527	82,953	86,732	125,791	126,129
Montana	54,343	21,724	19,790	20,056	54,207	53,943
Nebraska	180,967	143,432	133,327	137,337	181,815	180,935
Nevada	5,568	16,928	17,474	16,659	5,545	5,507
New Hampshire	1,419	602	684	690	1,437	1,432
New Jersey	3,686	1,816	1,772	1,789	3,776	3,765
New Mexico	35,327	17,608	16,389	16,400	35,318	35,210
New York	42,815	21,242	21,311	21,492	43,113	43,140
North Carolina	167,570	161,525	163,374	171,518	182,483	182,559
North Dakota	93,163	36,340	48,191	48,156	93,051	92,883
Ohio	91,887	57,238	55,390	57,085	94,358	94,675
Oklahoma	102,686	95,232	101,727	105,010	105,546	105,628
Oregon	43,626	16,559	15,402	15,632	43,783	43,676
Pennsylvania	70,511	37,906	38,737	39,552	72,810	72,890
Rhode Island	297	148	177	179	303	303
South Carolina	29,697	19,392	19,875	20,621	31,012	31,147
South Dakota	128,691	59,001	74,665	76,315	129,072	128,813
Tennessee	34,884	23,328	26,755	27,302	36,071	36,044

State	2011en	2014fd	2016fe	2016ff	2023en	2028el
Texas	262,149	279,564	293,335	303,714	265,540	264,476
Utah	23,084	14,089	14,284	14,825	23,711	23,794
Vermont	7,790	3,412	3,420	3,406	7,811	7,810
Virginia	43,026	21,661	24,841	25,230	44,003	45,477
Washington	49,623	27,445	24,017	24,616	49,931	49,853
West Virginia	9,194	4,697	5,679	5,814	9,457	9,824
Wisconsin	113,742	41,290	51,544	51,938	114,175	114,188
Wyoming	31,588	8,878	8,869	9,025	31,559	31,422
Tribal Data	396	1,170	297	306	391	386

Figure 3. 2016ff ag NH3 emissions by county (tons)

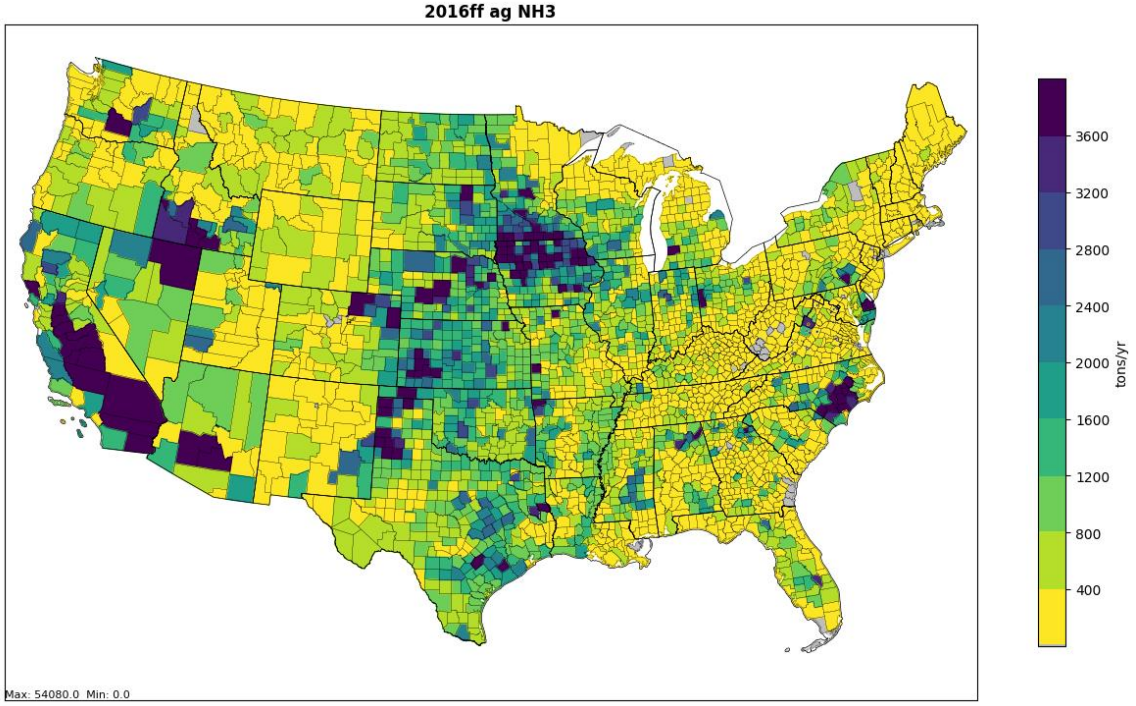


Figure 4. 2016ff ag VOC emissions by county (tons)