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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Estimating VOC Emissions from Agricultural Silage for EPA's National Emissions Inventory

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Source Category Description

- Agricultural silage is a new category and was included for the first time in the 2020 NEI.
- Agricultural silage is fermented cattle feed made from chopped forage such as corn or sorghum.
- Silage emits VOCs. Emissions occur during storage, mixing, and feeding processes.
- Using updated animal counts, an estimated 0.3 million tons of VOC were emitted from agricultural silage in 2020. Significant contributions came from California and Wisconsin.

Motivation for Including Ag Silage in the NEI

- One of EIAG's main goals is to make the NEI as complete as possible for sources/pollutants.
- To better address noted reactive VOC shortfalls near CAFOs (Confined Animal Feeding Operations) for ozone production.
- New research on emissions from agricultural silage is emerging that enables the development of emissions factors.

SCCs Assigned

SCC	Level 4 Description	Tier 1 Desc	Tier 2 Desc	Tier 3 Desc	Short Name
2801540001	Storage	Miscellaneous	Agricultural Crop Usage	Agricultural Silage	Ag Silage – Storage
2801540002	Mixing	Miscellaneous	Agricultural Crop Usage	Agricultural Silage	Ag Silage – Mixing
2801540003	Feeding	Miscellaneous	Agricultural Crop Usage	Agricultural Silage	Ag Silage - Feeding

- For more information, please see the 2020 NEI Technical Support Document at: https://www.epa.gov/system/files/documents/2023-03/NEI2020_TSD_Section17_AgSilage.pdf.

Activity Data

- Activity data are based on dairy cattle livestock counts (average annual number of standing head) and population information by state and county used for EPA's GHG inventory. The dataset is derived from the United States Department of Agriculture (USDA), particularly from the National Agricultural Statistics Service (NASS) survey and census.
- Counties that are not included in the NASS dataset are gap-filled using state-level animal counts and the ratio of county- to state-level counts.
- Data are available at the county-level, so no data allocation is necessary.

Emissions Factors

- The emission factors (EFs) are expressed in units of kg VOC per animal per year and are the product of three estimated quantities:
  - VOC production within silage (based on Hafner et al. 2013);
  - Fractional loss of VOC by volatilization (based on Hafner et al. 2012); and
  - Silage feeding rates to cattle (based on NASS data).
- Emission factors are calculated for three stages: silage storage, feed mixing, and feeding. Estimates are made for beef and dairy cattle, which are assumed to differ only in silage feeding rates.

Animal Type	Silage Process	Emissions Factor	Emissions Factor Unit
Dairy Cattle	Storage	5.998	kg/cow/yr
Dairy Cattle	Mixing	0.4493	kg/cow/yr
Dairy Cattle	Feeding	4.375	kg/cow/yr
Beef Cattle	Storage	0.4581	kg/cow/yr
Beef Cattle	Mixing	0.03431	kg/cow/yr
Beef Cattle	Feeding	0.3341	kg/cow/yr

Controls

- This method does not consider controls.
- SLTs should consider whether dairy farms in their areas implement any management practices (such as chemical additives that inhibit yeast and controlling silage density and feed area) known to reduce VOC emissions from agricultural silage.
- Some SLTs also submit emissions for grain elevators. These emissions are usually PM, but states should confirm that there is no double counting between any reported grain elevator VOC emissions and the ag silage VOC estimates.

Emissions Calculations

- Silage VOC emissions from each process are estimated by multiplying the livestock count of cattle in the county by the EF for the process.

$$E_c = \left(EF_{p,dairy} \times P_{c,dairy} \times 0.0011\frac{ton}{kg}\right) + \left(EF_{p,beef} \times P_{c,beef} \times 0.0011\frac{ton}{kg}\right)$$

Where:

E_c = Annual emissions of VOC in county c, in tons per year

Ef_p = Emissions factor for VOC for process p, in kg per cow

P_c = Population of dairy or beef cattle in county c based on the GHG reporting process in OAP and the NASS Census

Point Source Subtraction

- EPA does not perform point source subtraction is not performed for this category.
- There have been some sparse reporting of emissions from grain elevators in point sources in past NEIs, but that is usually only PM emissions
- A state should evaluate this source category and for VOC emissions that result from these type of ag silage operations, should rely on EPA methods and work to make the data to support those emissions in the nonpoint category better

VOC Speciation

- VOC speciation is needed to define the HAPs for this sector and to provide speciated VOC information for air quality models.
- VOC speciation is determined as the product of VOC production and the total fractional VOC loss for all three stages, determined individually for each compound.
- As discussed in Hafner et al. (2013), the relative importance of individual compounds depends on their production as well as emission conditions.
- Ethanol is the dominant component of VOC (36.81%), followed by propyl acetate (8.31%) and ethyl lactate (8.30%).

VOC Speciation Fractions

Group	Compound	CAS	Percentage of VOC
Acid	Propionic acid	79-09-4	1.04%
Acid	Acetic acid	64-19-7	7.64%
Acid	Isobutyric acid	79-31-2	0.75%
Acid	Butyric acid	107-92-6	0.65%
Acid	Isovaleric acid	503-74-2	0.05%
Alcohol	Ethanol	64-17-5	36.81%
Alcohol	2-Butanol	78-92-2	0.88%
Alcohol	1-Propanol	71-23-8	5.17%
Alcohol	Methanol	67-56-1	2.61%
Alcohol	2-Propanol	67-63-0	1.51%
Alcohol	2-Phenylethanol	60-12-8	0.06%
Alcohol	3-Methyl-1-butanol	123-51-3	0.16%
Alcohol	2-Methyl-1-propanol	78-83-1	0.07%
Alcohol	1-Butanol	71-36-3	0.07%
Alcohol	1-Hexanol	111-27-3	0.06%
Alcohol	2-Propenol	107-18-6	0.05%
Aldehyde	Valeraldehyde	110-62-3	1.80%
Aldehyde	Hexanal	66-25-1	2.57%
Aldehyde	2-Methylpropanal	78-84-2	0.44%
Aldehyde	3-Methylbutanal	590-86-3	1.67%
Aldehyde	Acetaldehyde	75-07-0	1.41%
Aldehyde	Butyraldehyde	123-72-8	0.65%
Aldehyde	Heptanal	111-71-7	0.40%
Aldehyde	Propionaldehyde	123-38-6	0.33%
Ester	Ethyl lactate	97-64-3	8.30%
Ester	Propyl acetate	109-60-4	8.31%
Ester	Ethyl butyrate	105-54-4	0.48%
Ester	Methyl acetate	79-20-9	7.56%
Ester	Propyl lactate	616-09-1	5.41%
Ester	Ethyl acetate	141-78-6	3.08%

2020 Emissions

- New category: very few SLT-based activity data and emissions submitted for this sector
  - Emissions: CA, several tribal agencies
  - Population Counts: DE. ID, NC
- We encouraged states to submit activity data, via the Wagon Wheel
- Agricultural silage in the US, Puerto Rico, and US Virgin Islands resulted in 0.3 million tons of VOC emissions nationally.

SCC	VOC Emissions (tons)
2802004001 (Storage)	164,164
2802004002 (Mixing)	12,297
2802004003 (Feeding)	119,739
TOTAL	**296,200**

- Emissions are concentrated in dairy-farm-rich counties, like SJV/CA and in WI.

2020 Emissions by State

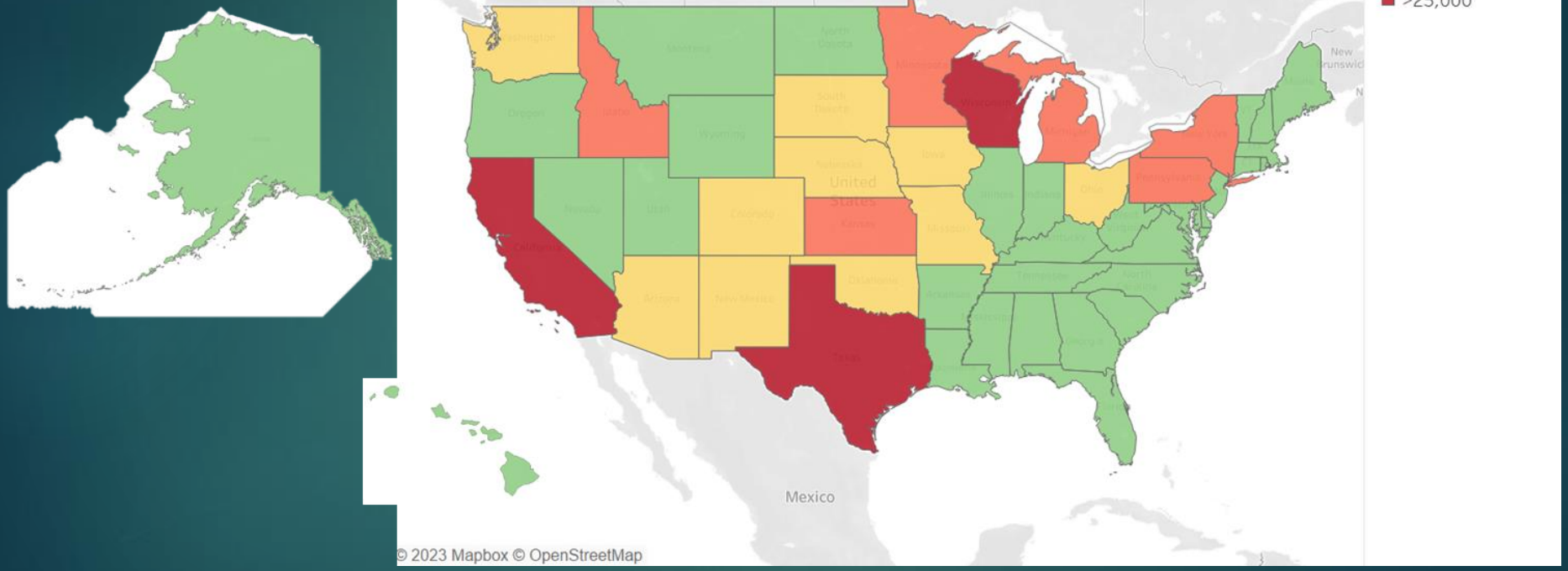
- Ag silage VOC emissions estimates for the top 10 states

State	State FIPS	Total VOC Emissions (tons)
CA*	6	41,980
WI	55	31,787
TX	48	25,385
NY	36	15,599
ID	16	15,568
PA	42	12,440
MN	27	12,055
KS	20	10,785
MI	26	10,165
IA	19	8,633

* Only state that submitted emissions to 2020 NEI for this sector

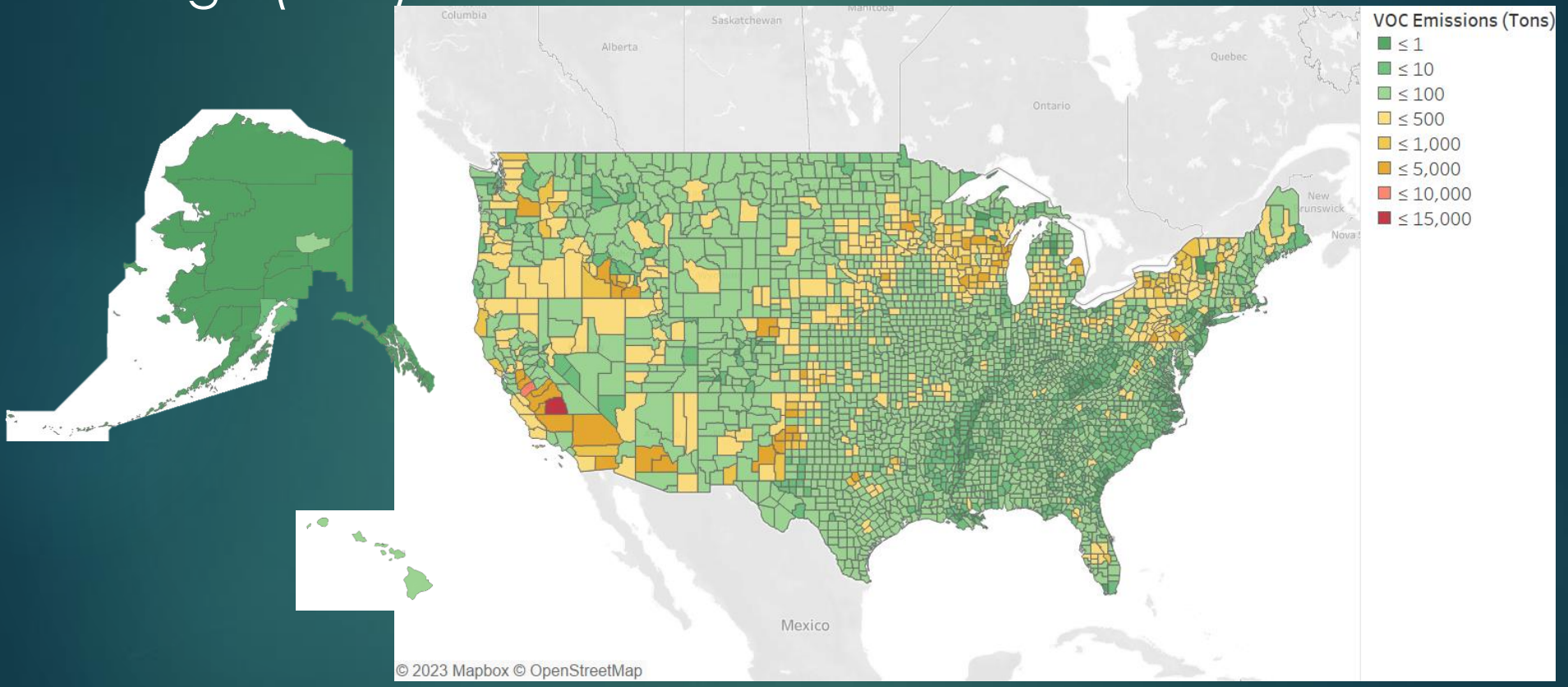
2020 State-Level VOC Emissions

2020 State-Level VOC Emissions from Agricultural Silage (tons)



2020 County-Level VOC Emissions

2020 County-Level VOC Emissions from Agricultural Silage (tons)



Future Work

- Explore developing a more detailed model based on Hafner et al. 2012 that considers the impact of meteorological conditions on ag silage VOC production/emissions. If data are available to support model development, then the more detailed model could be used to estimate emissions for the 2023 NEI.
- Explore use of alternative activity data instead of animal counts such as ag silage sales

Contacts and References

- For more information, contact:
  - Tesh Rao, USEPA
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  - Jonathan Dorn, Abt Associates
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- References
  - United States Department of Agriculture National Agricultural Statistics Service Quick Stats. https://quickstats.nass.usda.gov/
  - Hafner, S.D., Howard, C., Muck, R.E., Franco, R.B., Montes, F., Green, P.G., Mitloehner, F., Trabue, S.L., Rotz, C.A., 2013. Emission of volatile organic compounds from silage: Compounds, sources, and implications. Atmospheric Environment 77, 827–839. https://doi.org/10.1016/j.atmosenv.2013.04.076
  - Hafner, S.D., Montes, F., Rotz, C.A., 2012. A mass transfer model for VOC emission from silage. Atmospheric Environment 54, 134–140. https://doi.org/10.1016/j.atmosenv.2012.03.005

Questions?