



# Interim FARM ES Version 3.0 Documentation

Updated: May 2025

## INTRODUCTION

FARM Environmental Stewardship Version 3.0 uses the Ruminant Farm Systems (RuFaS) model.

RuFaS is a process-based model wherein biological, physical, and chemical cycles are modeled for the whole-farm system on a daily timestep in order to generate the results. The farm’s location is used to pull in relevant soil, temperature, and precipitation data.

The following aims to summarize the use of the RuFaS model within FARM Environmental Stewardship (ES). This document should be referenced for a high-level summary for model elements of most interest to FARM ES users and to reference defaults and minor customization used within FARM ES. It does not cover the details of the RuFaS model. The RuFaS website will provide full scientific module documentation in summer 2025.

This is a living document with updates ongoing.

Last updated: May 12, 2025.

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## METHODS BY EMISSIONS CATEGORY

The RuFaS website offers a summary of methods by section of the model:  
<https://rufas.org/about-rufas/>. Full model documentation will be available summer 2025.

### MANURE EMISSIONS

RuFaS uses a mix of IPCC Tier 2 and Tier 3 methods for manure emission calculations. The majority of manure-related emissions (e.g. housing emissions, slurry storage, lagoon emissions, etc.) are fully process-based and follow Tier 3 methods. For some manure management practices (compost bedded pack, open lots, etc.), IPCC Tier 2 methods are used with USDA country-specific methane conversion factors and process-based methods for VS excretion.

#### A. Separated solids

Currently assumes that separated solids go either to bedding (if the farm uses manure bedding) or that it's shipped off-farm. Greater specificity on separated solids will be a future enhancement to the RuFaS model.

#### B. Anaerobic digesters

Refer to RuFaS documentation for more details. In contrast to RuFaS default, FARM ES uses leakage rate assumption of 10%.

### ENTERIC EMISSIONS

RuFaS uses IPCC Tier 3 methods for enteric emissions calculations. The equation used for lactating cow enteric emissions is as followed, derived from Niu et al 2018:

$$\text{methane\_emis} = -126 + 11.3 \text{ dm\_intake} + 2.30 \text{ ndf\_conc} + 28.8 \text{ milk\_fat} + 0.148 \text{ bw}$$

Source:

Niu, M., Kebreab, E., Hristov, A. N., Oh, J., Arndt, C., Bannink, A., ... & Yu, Z. (2018). Prediction of enteric methane production, yield, and intensity in dairy cattle using an intercontinental database. *Global change biology*, 24(8), 3368-3389. <https://pubmed.ncbi.nlm.nih.gov/29450980/>

This equation has not been proven for other animal groups (calves, heifers, and dry cows) and therefore the IPCC equation is used for those animal groups.



## PURCHASED FEED EMISSIONS

Emissions from purchased feeds include upstream emissions associated with production, processing, and transport.

Only feeds that are included in lists from both the National Academies of Science, Engineering, and Medicine (NASEM) and National Research Council (NRC) are currently in the feed list within RuFaS / FARM ES because that information is necessary for tracking nutrition, growth, and excretion. Feed emission factors exist for other feeds (as detailed below), but those feeds are not yet options within FARM ES.

A database of emissions factors was compiled from 3 sources.

- County-specific emissions factors for 7 of the most commonly used dairy feeds (Alfalfa Hay, Alfalfa Haylage, Corn Grain, Corn Silage, DDGS, Soybean Meal, Wheat Middlings) were sourced from the Food System Supply-chain Sustainability (FoodS3) model (Pelton et al. 2024, Pelton et al. 2021, <http://www.foodscubed.umn.edu/>).

LEIF consulting, in coordination with collaborators from the UMN FoodS3 group, was commissioned to estimate regionally specific emission factors for 17 commonly fed by-products (Almond hulls, brewer's grains, canola meal, cereal waste, citrus pulp, corn cannery waste, wet corn distillers grains, dry corn gluten feed, wet corn gluten feed, whole cottonseed, malt sprouts, cane molasses, soybean hulls, defatted soybean meal, acid whey, condensed whey, and powdered whey). These 17 by-products account for more than 80% of all the by-products fed to dairy cows across the US according to de Ondarza and Tricarico's 2021 survey. See: FARM ES V3 Supporting Doc Byproducts LCA Methods on [nationaldairyfarm.com](http://nationaldairyfarm.com)

- National averages emissions factors for the remaining feeds were sourced from the IPCC (2021).

Purchased feed emissions are a national, regional, or county level average based on available agronomic practices to include all upstream emissions through transport to the farm.

### References:

- de Ondarza M.B. and Tricarico, J.M. 2021. A dataset of human inedible byproduct feeds consumed by dairy cows in the US. Data in Brief. 38(107358). <https://doi.org/10.1016/j.dib.2021.107358>
- Pelton, R.E.O., Kazanski, C.E., Keerthi, S., Racette, K.A., Gennet, S., Springer, N., Yacobson, E., Wironen, M., Ray, D., Johnson, K., Schmitt, J. 2024. Opportunities for mitigating greenhouse gas emissions in U.S. beef production. 2024. Nature Food.
- Pelton, R.E.O., Spawn-Lee, S.A., Lark, T.J., Kim, T., Springer, N., Hawthorne, P., Ray, D., Schmitt, J. 2021. Land Use Leverage Points to Reduce GHG Emissions in U.S. Agricultural Supply Chains. Environmental Research Letters. 16:11. 115002. <https://iopscience.iop.org/article/10.1088/1748-9326/ac2775/pdf>



## HOMEGROWN FEED EMISSIONS

RuFaS utilizes the [SWAT model](#) with adaptations from Sur-Phos and USDA crop and soil experts for field level emissions. Upstream fertilizer emissions are accounted for.

Given ongoing updates to the RuFaS crop and soil module as of the time of FARM ES release, FARM ES deviates from RuFaS in nitrous oxide emissions, using IPCC Tier 1 methods until RuFaS updates are finalized. FARM ES uses the primary user data for manure and fertilizer application to calculate nitrogen application and then uses IPCC Tier 1 to estimate direct nitrous oxide emissions at the field level.

## ENERGY EMISSIONS

The RuFaS model does not quantify GHG emissions from energy use. Within FARM ES, primary user data is multiplied by LCA-based emissions factors to estimate energy use emissions. The energy emissions include upstream impacts.

- A. Electricity: sourced from 2020 farmgate LCA, <https://pubs.acs.org/doi/10.1021/acs.est.5c01166>. See Table 1.
- B. Fuels: Combustion emissions sourced from the EPA emissions factor hub using stationary combustion. Upstream emissions sourced from GREET 2023. See Table 2.
- C. Dairy versus feed energy emissions:
  - a. The “On-ste Energy Use” line item in the results represents only energy used for dairy activities.
  - b. Energy used for feed production activities is embedded within the feed production emissions factor and included in the “Feed Production” emissions line item.
  - c. The current version of FARM ES Version 3 isolates the homegrown feed emissions into its own section. That section includes an estimate of energy used for crop production activities based on user entry.



**Table 1. Electricity Emissions Factors**

(Reference: <https://pubs.acs.org/doi/10.1021/acs.est.5c01166>)

	per kwh		
	kgCO <sub>2</sub>	kgCH <sub>4</sub>	kgN <sub>2</sub> O
<b>Intermountain</b>	0.3688	0.000379	4.96E-06
<b>Northeast</b>	0.270201	0.000343	2.36E-06
<b>Mississippi Valley</b>	0.481489	0.000537	5.56E-06
<b>Pacific Northwest</b>	0.072188	7.39E-05	9.6E-07
<b>Northern Plains</b>	0.472288	0.000447	7.36E-06
<b>West</b>	0.308105	0.00039	2.57E-06
<b>Upper Midwest</b>	0.543816	0.000517	8.36E-06
<b>New England</b>	0.30498	0.000387	3.02E-06
<b>Great Lakes</b>	0.531989	0.000549	6.93E-06
<b>Southeast</b>	0.441026	0.000575	3.44E-06
<b>Southwest</b>	0.407819	0.000488	4.07E-06
<b>Mid-Atlantic</b>	0.394515	0.00044	4.68E-06

**Table 2. Fuel Emissions Factors**

(Reference: <https://pubs.acs.org/doi/10.1021/acs.est.5c01166>)

	Per gallon		
	kg CO <sub>2</sub>	kg CH <sub>4</sub>	kg N <sub>2</sub> O
<b>Diesel</b>	11.8469	0.015329	0.001102
<b>Biodiesel</b>	2.4564	0.004123	0.002763
<b>Fuel Oil</b>	11.84338	0.014476	0.000113
<b>Propane</b>	6.96877	0.009523	7.56E-05
<b>Gasoline</b>	10.8667	0.013143	0.000395
	Per ccf		
<b>Natural Gas</b>	6.095146	0.020823	0.00015



## LAND USE CHANGE EMISSIONS

Land use change is derived from the Foods3 model (<https://foodscubed.umn.edu/>). It is not available for homegrown feeds at this time. Under the draft Greenhouse Gas Protocol Land Sector & Removal Guidance, the LUC could be reasonably classified as “direct LUC”, recognizing that the methods represent a hybrid of direct and statistical methods.

Land conversion data was used from Lark et al. at a 30 m × 30 m resolution for 2008-2017. Carbon was attributed to this conversion using the model in Spawn et al. , then totaled for the entire county (in this way it is like sLUC because it is for a region, however a much smaller region than is often used in sLUC methods). In Pelton et al. the researchers describe how the method and results more closely represent dLUC.

### References:

- Lark, T. J., Spawn, S. A., Bougie, M., & Gibbs, H. K. (2020). Cropland expansion in the United States produces marginal yields at high costs to wildlife. *Nature communications*, 11(1), 4295. <https://www.nature.com/articles/s41467-020-18045-z>
- Pelton, R.E.O., Spawn-Lee, S.A., Lark, T.J., Kim, T., Springer, N., Hawthorne, P., Ray, D., Schmitt, J. 2021. Land Use Leverage Points to Reduce GHG Emissions in U.S. Agricultural Supply Chains. *Environmental Research Letters*. 16:11. 115002. <https://iopscience.iop.org/article/10.1088/1748-9326/ac2775/pdf>
- Spawn, S. A., Lark, T. J., & Gibbs, H. K. (2019). Carbon emissions from cropland expansion in the United States. *Environmental Research Letters*, 14(4), 045009. <https://iopscience.iop.org/article/10.1088/1748-9326/ab0399/meta>

## CARBON SEQUESTRATION

**Homegrown Feeds:** Carbon sequestration is only available as a standalone figure for homegrown feeds at this time. It is the annual change in total carbon stocks through all soil layers.

**Purchased Feeds:** Carbon sequestration is embedded within the purchased feed emissions factors from Foods3 but are not possible to be broken out separately at this time.

## AVOIDED LANDFILL EMISSIONS ESTIMATE

### Derived from:

- de Ondarza, M. B., & Tricarico, J. M. (2021). Nutritional contributions and non-CO2 greenhouse gas emissions from human-inedible byproduct feeds consumed by dairy cows in the United States. *Journal of Cleaner Production*, 315, 128125. <https://www.sciencedirect.com/science/article/pii/S095965262102343X>



## MISCELLANEOUS

The RuFaS website offers a summary of methods by section of the model: <https://rufas.org/about-rufas/>. Full model documentation will be available in summer 2025.

## FAT AND PROTEIN CORRECTED MILK (FPCM)

FPCM is calculated in accordance with the IDF Carbon Footprint Guidance (2022), Equation 1.

## BEEF – MILK ALLOCATION

Allocation between beef and milk is calculated in accordance with the IDF Carbon Footprint Guidance (2022) using biophysical allocation.

## GWP VALUE

AR6 GWP100 values are used for most results in FARM ES except for purchased feed emissions, which use AR5 GWP 100.

## OFF-SITE ANIMALS

Emissions (manure, enteric, feed) from replacement animals raised off-site are accounted for.

## DEFAULT AND CALCULATED DATA

The full RuFaS model contains a multitude of input data that are more suited to research or academic use. The FARM ES platform does not display every possible RuFaS data input. Additionally, some FARM ES input values are pre-filled with default values that the user can override.

Generally, FARM ES uses RuFaS default values for both the RuFaS input data that is not requested of FARM ES users and for the pre-filled data. In some cases, default values are used from outside of RuFaS.

## ANIMAL MANAGEMENT

Default values for the animal management section are listed in the FARM Environmental Stewardship User Guide.

## FEED

### A. Regional Rations

The regional representative diets were formulated by industry experts using the Nutritional Dynamic System (NDS) ration formulation software (RUM&N., <https://www.rumen.it/en>) to provide default diet options for youngstock and dry cows in each region. Diets were formulated to deliver the nutrients necessary to meet the

requirements for 110% of the regional average milk production per cow per day reported by USDA for the year 2020. The feeds included in the diets for each region were based on data collected from over 2,000 farms through a survey conducted by the FARM-ES group and complemented by findings from recent studies (Asselin-Balençon et al., 2013; Thoma et al., 2013; de Ondarza and Tricarico, 2021).

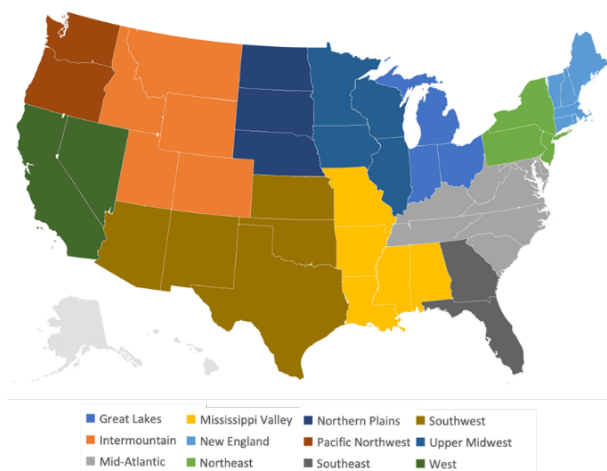


Figure 1. Map of regions used for default rations of youngstock and dry cows

Source: <https://pubs.acs.org/doi/10.1021/acs.est.5c01166>

#### References:

- Asselin-Balençon, A. C., Popp, J., Henderson, A., Heller, M., Thoma, G., & Jolliet, O. (2013). Dairy farm greenhouse gas impacts: A parsimonious model for a farmer's decision support tool. *International Dairy Journal*, 31, S65-S77.
- de Ondarza M.B. and Tricarico, J.M. 2021. A dataset of human inedible byproduct feeds consumed by dairy cows in the US. *Data in Brief*. 38(107358). <https://doi.org/10.1016/j.dib.2021.107358>
- Thoma, G., Popp, J., Nutter, D., Shonnard, D., Ulrich, R., Matlock, M., ... & Adom, F. (2013). Greenhouse gas emissions from milk production and consumption in the United States: A cradle-to-grave life cycle assessment circa 2008. *International Dairy Journal*, 31, S3-S14.

#### B. Regional Byproduct Mixes

The regional representative byproduct mixes were derived from:

- de Ondarza, M. B., & Tricarico, J. M. (2021). A dataset of human-inedible byproduct feeds consumed by dairy cows in the United States. *Data in Brief*, 38, 107358. <https://www.sciencedirect.com/science/article/pii/S2352340921006405>



C. Mineral Mixes

See: FARM ES V3 Supporting Doc Mineral Mix.pdf for Regional Diets on nationaldairyfarm.com

D. Feed List and Dry Matter Content

See: FARM ES V3 Supporting Doc FARM ES V3 Feeds List.xlsx for feed list and dry matter content on nationaldairyfarm.com

MANURE

A. Off-Site Calves

Off-site calves are assumed to be housed in calf hutches.

B. Off-Site Heifers

- For farms where the lactating cows are NOT in an open lot, off-site heifers are assumed to be in a freestall, with straw bedding, manual scraping, and slurry storage.
- For farms where the lactating cows are in a dry lot, off-site heifers are assumed to be in a dry lot.

C. Solid-liquid separators configurations

**Table 3. Solid-liquid separator configurations**

Separator Name	% dry solids	total solids removal efficiency	volatile solids removal efficiency	N removal efficiency	total ammoniacal N removal efficiency	P removal efficiency	K removal efficiency
Rotary Screen	0.2	0.35	0.4	0.3	0.15	0.4	0.15
Screw Press	0.35	0.25	0.3	0.3	0.1	0.2	0.23
Weeping Wall	0.2	0.35	0.4	0.1	0.05	0.18	0.07
Settling Basin	0.2	0.32	0.33	0.25	0.1	0.38	0.23
Roller Press	0.18	0.12	0.15	0.15	0.05	0.1	0.11
Belt Press	0.2	0.35	0.52	0.3	0.15	0.4	0.15
Sloped Screen	0.2	0.59	0.5	0.17	0.08	0.11	0.15



## FIELD

### A. Manure Nutrient Content

**Table 4. Default Manure Nutrient Content**

Source: <http://manuredb.umn.edu/>

	Liquid default	Solid Default
N	0.21%	0.54%
P	0.08%	0.25%
K	0.21%	0.46%

### B. Tillage

**Table 5. Implement configuration details**

Implement	Incorporation fraction	Mixing fraction	Tillage depth (mm)
subsoiler	0.7	0.7	350
moldboard-plow	0.95	0.95	150
coulter-chisel-plow	0.5	0.5	150
cultivator	0.3	0.3	100
seedbed-conditioner	0.1	0.1	60
disk-harrow	0.5	0.5	25
strip till	0.25	0.25	76