Interim FARM ES Version 3.0 Documentation

Updated: July 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 offers full scientific documentation: https://www.rufas.org/.

This is a living document with ongoing updates.

Last updated: July 2, 2025.

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DOCUMENT HISTORY

- **5/12/2025: Original Document**
- **6/17/2025**
  - Updated / modified information about carbon sequestration
  - Added documentation of pre-set scenario assumptions available to-date
- **7/2/2025**
  - Added reference to RuFaS documentation which was released end of June
  - Added information about how RuFaS is a statistical model under ‘Miscellaneous’

METHODS BY EMISSIONS CATEGORY

Full RuFaS model documentation is available here: https://www.rufas.org/, and should be referenced for a thorough understanding of the model.

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 conversation 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:

methane_emis = -126 + 11.3 dm_intake +2.30 ndf_conc +28.8 milk_fat + 0.148 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
- 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		
	kgCO2	**kgCH4**	**kgN2O**
Intermountain	0.3688	0.000379	4.96E-06
Northeast	0.270201	0.000343	2.36E-06
Mississippi Valley	0.481489	0.000537	5.56E-06
Pacific Northwest	0.072188	7.39E-05	9.6E-07
Northern Plains	0.472288	0.000447	7.36E-06
West	0.308105	0.00039	2.57E-06
Upper Midwest	0.543816	0.000517	8.36E-06
New England	0.30498	0.000387	3.02E-06
Great Lakes	0.531989	0.000549	6.93E-06
Southeast	0.441026	0.000575	3.44E-06
Southwest	0.407819	0.000488	4.07E-06
Mid-Atlantic	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 CO2	kg CH4	kg N2O
Diesel	11.8469	0.015329	0.001102
Biodiesel	2.4564	0.004123	0.002763
Fuel Oil	11.84338	0.014476	0.000113
Propane	6.96877	0.009523	7.56E-05
Gasoline	10.8667	0.013143	0.000395
	Per ccf		
Natural Gas	6.095146	0.020823	0.00015

LAND USE CHANGE EMSSIONS

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.

Carbon sequestration is handled in RuFaS as a net increase in soil organic carbon over time. Built based on the DAYCENT model, RuFaS models soil carbon as a series of pools with unique cycling rates and biogeochemical roles within the soil profile that change with depth. In brief, soil carbon is divided into structural (more stable, e.g. plant cell wall) and metabolic (labile, e.g. starch/sugar) pools which are decomposed to the active, passive, and slow pools. Metabolic C is decomposed directly to the active pool, while structural carbon is decomposed to both slow and active based on its chemical composition. Carbon lost during decomposition is as CO2.

This method has been used in several publications to assess the potential impacts of agricultural soil management practices on carbon sequestration. Management decisions that allow more carbon to enter slower-cycling, more stable pools are more likely to maintain or increase soil carbon over time. These can include reduced tillage, higher crop residue retention, and optimized N fertilization.

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. For methodology description, please see the supplementary information for the following:

Pelton, Rylie EO, et al. "Greenhouse gas emissions in US beef production can be reduced by up to 30% with the adoption of selected mitigation measures." Nature Food 5.9 (2024): 787-797. https://www.nature.com/articles/s43016-024-01031-9

AVOIDED LANDFILL EMISSIONS ESTIMATE

This figure is provided for informational purposes only and does not influence the farm's total GHG footprint. 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 full scientific documentation: rufas.org

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.

STATISICAL RUNS AND OUTPUT VARIATION

The model behind FARM ES uses statistical sampling, so the results can vary slightly even when running an evaluation with the same input data. RuFaS is a sophisticated model that uses a statistical sampling probability to construct its animal population, resulting in potential variations in the outcomes of each individual simulation. FARM ES V3 reports the average of 4 simulations as recommended by the RuFaS team, however even these average results will vary slightly with repetition. These variations are inherent to the modeling approach and do not indicate errors in the inputs, the model, or its implementation. They reflect the complexity of the physical systems being simulated and the probabilistic nature of the model's simulations. Users should be aware of this inherent variability and understand that any one result is not a definitive prediction but instead is reflective of one of expected outcomes.

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).

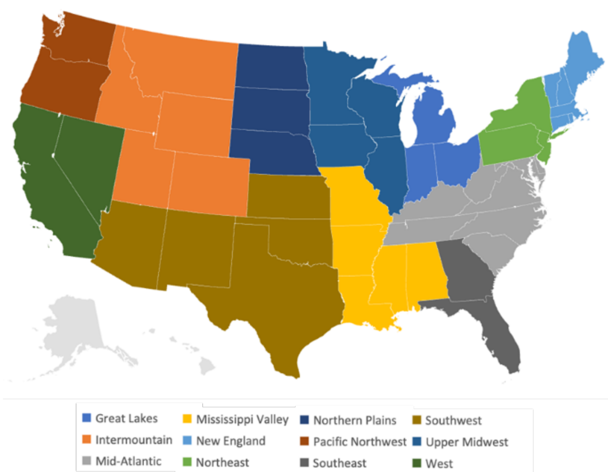

Figure 1. Map of regions used for default rations of youngstock and dry cows
Source: https://pubs.acs.org/doi/10.1021/acs.est.5c01166

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

PRE-SET SCENARIOS

As a general note, RuFaS is a statistical model and there can be expected variation. Good rule of thumb for a “meaningful” change:

- +/-1% difference in milk production, or
- +/-0.02 CO_2e / FPCM difference

MANURE

A. Cap and Flare
- Only available for farms with a slurry or lagoon
- When selected, adds cap and flare to any on-site slurry or lagoon

FIELD

A. No-till
- Only available if the evaluation entered information in the Field Management section regarding cropping
- Any tillage events are removed
- Does not alter other practices that may in fact change when tillage is removed

ANIMAL

B. Improved cow repro & management

Inputs adjusted:
- Conception rate % -increase by 10 [e.g.35% becomes 45%]
- Estrus detection rate % –increase by 10
- Milk production –increase 2.2 lbs per cow per day x 305 days
- % calves that are replacements –[see below]
- Do not breed time –decrease by 25 days

Notes:
- Do not run if farm already has conception rate of >45% OR has detection rate of >60%
- In this scenario, looking to keep herd size static, which means less tolerance for cows that aren't getting pregnant (DNB) and breeding fewer for replacement purposes

Calculation for the adjusted % calves that are replacements:

$$P_{rep,new} = Proportion\ of\ calves\ that\ are\ replacements, new$$

$$P_{rep,base} = Proportion\ of\ calves\ that\ are\ replacements, baseline$$

$$T = Turnover$$

$$H = Herd\ size$$

$$VWP = Voluntary\ waiting\ period\ (in\ days)$$
$$CR = Conception\ rate, new$$
$$CR_0 = Conception\ rate, baseline$$
$$DR \quad = Heat\ detection\ rate, new$$
$$DR_0 = Heat\ detection\ rate, baseline$$

$$P_{rep,new} = 1 - \left(\left(1 - P_{rep,base}\right) * \frac{(1-T) * H * 365}{CI} / \frac{(1-T) * H * 365}{CI_0}\right)$$

Where:

$$CI = VWP + \frac{21}{2} + \left(\frac{1}{CR} - 1\right) \cdot 21 + \left(\frac{1}{DR} - 1\right) \cdot \left(\frac{1}{CR}\right) \cdot 21 + 280$$

$$CI_{base} = VWP + \frac{21}{2} + \left(\frac{1}{CR_0} - 1\right) \cdot 21 + \left(\frac{1}{DR_0} - 1\right) \cdot \left(\frac{1}{CR_0}\right) \cdot 21 + 280$$

C. Improved cow health

Inputs adjusted:

- Milk production –increase 2.2 lbs per cow per day x 305 days
- Cull rate by lactation –decrease by 5% (baseline times 0.95)
- Do not breed time –decrease by 25 days
- Cull milk production –increase by 2.2 lbs

Notes:

- In this scenario, looking to keep herd size static. Because reduced non-production culls, needed to increase reproduction / production culls: decreased DNB day and increased cull milk (together this results in less tolerance for not pregnant cows).
- With better overall health and wellbeing, herd is making more milk per cow and have fewer “forced” culls –which you offset with slightly more selective culling of poor repro/production cows (via the DNB time and cull milk production cutoffs)