METHANE MITIGATION SOLUTIONS

Environmental Defense Fund
Ceres
Pure Strategies Inc.

Methane mitigation solutions evaluation

TABLE 1

Methane mitigation solutions evaluation

EDF and Ceres do not endorse specific solutions or the research associated with each solution. Companies should evaluate solutions before adoption, as their applicability can vary widely depending on each company's unique supply chain.

This table is part of the [Dairy Methane Action Plan guide](). Please refer to the full guide for additional context and details, including definitions of solutions and their rankings.

INTERVENTIONS AND SOLUTIONS		FARM CHARACTERISTICS				SOLUTION CHARACTERISTICS								
Intervention pathway	**Mitigation solution**	**Regional regulatory applicability**	**Climate applicability**	**Farm type applicability**	**Farm size applicability**	**Implementation stage**	**Solution readiness**	**Implementation burden**	**Cost range**	**Cost type**	**GHG reduction potential**	**Technology level**	**Alignment with existing protocols/ standards**	**Level of MMRV required**
Enteric reductions	3-NOP (e.g., Bovaer®)	Commercially available and approved for intended use of methane reduction[1, a]	All	Favors intensive[b]	All	Commercial solution	High	Low/med	Med/high[2]	OpEx	Med/high[3, 4, 5]	Low	Med	Med
Enteric reductions	*Asparagopsis sp.*[c] (e.g., Brominata®, Methane Tamer™, SeaFeed™, SeaGraze®, SeaStock) (O)	Commercially available in Europe, Australia[d]	All	Favors intensive[b]	All	Commercial solution/ research/ advocacy depending on region	Low/med	Low/med	Med/high[6]	OpEx	High[e, 7, 8]	Low	Med	Med/ high
Enteric reductions	Breeding/genetics improvements for CH_4 (e.g., Semex®) (O)	All	All	All	All	Research/ limited commercial solution	Med	Low	Unknown/ low	OpEx	Med[g, 9, 10]	Med	Med	Med
Enteric reductions	Diet optimization (O)	All	All	All	All	Commercial solution	High	Low	Low	OpEx	Low[22]	Low	Med	Med
Enteric reductions	Essential oils (e.g., Agolin®, Mootral Enterix™) (O)	Commercially available in North America, Europe, Asia[11]	All	Favors intensive[b]	All	Commercial solution	High	Low/med	Low[12]	OpEx	Low[13]	Low	Med	Med
Enteric reductions	Feed storage/ quality (O)	All	Warm[h]	All	All	Commercial solution	High	Med	Med	Both	Low[14, 15]	Low	Med	Med
Enteric reductions	Lipid supplementation (O)	All	All	Favors intensive[b]	All	Commercial solution	High	Low/med	Low	OpEx	Low[16]	Low	Med	Med

INTERVENTIONS AND SOLUTIONS		FARM CHARACTERISTICS				SOLUTION CHARACTERISTICS								
Intervention pathway	**Mitigation solution**	**Regional regulatory applicability**	**Climate applicability**	**Farm type applicability**	**Farm size applicability**	**Implementation stage**	**Solution readiness**	**Implementation burden**	**Cost range**	**Cost type**	**GHG reduction potential**	**Technology level**	**Alignment with existing protocols/ standards**	**Level of MMRV required**
Enteric reductions	Methane capture headpiece (e.g., ZELP)	Limited (piloting in Europe)	All	All	All	Research	Low	Med	Med[17]	Both	High[18]	High	High	Low
Enteric reductions	Methane vaccines (e.g., ArkeaBio™, Lucidome Bio)[(0)]	None	All	All	All	Research/ advocacy	Low	Low	Unknown	OpEx	Unknown (likely low/ med)[19]	Unknown	Unknown	Unknown
Manure management	Anaerobic digesters[i, j (0)]	All	Warm[h]	Intensive	Large	Commercial solution	High	High	High	Both	High[20, 21]	High	High	High
Manure management	Composting[i (0)]	All	Warm[h]	All (favors smallholders and intensive dry lot)	All (favors small/ med)	Commercial solution	High	Med/high	Low	OpEx	High[22]	Low	High	Med
Manure management	Daily spread[(0)]	All	Warm/ temperate	All (favors intensive dry lot)	Small/ med	Commercial solution	High	Low/med	Med	Both	High[37]	Low	High	Low
Manure management	Manure additive: Acidification[(0*)]	All	Warm[h]	All	All	Commercial solution/ research	Low/med	Low	Low[42]	OpEx	High[23,24]	Low/med	Low/med	Med/ high
Manure management	Manure cover and flare systems[(0)]	All	Warm[h]	Intensive	Med/large	Commercial solution	High	Low	High[25]	Both	Med/high[26]	High	Med	Med
Manure management	Manure operational improvements[(0)]	All	Warm[h]	All	All	Commercial solution	High	Low/med	Low	OpEx	Varies	Low	Low/med	Med
Manure management	Manure separators[i (0)]	All	Warm[h]	Intensive	Med/large	Commercial solution	High	Med	Med	Both	Med/high[27, 28, 29]	Med/high	Med	Med
Manure management	N2 Applied[(0)]	Commercially available in Europe	Warm[h]	Intensive	Med/large	Commercial solution/ research	Med	Med	High	Both	High[30]	High	Med	Med
Manure management	Pasture-based management[(0)]	All	Warm[h]	Pastoral or smallholder	All	Commercial solution	High	High	Med	OpEx	Med[2, k]	Low	Med	High
Productivity optimization	Activity trackers[(0)]	All	All	All	All (tech solutions favor med/ large)	Commercial solution	High	Med	Med[31]	Both	Varies[32,33]	Varies	High	Low
Productivity optimization	Animal health improvements	All	All	All	All	Commercial solution	High	Low	Low	OpEx	Varies[34]	Low	High	Low
Productivity optimization	Breeding/ genetics improvements for yield[(0)]	All	All	All	All	Commercial solution	High	Low	Low[35]	OpEx	Varies[36]	Low	High	Low

INTERVENTIONS AND SOLUTIONS		FARM CHARACTERISTICS				SOLUTION CHARACTERISTICS								
Intervention pathway	Mitigation solution	Regional regulatory applicability	Climate applicability	Farm type applicability	Farm size applicability	Implementation stage	Solution readiness	Implementation burden	Cost range	Cost type	GHG reduction potential	Technology level	Alignment with existing protocols/ standards	Level of MMRV required
Productivity optimization	Herd management/ stocking density (O)	All	All	All	All	Commercial solution	High	Low	Low	OpEx	High[37]	Low	High	Low
Productivity optimization	Herd management/ young stock optimization (O)	All	All	All	All	Commercial solution	High	Low	Low	OpEx	Low/med[38]	Low	High	Low
Productivity optimization	Robotic milking (O)	All	All	Intensive or pastoral	Med/large	Commercial solution	High	High	High[39]	CapEx	High[40,41]	High	High	Low

(O) Indicates the solution can be used in certified organic farming systems

(O*) Organic acids (e.g., citric acid, acetic acid) can be used in organic farming systems. Further research is needed to determine if using sulfuric acid would violate organic standards and what (if any) long-term effects might exist from continued application of sulfur-treated manure on soil and forage.

Table 3 Footnotes:

a After safety and efficacy review, Elanco has received FDA permission to market 3-NOP for this intended use in the United States.

b More easily adopted in intensive or non-pastoral smallholder systems, as it is easier to continuously supplement and control feed. This solution can still be applied in pastoral systems but with more difficulty.

c Further research is needed to better understand the impact that feeding *Asparagopsis sp.* has on animal health and the toxicological risks associated with bromoform residues in milk.

d In North America, various federal regulations make transit problematic to transport milk across state lines without approval from the FDA. The use of *Asparagopsis sp.* is allowed within states with the submission of an uncontested GRAS application.

e The range of reductions is generally based on dosage. Planned dosage levels demonstrate reductions of around 60%, which categorizes this solution as having a high GHG reduction potential.

f While the cost of Rumensin is currently low, the manufacturer is attempting to monetize the carbon savings which could drive up the price.

g The methane reduction potential estimates are over 25-30 years, so considerably less over the near term of a 2030 or 2035 corporate goal.

h This solution is applicable to all climates but is most impactful in warm climates.

i This solution includes multiple solution technologies which may have varying methane reduction potentials.

j A critical design and maintenance consideration for anaerobic digesters is ensuring they remain airtight throughout their lifetime operation. Even a small leak in the methane path to the generator or pipeline can release methane directly into the atmosphere and negate much of the digester's reduction potential.

k Pasture-based systems can impact all intervention pathways. Manure methane is expected to decrease, while enteric emissions may increase or decrease depending on forage quality. Further, depending on how well the grazing is managed, carbon can either be sequestered or released from the soil.

REFERENCES

1 Methane-reducing feed ingredient Bovaer® ready for U.S. market launch. (2024, May). dsm-Firmenich. https://our-company.dsm-firmenich.com/en/our-company/news/press-releases/2024/methane-reducing-feed-ingredient-bovaer-ready-for-us-market-launch.html.

2 Why won't companies use this quick fix to reduce cow methane emissions? - BNN Bloomberg. (2023, June 28). BNN. https://www.bloomberg.com/news/features/2023-06-28/this-quick-fix-reduces-methane-emissions-from-cow-burps

3 Melgar, A., et.al. (2020). Dose-response effect of 3-nitrooxypropanol on enteric methane emissions in dairy cows. *Journal of dairy science*, *103*(7), 6145-6156. https://doi.org/10.3168/jds.2019-17840

4 Melgar, A., et. al. (2021). Enteric methane emission, milk production, and composition of dairy cows fed 3-nitrooxypropanol. *Journal of dairy science*, *104*(1), 357-366. https://doi.org/10.3168/jds.2020-18908.

5 Kebreab, E., et. al. (2023). A meta-analysis of effects of 3-nitrooxypropanol on methane production, yield, and intensity in dairy cattle. *Journal of dairy science*, *106*(2), 927-936. https://doi.org/10.3168/jds.2022-22211.

6 Seaweed startup raises $7 million to reduce ruminant methane emissions. (2022, June 28). The Fish Site. https://thefishsite.com/articles/seaweed-startup-raises-7-million-to-reduce-ruminant-methane-emissions-symbrosia

7 Roque, B. M., Salwen, J. K., Kinley, R., & Kebreab, E. (2019). Inclusion of Asparagopsis armata in lactating dairy cows' diet reduces enteric methane emission by over 50 percent. Journal of Cleaner Production, 234, 132-138. https://doi.org/10.1016/j.jclepro.2019.06.193.

8 Glasson, C. R., et. al. (2022). Benefits and risks of including the bromoform containing seaweed Asparagopsis in feed for the reduction of methane production from ruminants. *Algal Research*, *64*, 102673. https://doi.org/10.1016/j.algal.2022.102673.

9 De Haas, Y., Veerkamp, R. F., De Jong, G., & Aldridge, M. N. (2021). Selective breeding as a mitigation tool for methane emissions from dairy cattle. Animal, 15, 100294. https://doi.org/10.1016/j.animal.2021.100294.

10 *Semex & Methane Efficiency*. Semex® Genetics for Life®. https://www.semex.com/us/i?page=methane

11 *Agolin®*. Alltech® Agolin®. https://agolin.com/about-us/

12 Feedworks USA. (2022). Split-Herd trial summary: More milk, less feed. In *Feedworks USA* [Report]. https://theagolinstory.com/wp-content/uploads/2023/05/Split_Herd_Trials.pdf

13 Belanche, A., Newbold, C. J., Morgavi, D. P., Bach, A., Zweifel, B., & Yáñez-Ruiz, D. R. (2020). A meta-analysis describing the effects of the essential oils blend Agolin® ruminant on performance, rumen fermentation and methane emissions in dairy cows. *Animals*, *10*(4), 620. https://doi.org/10.3390/ani10040620.

14 Sutton, A., Lander, C. H., Federation of Animal Science Societies (FASS), & U.S. Department of Agriculture (USDA). (2003). Nutrient Management Technical Note No. 5. In Ecological Sciences Division. https://efotg.sc.egov.usda.gov/references/public/ND/feed_animal_management_for_dairy_cattle.pdf

15 Bolton, K., University of Wisconsin-Extension, Holmes, B. J., & University of Wisconsin-Madison. (n.d.). Management of bunker silos and silage piles. https://fyi.extension.wisc.edu/forage/files/2014/01/mgmt-bunkers-piles-bjh2.pdf

16 Knapp, J. R., Laur, G. L., Vadas, P. A., Weiss, W. P., & Tricarico, J. M. (2014). Invited review: Enteric methane in dairy cattle production: Quantifying the opportunities and impact of reducing emissions. Journal of dairy science, 97(6), 3231-3261. https://doi.org/10.3168/jds.2013-7234.

17 Hanson, M. (2021). The latest mask design: for cows. Dairy Herd Management. https://www.dairyherd.com/news/education/latest-mask-design-cows

18 https://www.zelp.co/the-technology-2/

19 Reisinger, A., et. al. (2021). How necessary and feasible are reductions of methane emissions from livestock to support stringent temperature goals?. Philosophical Transactions of the Royal Society A, 379(2210), 20200452. https://doi.org/10.1098/rsta.2020.0452.

20 Aguirre-Villegas, H. A., & Larson, R. A. (2017). Evaluating greenhouse gas emissions from dairy manure management practices using survey data and lifecycle tools. Journal of cleaner production, 143, 169-179. https://doi.org/10.1016/j.jclepro.2016.12.133.

21 Scott, A., & Blanchard, R. (2021). The role of anaerobic digestion in reducing dairy farm greenhouse gas emissions. Sustainability, 13(5), 2612. https://doi.org/10.3390/su13052612.

22 IPCC. (2019). Emissions from Livestock and Manure Management. In 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch10_Livestock.pdf

23 Sokolov, V., VanderZaag, A., Habtewold, J., Dunfield, K., Wagner-Riddle, C., Venkiteswaran, J. J., & Gordon, R. (2019). Greenhouse gas mitigation through dairy manure acidification. Journal of environmental quality, 48(5), 1435-1443. https://doi.org/10.2134/jeq2018.10.0355.

24 Ambrose, H. W., Dalby, F. R., Feilberg, A., & Kofoed, M. V. (2023). Additives and methods for the mitigation of methane emission from stored liquid manure. Biosystems Engineering, 229, 209-245. https://doi.org/10.1016/j.biosystemseng.2023.03.015.

25 Oliver, J. & Ray, L. (2023). Manure storage impermeable cover and flare systems - Potential climate benefits and considerations. Progressive Dairy. https://ecommons.cornell.edu/server/api/core/bitstreams/8586a845-6ed2-4c50-bab8-03b46a95d02b/content.

26 Wightman, J. L., & Woodbury, P. B. (2016). New York dairy manure management greenhouse gas emissions and mitigation costs (1992–2022). Journal of environmental quality, 45(1), 266-275. https://acsess.onlinelibrary.wiley.com/doi/abs/10.2134/jeq2014.06.0269.

27 Holly, M. A., Larson, R. A., Powell, J. M., Ruark, M. D., & Aguirre-Villegas, H. (2017). Greenhouse gas and ammonia emissions from digested and separated dairy manure during storage and after land application. Agriculture, Ecosystems & Environment, 239, 410-419. https://doi.org/10.1016/j.agee.2017.02.007.

28 Bockhahn, J., Wright, P., & Gooch, C. (2020). Screw Press Solid-Liquid Separation. https://ecommons.cornell.edu/items/4de02540-3352-49f9-a0b8-a542bb214779.

29 El Mashad, H. M., Barzee, T. J., Franco, R. B., Zhang, R., Kaffka, S., & Mitloehner, F. (2023). Anaerobic Digestion and Alternative Manure Management Technologies for Methane Emissions Mitigation on Californian Dairies. Atmosphere, 14(1), 120. https://doi.org/10.3390/atmos14010120.

30 Nyvold, M., & Dörsch, P. (2024). Complete elimination of methane formation in stored livestock manure using plasma technology. Frontiers in Sustainable Food Systems, 8, 1370542. https://doi.org/10.3389/fsufs.2024.1370542.

31 NY Farm Viability Institute. (2019, September 4). Do these things work? Determining the effectiveness of automated health monitoring systems for NY dairies. New York Farm Viability Institute. https://nyfvi.org/2019/07/21/do-these-things-work-determining-the-effectiveness-of-automated-health-monitoring-systems-for-ny-dairies

32 Džermeikaitė, K., Krištolaitytė, J., & Antanaitis, R. (2024). Relationship between Dairy Cow Health and Intensity of Greenhouse Gas Emissions. Animals, 14(6), 829. https://doi.org/10.3390/ani14060829.

33 Liu, C., Wang, X., Bai, Z., Wang, H., & Li, C. (2023). Does digital technology application promote carbon emission efficiency in dairy farms? Evidence from China. Agriculture, 13(4), 904. https://doi.org/10.3390/agriculture13040904.

34 Džermeikaitė, K., Krištolaitytė, J., & Antanaitis, R. (2024). Relationship between dairy cow health and intensity of greenhouse gas emissions. Animals, 14(6), 829. https://doi.org/10.3390/ani14060829.

35 Schmidt, S. (2023, September 12). Do breeding investments increase the productivity of Wisconsin dairy farms? - Agricultural & Applied Economics. Agricultural & Applied Economics. https://aae.wisc.edu/2023/05/26/do-breeding-investments-increase-the-productivity-of-wisconsin-dairy-farms

36 Bell, M. J., Wall, E., Russell, G., Morgan, C., & Simm, G. (2010). Effect of breeding for milk yield, diet and management on enteric methane emissions from dairy cows. Animal Production Science, 50(8), https://doi.org/10.1071/AN10038

37 Llonch, P., Haskell, M. J., Dewhurst, R. J., & Turner, S. P. (2017). Current available strategies to mitigate greenhouse gas emissions in livestock systems: an animal welfare perspective. Animal, 11(2), 274-284. https://doi.org/10.1017/S1751731116001440.

38 Palczynski, L.J., Bleach, E.C.L., Brennan, M.L., Robinson, P.A. (2022). Youngstock Management as “The Key for Everything”? Perceived Value of Calves and the Role of Calf Performance Monitoring and Advice on Dairy Farms, Frontiers in Animal Science, 18 April 2022, Vol 3 – 2022, https://doi.org/10.3389/fanim.2022.835317.

39 Robotic milking System. (2023, December 6). University of Maryland Extension. https://extension.umd.edu/resource/robotic-milking-system/

40 Duplessis, M., Vasseur, E., Ferland, J., Pajor, E. A., DeVries, T. J., & Pellerin, D. (2021). Performance perception of Canadian dairy producers when transitioning to an automatic milking system. JDS communications, 2(4), 212-216. https://doi.org/10.3168/jds.2021-0082.

41 De Koning, C. J. A. M. (2010). Automatic milking–common practice on dairy farms. https://api.semanticscholar.org/CorpusID:43759249