An Environmental and Economic Path Toward Net Zero Dairy Farm Emissions

Preface

Jason Clay, Ph.D., SVP Markets, WWF-US

When the Markets Institute at WWF was launched in 2014, the goal was to bring together Thought Leaders with different perspectives from across the food system to identify key issues, trends, tools and innovations that would affect food most in the decades to come. The reason — we were winning conservation battles but losing the war. Every indicator was headed in the wrong direction, and a significant portion of it driven by our food production. It took from 30 to 60 years between when an environmental issue was identified and when we had on-the-ground solutions to address it. The issues we continue to address include deforestation and habitat loss, biodiversity loss, water use and pollution, overfishing, soil health and erosion, and of course, the quarter of all human-caused greenhouse gas emissions that come from food production.

In recent years, animal proteins have begun to face sharper criticism, for their impacts on diet and health, animal welfare, environmental impacts, GHG emissions etc. Animal proteins are critical components in the diets of many globally. As we consider the growing challenges of hunger and malnutrition, food accessibility, and nutritional disparity, it is clear that many people in the world could benefit from more animal protein, not less. With so many cultures and diets globally, WWF is reluctant to tell people what to eat, but we have begun to look more closely at the impacts of those choices and whether they can be managed more sustainably. For three decades, we have worked to ensure that whatever people eat is produced with fewer impacts. With more people, higher incomes, and more and different consumption, we need to produce more food with less. The changes are necessary, urgent, but also possible and easier than one might think if the right incentives and policies are put into motion quickly. But there's no time to lose.

Farmers are market actors. Even in the US corn belt in the 1880s, farmers imported corn from further east and used it to produce animal protein — dairy, eggs, chickens, and pork. They added value to their crops by turning them into more valuable animal protein and by taking crops off the market at harvest when prices were lowest. This is how animal protein is still produced around the world.

Livestock turn grass, crops, food waste and forage into proteins that people can eat. We know that very little pastureland can be used to produce agricultural crops. The jury is still out about how much carbon is sequestered in grasslands, but as measures and incentives improve, farmers, ranchers, and plant breeders will find ways to sequester more carbon, retain more organic matter in soils, and reduce water needs, as well as agrochemical inputs.

Milk has long been a poster child of a healthy product but is increasingly getting attention for significant GHG emissions. The question is, can dairy farmers reduce the emissions embedded in milk? If so, how, by how much and at what cost? This paper reflects the practices and technologies being adapted in large freestall dairies in the Midwest, and specifically those pursued by dairy farmer and Markets Institute Thought Leader, Mike McCloskey on his Indiana farm. This concept is being further modeled and studied by the US dairy industry — led by dairy farmers, cooperatives, processing companies and industry organizations — as part of its Net Zero Initiative to understand the potential value to farms of all sizes and geographies.

Diets will shift — they always have and always will. But we need to make sure that all food is produced with fewer impacts, especially animal protein and especially GHG emissions. We are publishing this analysis not only because dairy is important but because what US dairy is doing can be adapted and implemented by all animal proteins. This piece is to show poultry, pork, eggs, beef, and aquaculture that entire sectors can reduce GHG emissions, even more so if they work together. There are no one-size-fits-all solutions, but what dairy is doing should give key insights to other sectors on what they can do as well. And, when they do, we would be happy to publish them so that everyone can learn faster.

Introduction

Many companies have made commitments to achieve net zero greenhouse gas (GHG) emissions by 2030, and even more have made commitments for 2050. While target setting is a crucial step towards limiting global emissions, in many industries technologies and climate-smart practices already exist that can be implemented to make progress towards reaching net zero emissions as companies continue to explore how to fully achieve their goals.

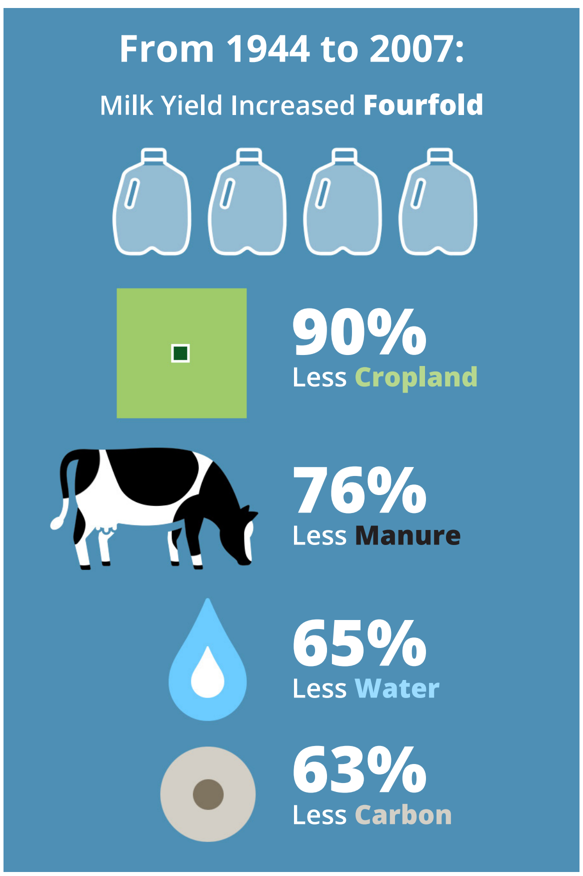


Figure 1[1]

Within the food industry, animal-sourced proteins continue to garner considerable attention due to their high carbon footprint relative to other types of food. The US dairy industry has made great strides toward increased production efficiency (Figure 1), which has led to reduced emissions, but mitigating the impacts of the GHGs that come from manure and the unique biology of ruminants remains a challenge. Farm management technology and mitigation practices exist that help, and others are being developed to make net zero GHG emissions for dairy production a reality. When coupled with the right incentives and policies, net zero emissions for large dairies could be possible within five years and could contribute to net annual returns of $1.9 million (per dairy) while also proving the business case and helping to make new technologies and practices more accessible to farms of all sizes.[2]

This analysis focuses on technologies and practices for attaining net zero GHG emissions in milk production from field to farm gate — where approximately 72-75% of GHG emissions from the dairy sector occur.[3] Based on a comprehensive life cycle assessment (LCA) undertaken in five US dairy production regions involving more than 500 farmers, the largest GHG footprints in order of magnitude are: enteric fermentation (the cow's digestive process that produces methane), manure management, feed production, and energy (farm energy use and generation) (Figure 2). Although manure has the second largest emissions footprint, it can also be part of the solution via its conversion to energy and fertilizer to improve soil and, therefore, crop yields for feed. Prudent use of manure as fertilizer also reduces the need for commercial fertilizer, a meaningful emitter of GHG when manufactured. The dairy farming model presented here represents key circularity principles as part of the solution to achieving net zero emissions.

For the purposes of this paper, net zero emissions are considered to be achieved by balancing GHG emissions with GHG removals and sequestered carbon. As cows will always naturally produce methane, net zero for the dairy industry involves addressing that which can't be eliminated — negating residual methane and nitrous oxide emissions through strategic synergies with other industries to reach that balance, rather than purchasing offsets.[4]

[1] US Sustainability Alliance, US Dairy Fact Sheet, https://thesustainabilityalliance.us/u-s-dairy-fact-sheet/.

[2] $1.9 million estimate based on the pilot size dairy described in this analysis.

[3] While a small portion of GHG emissions may be attributable to beef as dairy cows are typically sold as beef after milk production is no longer efficient, this analysis focuses on emissions from milk production, which makes up the bulk of a dairy cow's lifecycle.

[4] The Science Based Targets Initiative (SBTi) is developing a framework to better define net zero and enable companies to understand more clearly what it means for them. This paper speaks more broadly about net zero as a concept, but WWF is a founding partner in the SBTi and supports the development of this framework.

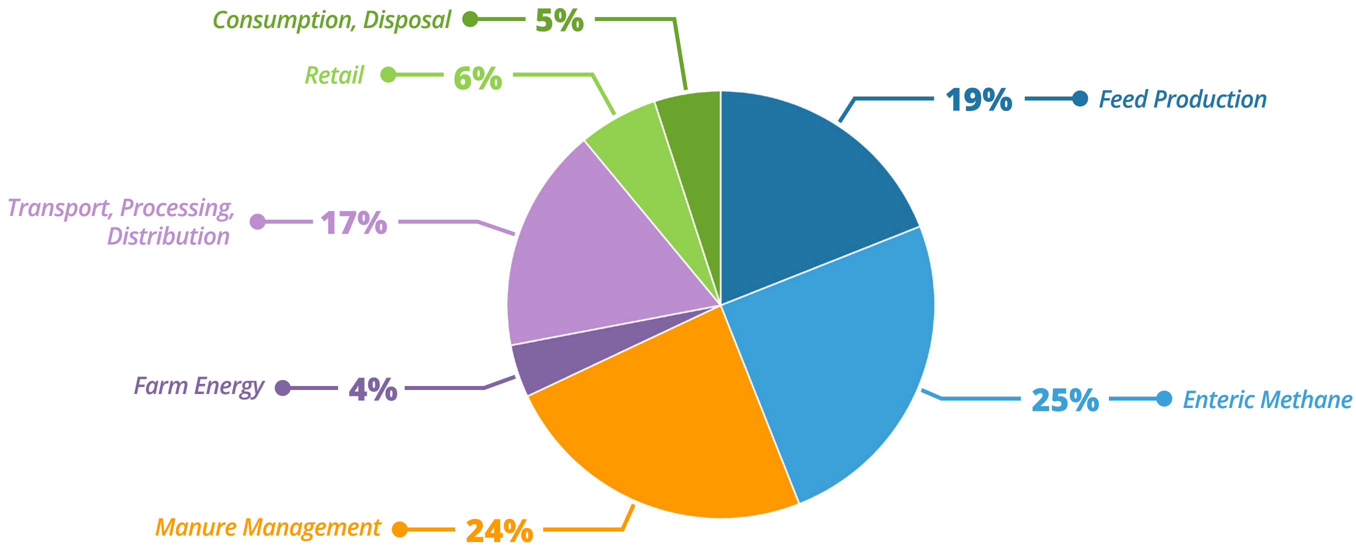


Figure 2: Supply Chain Contributions to the Carbon Footprint of Milk

Derived from Thoma et al.

A Groundbreaking Pilot

US dairy industry stakeholders, led by dairy farmers, cooperatives, processing companies, and industry organizations, have developed the Net Zero Initiative (NZI) to demonstrate that it is possible for dairy farms to reach net zero emissions.[5] NZI's ultimate goal is to advance and scale access to the most effective environmental and economically viable practices on farms of all sizes across the US. Nestlé recently committed up to $10 million to this initiative, although additional funding is needed from government, business, and other stakeholders.

NZI is developing a pilot based on practices outlined in this paper to demonstrate that it is possible to reach net zero emissions by finding the right mix of economically viable practices, technologies, and incentives. At the time of writing, NZI partners are seeking dairy farms for potential pilot participation, based on a willingness to invest and investments already made in technology and practices necessary to reach net zero emissions, as well as an agreement to share data with the project.

Pilot Farm			
	Total Acres	*Acres/Cow*	*Cows*
Milking cows			3,000
Dry cows			493
Acres & herd size	*5,763*	*1.65*	*3,493*
Hundredweight (CWT) (herd/year)			*985,500*

Figure 3: Basic Size Assumptions for Pilot Farms

The economic models considered in this analysis, which form the base assumptions for the NZI pilot, were built around assumptions of a large, conventional upper Midwestern US dairy operation and the GHG emissions associated with a herd of 3,000 milking cows and approximately 500 dry cows. The assumption includes on-farm production of approximately 80% of the forage and corn grain needed for feed using 1.65 acres per cow. The impact of raising replacement heifers was excluded from the modeling as management practices vary considerably farm to farm.

Many of the mitigation practices in this analysis are or can be implemented today by large-scale farmers by leveraging current research, technology, and incentives, whereas others require policy shifts or enhanced incentive systems to break even on the time and investment required to achieve net zero. For farms of smaller scale additional time and incentives will be needed, however, the adoption of practices and technologies by large-scale farms now will de-risk the approach and reduce the financial investment required to replicate adoption across a broader coalition of dairy farms.

By focusing on enteric methane emissions, manure management and nutrient recovery, feed production and efficiency, and the generation and sale of renewable energy and byproducts, with the right policies and incentives in place, large-scale dairies can achieve net zero GHG emissions while also improving their bottom lines.

[5] NZI was founded by dairy organizations representing farmers, cooperatives, and processors including Dairy Management, Inc, the Innovation Center for U.S. Dairy, Newtrient, National Milk Producers Federation, U.S. Dairy Export Council, and International Dairy Foods Association.

NZI: Four Key Areas of Focus

Feed production & practice changes

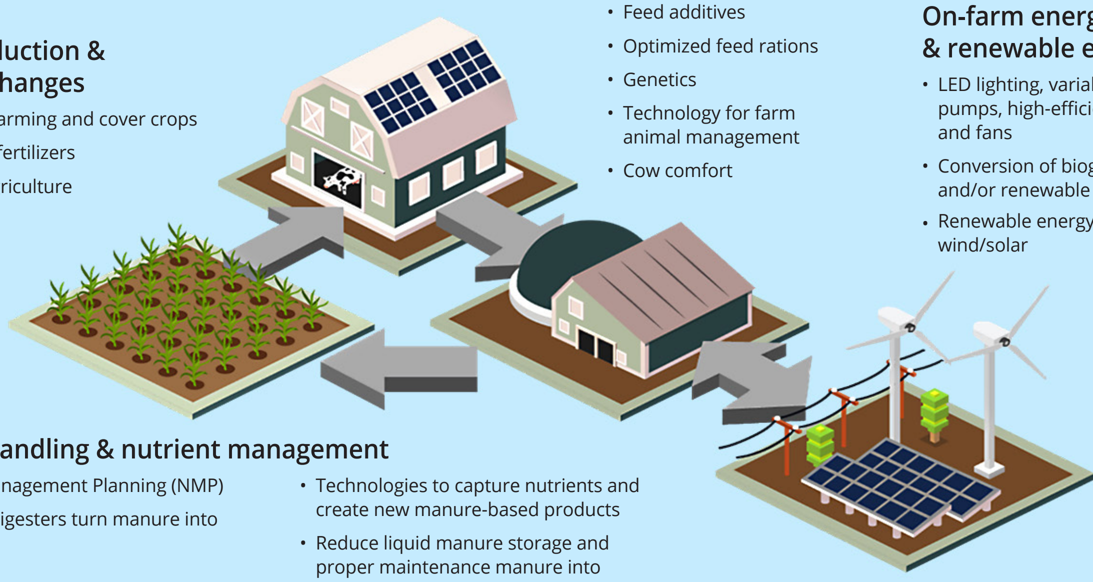
- No/low-till farming and cover crops
- Renewable fertilizers
- Precision agriculture

Cow care & efficiency

- Feed additives
- Optimized feed rations
- Genetics
- Technology for farm animal management
- Cow comfort

On-farm energy efficiency & renewable energy usage

- LED lighting, variable speed vacuum pumps, high-efficiency refrigeration, and fans
- Conversion of biogas into electricity and/or renewable natural gas
- Renewable energy sources from wind/solar



Manure handling & nutrient management

- Nutrient Management Planning (NMP)
- Anaerobic digesters turn manure into biogas
- Technologies to capture nutrients and create new manure-based products
- Reduce liquid manure storage and proper maintenance manure into biogas

Visuals do not represent all possible practices, technologies, or benefits. Not all practices and technologies will apply to all farms, and may vary based on farm location, size, and other factors.

Practices to Reduce Emissions

Feed Production and Efficiency

Precision agriculture, cropping practices such as no-till, cover crop, crop rotation, and use of manure-based fertilizers all have the potential to significantly reduce GHG emissions. These strategies focused on regenerative agriculture principles also recycle on-farm nutrients while improving soil health and organic matter, thus enabling dairies to be more efficient in their feed production while enhancing soil health. This results in a mutually reinforcing cycle that improves yields and reduces negative environmental impacts over time.[6] Furthermore, soil with more organic matter (above and below ground) can absorb and retain more water, thus reducing soil erosion, flood risk, irrigation needs, and use of other inputs with high embedded GHG emissions like synthetic fertilizers, herbicides, and pesticides.

Though there are transition costs, some early research indicates that the adoption of these practices in most soil types has the potential to save money long term. However, there are gaps in the data where additional research would be valuable to better measure the impact of these strategies on reducing GHG emissions (e.g. soil carbon sequestration and soil health benefits from no-till/minimal till, cover cropping, perennial cover, and crop rotation practices for dairy forage crops).

Nutrients in manure are particularly valuable for crop production and can be used in place of synthetic fertilizers to meet plant nutrient needs. However, disturbing the soil through the incorporation of fertilizers can lead to increased biological activity, often resulting in the release of carbon dioxide and nitrous oxide, a GHG that has a global warming potential of 300 times carbon dioxide. As such, it is important to understand the relative benefits of direct liquid manure application to the soil versus the use of manure-based fertilizer products. The latter requires adoption of specific manure and end product technologies that apply product as needed with minimal soil disturbance. More precise application of these nutrients could improve the physical properties and microbial ecology of soil systems as well as the relative productivity of the crops grown in them.

Another promising development comes from research by the Salk Institute, which suggests that gene-edited seeds for cover crops could enable greater carbon sequestration. Although the development is not sufficiently advanced to include in the estimates presented here, such technologies have the potential to reduce loss of carbon to the atmosphere and help dairies achieve net zero emissions.

Estimates of actual sequestration for the various practices discussed throughout this section will be refined through the pilot research, as much of the current literature indicates high variability based on location, soil type, and many other factors. While there will likely still be differences based on such characteristics, the pilot measurements will enable greater accuracy of how different cropping practices reduce GHG emissions.

[6] The model estimates 1.65 acres/cow for feed production based on a Midwestern dairy. Actual acreage for feed production varies significantly by region. This analysis focuses on on-farm fee production.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Enteric Emissions

Around 35% of the on-farm carbon footprint of dairy production is attributable to the methane produced by enteric fermentation, the process which enables cows and other ruminants to eat and break down forage feeds and byproducts from fruit, nut, and vegetable production unfit for human consumption. The makeup of forage and feed components in a cow's ration plays a significant role in the amount of methane released and can also influence factors such as cow health, weight, and milk composition. Therefore, optimizing feed for animal health, milk production, and reduction in enteric emissions is part of a critical path to achieving net zero emissions.

Another strategy to reduce methane from enteric fermentation is through genetic selection, which is possible when optimizing for production efficiency. More efficient cows produce more milk per unit of feed they consume, and thus their methane emissions per unit of milk are lower. Adopting a genetic strategy that will improve the cow's health and increase its lifespan will result in overall reduction of methane emissions.

In addition to feed optimization based on current feed and forage options, research is being conducted on feed supplements that reduce methane from enteric fermentation. A product from the Netherlands is reported to reduce methane emissions from enteric fermentation by up to 40%. (For this case, a 30% reduction is included in the current GHG reduction calculations.) However, this supplement and several other products are not currently approved for use in the US, and their cost is not yet known. Although safety trials on some products have already been completed, if a supplement meets the FDA definition of a drug, rigorous regulatory testing will be required to demonstrate safety and efficacy. Meeting this requirement could potentially take several years. Such regulations demonstrate that some of the challenges to achieving net zero dairy production lie outside of the availability of technology or the willingness of dairy farmers to adopt it.

Improved Manure Management, Energy Generation, and Use

Along with enteric fermentation, manure is one of the greatest contributors to GHG emissions for a US dairy farm (see Figure 2). For dairies that also grow feed crops, some of the liquid manure can be applied to fields as fertilizer, as previously discussed. Although dairy farms apply nutrients consistent with crop agronomic requirements, the nutrients in liquid manure are rarely present in the right proportion to what the plants and fields require. Additionally, depending on crop rotation and land base, farmers often move manure to more distant fields in order to maintain their nutrient balance.

New technologies have been developed, with more entering the market, to convert liquid manure into many useful products, such as dried and pelletized fertilizers and energy. Dry manure-based fertilizer could be applied to fields as needed, with surplus sold to local markets, potentially even at an organic premium. Renewable energy, such as biogas and electricity, can be used to reduce on-farm energy costs and/or sold off-farm to energy markets, although producing electricity with manure is largely not yet economically viable based on the current incentive systems, as discussed later in this paper. Both practices could enhance net economic returns and contribute to overall emissions reductions.

Anaerobic digesters convert a portion of manure organic matter into energy, which can either be used to generate electricity (to power the dairy and/or sell to the grid) or cleaned, compressed, and sold as natural gas. Industrial thermal energy is responsible for around 11% of US emissions; if further incentives are developed that would make it feasible to use biogas from digesters to reduce industrial GHG emissions, which require the higher heat produced from natural gas (versus electricity), this would reduce that sector's emissions along with those of the dairy. This would make digesters an even more attractive option as they could also reduce the negative environmental impacts associated with fracking for virgin natural gas.[7] When manure is combined with other digester inputs, such as organic substrates like food waste, digesters can further enable dairies to negate their GHG emissions — resulting in a synergistic benefit of reducing landfill-bound waste and avoiding methane emissions while creating economic value for the farmer through its sale.

Substrates have tremendous potential to produce more renewable energy with the same resource (an anaerobic digester); however, current policy limitations restrict and affect the economic viability of on-farm anaerobic digesters. One challenge is that many public utilities do not offer electricity prices attractive to producers. In addition, farmers can receive a higher price for selling renewable cellulosic biogas produced by processing manure in a digester. If substrates are added, the value generally decreases.

Adding substrates such as food waste is currently unattractive to farmers based on existing incentive structures. The carbon intensity score of manure is much higher relative to that of organic substrates, which results in a more lucrative incentive from California's Low Carbon Fuel Standard (LCFS). The federal Renewable Fuel Standard (RFS) incentive is also lower for organic substrates than for manure. In the case of both incentive programs, the overall economic value of the energy produced by the project is lowered if organic substrates are included in addition to the manure. This provides a disincentive for the farm even though digesters generally would produce greater volumes of energy, as well as reduce methane in landfills, were they to add organic substrates.[8]

Instead of discounting the value of gas for adding substrates, the farmer should be paid the appropriate value for the cellulosic gas produced from the manure, while being enabled to sell the additional gas produced by adding substrates on the market. Additionally, policies could be developed to pay producers for avoided emissions. For example, if a municipality were to divert food waste to farmers in exchange for reducing landfill volume, it could be mutually beneficial to both farmers and government to reduce waste (and therefore overall cost and emissions) in landfills while producing energy. This would result in reduced methane in landfills, reduced landfill costs, increased availability of renewable energy, and financial support for dairies transitioning to net zero emissions production.

Some farms have been successful in charging tipping fees comparable to or less than what organizations would pay to landfill their food waste, enabling another income stream for food waste to be processed in biodigesters. In 2017, 267.8 million tons of municipal solid waste were generated, over 40 million tons of which were food, with an average tipping fee of $55.36 per ton. However, receiving certain types of food waste from retail or foodservice (versus pre-consumer food waste) can require de-packaging equipment so that packaging does not contaminate the waste and cause problems for the digester system. Such de-packaging equipment is essential but generally falls outside of typical subsidy programs. Were subsidies available to enable farmers to accept this kind of waste, the revenue from tipping fees could prove attractive to supplement energy-based income from digesters. 40 million tons of food waste at $55.36 a ton is over $2.2 billion. While logistical factors such as distance from source of waste to the farm would likely not allow all of that waste to be diverted to farms for processing in digesters, 15% of that $2.2 billion could mean over $300 million that could go towards improving farmer incomes while reducing methane emissions.

In addition to the gas harvested from anaerobic digesters, the slurry (digestate) left over can be processed via other technologies to harvest nutrients (e.g. nitrogen (N), phosphorous (P), and potassium (K)), as well as aqueous ammonia, which can be applied as fertilizer. These products can then either be used by the dairy or sold, creating both economic and environmental value. Clean water can also be processed from the slurry and used directly on farm or safely discharged into the environment.

Organizations supporting the dairy industry are currently exploring avenues for sale of byproducts from improved manure management. While there is a market for these products, more research is needed to compare the benefits of manure-based fertilizer versus traditional inorganic fertilizer not only for crop production, but also soil health and other ecosystem benefits. Such research is critical to grow the market for manure byproducts.

The benefits of improved manure management include avoided manure emissions, gains from nutrient recycling, avoided landfill emissions from substrates, reduced fossil fuel energy usage, and replacement of fossil fuels with renewable products. The potential for even greater reductions with improvements in manure management are tremendous.

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[7] WWF's Renewable Thermal Collaborative (RTC) is the leading coalition for organizations committed to scaling up renewable heating and cooling.

[8] Although two types of feedstocks (i.e. manure and food waste) can be used in one project with a split revenue stream, testing and separately metering the feedstocks on a second digester cell is cos prohibitive.

	Field to Farmgate Baseline*	Net Zero Practices Range	
		High	Low
Cow care & efficiency *(Enteric Print)*	3.69	1.32	1.40
Feed production & production changes *(Feed Print)*	2.80	(0.38)	(0.31)
Manure handling & nutrient management *(Manure Print)*	3.54	0.24	0.26
Renewable energy & use efficiency *(Energy Print)*	0.57	0.21	0.23
GHG benefit from RNG - manure	--	(0.16)	(0.14)
GHG benefit from RNG - substrate	--	(0.29)	(0.19)
Community substrates	--	(3.81)	(2.54)
Farm gate GHG emissions	10.60	(2.86)	(1.28)

Figure 4: Total GHG reduction potential (lbs of CO_2e per gallon of Fat and Protein Corrected Milk (FPCM))[9]

Thoma 2013, Regional Analysis of greenhouse gas emissions from USA dairy farms: A cradle to farm-gate assessment of the American dairy industry circa 2008

Adding Up the Numbers

Greenhouse Gas Emissions Reduction Potential

In figure 4 the baseline GHG analysis (Field-To-Farmgate, Thoma, 2013) for average dairies in the US against the proposed reductions from the technologies and practices described in this analysis is shown; direct comparisons are not appropriate because there are a number of differences between the approaches and data sets used for the two analyses. These changes cannot be made overnight, but with the appropriate planning, investment, and incentives, net zero emissions could be achieved for a certain subset of dairies within five years. To understand the potential for larger-scale impact, consider that in 2018, 217,575 million pounds of milk were produced in the US. With an estimated 10.6lb CO2e per gallon, GHG emissions are estimated at 268 billion lbs.[10] If even 10% of dairy production in the US were able to achieve net zero, in addition to the gains made through continuous improvement in pursuit of the net zero goal, the reduction in environmental impact would be significant.

The order of magnitude of these impacts will certainly depend on a variety of factors ranging from soil conditions to temperature, among others. These figures are illustrative of what is possible and will continue to be refined through the course of the NZI pilot and beyond.

Economic Impact Potential

The table (Figure 5) illustrates the combined estimated economic potential from each category of GHG emissions of a net zero dairy based on the analysis above. Similar to GHG reduction, these returns will not be realized all at once and serve to illustrate the possibilities posed by this analysis, but the gains described are possible over a five-year period if policy shifts occur and if producers adopt developing technologies and practices.

While achieving all of these estimated numbers would be a home run, even reaching 50-75% of these results would be enough to make implementing net zero dairy practices economically attractive for farmers. The estimated revenue potential of environmental services credits (carbon,

Pilot Farm (summary)	*Revenue (per CWT)*	*Revenue (total)*
Feed production *Net return (annual)*	$0.07	$69,161
Enteric emission *Net return (annual)*	$0.10	$97,950
Manure management *Net return (annual)*	$0.77	$757,919
Energy generation and use *Net return (annual)*	$0.43	$426,993
Dairy Farm Innovation Program *Net return (annual)*	$0.58	$576,345
Net return (conventional, electric, annual)	*$1.96*	*$1,928,368*

Figure 5: Net Zero Farm Economic Potential across GHG Footprints

*Assuming a conventional Midwestern US-style dairy with a herd of 3,000 milking cows and approximately 500 dry cows, including on-farm production of approximately 80% of the forage and corn grains needed for feed using 1.65 acres per cow. See Figure 3 for further details on pilot farm breakdown.

**See Appendix 1 for further breakdown of revenue calculations.

[9] The range of table values was provided by DMI based on the Net Zero 2020 analysis they conducted under the Net Zero Initiative. Table values were calculated based on best available science based literature, land-grant state-wide agronomic recommendations, established engineering principles and practices, and professional judgement-based assumptions that are representative for the farm size and location analyzed (Upper Midwest dairy, 3,000 lactating cows and 493 dry cows). Values shown are based on fat and protein corrected milk (FPCM) and a methane GWP of 25 as this value is what is used by the EPA WARM tool. Actual emissions will vary based on numerous factors.

[10] A previous version of this analysis included a conversion error, which was corrected on February 25, 2021. In the previous version, we failed to convert 217,575 million pounds of milk to gallons before multiplying by the Thoma 2013 Field to Farmgate estimate of 10.6 lb CO2e per gal of milk. The number is now correct based on this formula: 217,575 million lbs milk ÷ 8.6 lb/gal x 10.6 lb CO2e/gal FPCM = 268 billion lb CO2e/gal of milk. The previously incorrect conversion had no impact on the conclusions of the case study.

water pollutant reductions) as well as the sale of energy and manure-based products has the potential to create significantly higher returns than outlined in this analysis.

The Dairy Farm Innovation Program, a proposed incentive program dependent on policy changes such as those outlined in the following section, would compensate dairy farmers for the societal value created through the "all-in" adoption of new technologies and management practices in reaching net zero. While many of the practices and technologies outlined in this paper have the potential to provide economic benefits to farmers over time if they receive support with initial investments and incentives, others are environmentally beneficial but the costs may not outweigh the financial gains. The Dairy Farm Innovation Program would encourage farmers to adopt such practices for the public good and would be funded by government. A similar program is being proposed in New Zealand and could inform how it could be structured elsewhere to determine factors necessary for success.

Incentives and Policy Development

As discussed, a variety of technologies and climate-smart practices already exist or are in development that can help mitigate the impacts of GHGs from this sector. But to make a transition to net zero practices economically feasible for the nation's farmers and ranchers, there must be financial incentives and support from government policies and programs to supplement market-based incentives. It may take decades for dairies to yield sufficient market returns for net zero practices to make financial sense, but the timeline for action is much more urgent. While a handful of producers may be able to wait for delayed economic returns, the majority are unable to do so without some assistance.

Current prices continue to place pressure on the dairy industry, necessitating better utilization and expansion of subsidies and incentives from programs such as the Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP), the EPA's RFS Renewable Identification Numbers (RINs) program and others. More research is needed to demonstrate the short and long-term benefits and economics of agricultural practices that contribute to net zero, which will enable farmers to make decisions about these practices without relying on government or corporate incentives and policies.

The practices and technologies that will enable net zero emissions are currently supported by incentives from EQIP, RINs, other NRCS grants, and California's Low Carbon Fuel Standard (LCFS, though this case uses a lower value than the CA incentive to be more conservative), as well as the Investment Tax Credit. These incentives provide crucial financial assistance for transitioning to better practices, as well as for energy generated from anaerobic digesters. However, further incentives should be developed from state and federal governments, including expanding water quality trading markets, creating renewable nutrient standards, promoting off-farm substrate usage for energy generation, and more. In other cases, current programs should be expanded to include taking the California LCFS program to additional states, expanding environmental services markets, and increasing the number or value of USDA, DOE, and EPA assistance and grant programs.

Water quality trading is one example of a critical area where policy shifts could enable the market to monetize ecosystem services more than is currently being done. Water quality improvements can be sourced from agriculture at a much lower societal cost than from industrial or municipal sources. For example, it can cost more than $80 for a

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municipal waste treatment plant to remove a pound of nitrogen from wastewater.[11] At this time, dairy farmers are not provided any financial incentive to reduce nitrogen runoff on farms. However, estimates in this analysis suggest that if even approximately $10/lb. were paid to reduce nitrogen runoff (water quality trade revenue), a fraction of the approximately $80 or more paid by municipalities, it would incentivize dairy farmers to find more cost-effective ways to do so, using market mechanisms to save state and federal governments money. Although this practice would not necessarily reduce GHG emissions, it would ameliorate other harmful environmental impacts while providing critical financial support to help offset the costs of other net zero practices. As a sign of policy moving in this direction, there are several states considering legislation related to water quality trading. One example is the Commonwealth of Pennsylvania, where the State Senate passed SB575, which would provide a mechanism for farmers to generate revenue from reducing nutrient runoff, somewhat similar to the Midwestern example used in the model calculations above.

Substrates and the approval of feed supplements for use in the US (as previously discussed) comprise two other significant areas where policies and incentive systems need to change to unlock the potential of net zero dairy. The current policies in these areas limit the ability of dairies to take advantage of technology and practices that could significantly reduce their carbon footprints. By enabling market-based solutions to watershed pollution and GHG emissions, governments can reduce costs and create benefits for both farmers and nature.

The Electric Pathway represents another opportunity to enhance economic returns for biogas. This pathway, under EPA's RFS program, allows for renewable electricity produced from biodigesters to be considered renewable fuel when used for transportation purposes. Thus, renewable electricity used to power electric vehicles is eligible to generate and sell RINs, which would provide a valuable income stream to incentivize adoption, particularly for dairies that are not located near a natural gas pipeline. However, although the Electric Pathway was approved in 2014, the EPA has been slow to process petitions for this and other pathways, rendering it unattractive to farmers who may depend on such incentives to facilitate their investment in a biodigester. Were the EPA to prioritize the approval of petitions, the adoption of the Electric Pathway for biodigesters would likely be accelerated, encouraging additional dairy farmers to consider this as a viable pathway to increase economic stability.


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Further, many large companies have made environmental commitments to reduce embedded GHG emissions in the products they make or sell and are struggling to reach them, especially Scope 3 emissions [based on Science Based Targets (SBTs)], which are in large part from primary production such as those from milk production on dairy farms. There could be significant interest from large dairy buyers in reducing embedded carbon in their products by purchasing value-added carbon "insets" directly from farmers or cooperatives within their supply chains, which could increase the potential carbon credit value. Some of these companies might even be interested in finding ways to bundle and purchase carbon credits produced on dairy farms where they buy milk. Were the companies to work closely with the dairy industry to advance these initiatives and enable greater GHG reductions, they could potentially use these measures to help companies meet their reduction targets for Scope 3 emissions, and incentivize dairies through long-term contracts or other purchase or offtake agreements.

Nevertheless, to finance some of these changes, producers must sell off their rights to those carbon reductions or carbon removals via carbon credits, either to companies they work with or on the carbon marketplace. If both the farmer and the buyer were to claim these reductions or removals this would be considered double counting, so if the reductions are sold, the farmer can no longer be considered net-zero. This conundrum is beyond the scope of this paper; however, it highlights the need for greater harmonization across the various carbon payment systems that exist in order to stimulate uptake, incentives for farmers, and understanding of carbon markets.

[11] $80 per pound represents an estimate for pricing that would be needed as part of a trading program to get adoption from investors to reduce the nitrogen in a watershed and avoid the cost of building new treatment facilities. There are many literature references on treatment plant costs that range from lower than this number to much higher than this number depending on the current level of treatment, the desired final treatment level, the type of treatment system, and the waste stream to be treated.

Conclusion

By optimizing feed production, feed efficiency, enteric emissions, manure and nutrient management, and energy generation and use, and realizing the synergies that can be created when appropriate technologies and practices are applied in a circular fashion, dairy farms can make net zero GHG emission production a reality. When these are coupled with the right incentives, market-based approaches, and supportive policies, they can create an economically viable path towards increasing farmer livelihoods with the potential for the return to increase over time as soil health improves, technologies evolve, and carbon markets develop. The current state of the technology and markets that underlie this analysis should allow for early adoption by large-scale dairy producers, resulting in tremendous environmental benefit over the next five years while simultaneously de-risking and driving efficiencies in both technology and operational costs for smaller-scale farm adoption in the future. If all dairy farms over 2,500 head were to adopt these practices, we could remove greenhouse gases equivalent to taking approximately 768,000 to 1.7 million cars per year off the road, based on the range of low to high end GHG reduction potential described above.[12] If US farms above 2,500 head can do this, imagine the possibilities if farms of all sizes are enabled to further reduce their emissions through these practices.

Companies utilizing dairy products should work hand in hand with dairy producers to support this transition, which can help enable a reduction in their own carbon footprints as well as the embedded carbon in dairy products. Meanwhile, governments can enhance current incentive programs as well as create new ones to empower and encourage dairies to achieve net zero GHG emission production in addition to water quality improvements. The potential pathways outlined in this analysis illustrate the positive benefits for multiple stakeholders throughout the value chain. Although the focus of this analysis has been on reducing GHG emissions, improved water quality, soil health, biodiversity conservation, and other benefits may also be realized through some of the practices outlined and should be further explored to truly realize the potential environmental benefits.

If net zero emissions are possible for dairy, other types of animal protein production systems shouldn't be far behind. By leading the charge on committing to net zero emissions through operational change, technology implementation, market-based solutions, and advocating for effective policy change, the dairy industry has the opportunity to pioneer change in the food system and demonstrate a pathway to greater economic and environmental progress. If this initiative can lead other types of animal protein production to significantly reduce GHG emissions, we could begin to take the environmental impact out of the equation in making decisions about what we eat. By researching and incentivizing the right production systems, nutritional, environmental, and economic needs across the value chain could be met simultaneously.

Katherine Devine, Director, Business Case Development
Markets Institute, World Wildlife Fund
Katherine.Devine@wwfus.org

[12] Although this analysis focused on a herd of 3,000 head, USDA data breaks down statistics based on herd sizes of greater than 2,500 or 5,000. This estimate is based the USDA breakdown as of 2017 to understand the potential for high level impacts.

Appendix 1: Economic Potential

Pilot Farm (summary)	*Revenue (per CWT)*	*Revenue (total)*
Feed production *Net return (annual)*	$0.07	$69,161
Enteric emission *Net return (annual)*	$0.10	$97,950
Manure management *Net return (annual)*	$0.77	$757,919
Energy generation and use *Net return (annual)*	$0.43	$426,993
Dairy Farm Innovation Program *Net return (annual)*	$0.58	$576,345
Net return (conventional, electric, annual)	*$1.96*	*$1,928,368*

Figure 5: Net Zero Farm Economic Potential across GHG Footprints

Feed Production

Feed Production	*Ton CO2e (acre/yr)*	*Value (per ton)*	*Value (acre/yr)*	*Credit value (farm/yr)*
Carbon credit revenue (estimate)				
Soil carbon sequestration	1	$12		$69,161
Net annual return				*$69,161*

Figure 6: Feed Production GHG reduction revenue potential based on model

Soil carbon sequestration estimates include carbon credits based on available incentive markets.[13]

Enteric Emissions

Enteric Emissions (estimate)	*Ton CO2e (acre/yr)*	*Value (per ton)*	*Value (herd/yr)*
Carbon credits attributed to feed additives	1.2	$12	$43,200
Feed additive cost ($0.10 per cow/day)			($109,500)
Milk/components productivity gain (1.2%)			$164,250
Total cost			*($109,500)*
Net annual return			*$97,950*

Figure 7: Enteric GHG reduction revenue potential based on model

Feed supplement costs used in the table above are estimates based on limited information and have not yet been confirmed with a specific manufacturer (Figure 7). Productivity gains are usually also attributable to feed supplements.

[13] Market rates vary: $3/ton (voluntary carbon credit), $12-15/ton (California Cap and Trade Compliance Market), private markets $15-20 (Bayer, Indigo), and more.

Manure Management

Part of improving manure management relies on the use of various technologies, which require upfront investment to purchase and install, as well as ongoing operating costs. These costs are partially offset by the reduction in traditional manure handling costs, which can be considerable; for a dairy of the proposed pilot size (3,000+ head), these costs can be in excess of $800,000 on an annual basis. In areas with high concentrations of dairy farms, farm clusters can be formed to feed manure into one digester, allowing costs to be spread across many farms instead of being borne by one. This model has been successful in California, where subsidies have been applied to build pipeline connections, and where the LCFS makes the model economically attractive.

However, additional economic benefits can only be obtained by the farmer through other means, such as sales of manure-based fertilizers and renewable energy. Markets currently exist for some products, but not for others that may still be in the early stages of market development, or where the market is currently paying very little relative to the investment required by the producer. Additionally, some of these benefits are only available in certain regions of the country and may not be accessible to farmers implementing such practices elsewhere.

Manure Management		*Total*
Nutrient recovery technology cost (estimate)		
	Capital cost	($6,000,000)
	Financing cost	($441,491)
	Operating cost	($1,000,000)
	Total annual CAPX+OPX	*($1,441,491)*
Fertilizer revenue (estimate)		
	Potential new manure-based products (fertilizer) revenue	*$450,000*
Water quality credit / Trade revenue (estimate)		
	Nutrient (N or P) avoided from environment *Credit values based on Wisconsin trading market currently under*	*$750,000*
Investment tax credit (estimate)		
	30% tax credit applied as capital equipment refund	$132,447
Traditional manure management (estimate)		
	Cost of transporting and utilizing liquid manure Avoided cost (annual) (cents/gallon)	$866,963
Total cost		*($1,441,491)*
Net annual return (conventional)		*$757,919*

**Assumes a portion of the new manure-based used on farm and a portion sold off farm for modeling purposes*

Figure 8: Manure management GHG reduction revenue potential based on model[14]

[14] These numbers were modeled by DMI based on the pilot farm size described in this paper, based on a combination of publicly available data, as well as discussions with farmers, investors, and other stakeholders.

Energy Generation and Use

The estimated annual capital and operating cost of the technologies recommended for creating value-added products from manure need to be covered by incentives, sales of products and energy, and ecosystem services credits. Based on the pilot herd size, sales of new manure-based products could conservatively yield approximately $440,000, water quality credit trading another $750,000, and electric energy sales $1,000,000. When the cost of traditional manure management ($800,000) is also subtracted, the revenues more than offset the annual operating and capital cost for these technologies for a large-scale dairy, without including the benefits from feed production, avoided carbon emissions, and other incentives.

The revenue associated with energy generation is estimated relative to electrical energy values rather than the more lucrative renewable natural gas (RNG) programs that exist today. The total value of RNG into the California transportation section, with the low carbon fuel standards (LCFS) and RINs credits applied, recently averaged annually in excess of $40 per MMBTU. Converted to hundredweights (CWT), this is in excess of $3.00 per CWT, whereas this analysis only contemplates a value of approximately $0.50 per CWT in electric energy given that the renewable natural gas market may not be able to sustain these prices over the long term (as a reference, current national gas prices are around $1.76 per MMBTU and current RNG prices into the CA transportation market are approximately $80.00 per MMBTU).

Energy Generation and Use		*Total (electric)*
Digester cost (estimate)		
	Digester capital cost	($4,500,000)
	Fiber separation capital cost	($500,000)
	Genset and interconnect capital cost	($2,000,000)
	Total capital cost	($7,000,000)
	Financing cost (electric, annual)	($515,072)
	Operating cost (electric, annual)	($300,000)
	Total annual CAPX+OPX (electric)	($815,072)
Digester revenue (estimate)		
	Net avoided on-farm electrical energy	$550,000
	Adding organic substrate from off-farm	$250,000
	Electric vehicle supply premium	$200,000
	Total digester energy revenue (electric)	*$1,000,000*
	Total carbon credit on California compliance market	*$242,065*
Total cost		*($815,072)*
Net annual return		*$426,993*

Figure 9: Energy use and generation GHG reduction revenue potential based on model[15]

[15] These numbers were modeled by DMI based on the pilot farm size described in this paper, based on a combination of publicly available data, as well as discussions with farmers, investors, and other stakeholders.

Dairy Farm Innovation Program

The Dairy Farm Innovation Program, which is dependent on proposed policy changes, would compensate dairy farmers for the societal value created through the "all-in" adoption of new technologies and management practices in reaching net zero.

Dairy Farm Innovation Program	*Ton CO2e (acre/yr)*	*Value (per ton)*	*Value (acre/yr)*	*Credit value (farm/yr)*
Carbon credit revenue (estimate)				
Dairy Farm Innovation Incentive Program			$100	$576,345
Net annual return				*$576,345*

Figure 10: Dairy Farm Innovation Incentive Program revenue potential based on model

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