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Symposium review: Development of a funding program to support research on enteric methane mitigation from ruminants*

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ABSTRACT

Enteric methane is a major source of greenhouse gas emissions from milk production systems. Two organizations based in the United States, the Foundation for Food and Agriculture Research and the Dairy Research Institute, have developed a collaborative program to align resources and fund projects to identify, develop, and validate new and existing mitigation options for enteric methane emissions from dairy and beef cattle. This collaborative program is called the Greener Cattle Initiative. The program will develop requests for proposals and award grants on projects that address challenges within, but not limited, to the following research areas: dairy and beef cattle nutrition, rumen microbiome, dairy and beef cattle genetics, sensing and data technology for enteric methane measurement and prediction, and socioeconomic analysis of enteric methane mitigation practices. The program is structured as a consortium with closed participation and a flat governance collaboration model. The Greener Cattle Initiative program will continue incorporating participants from the food and agriculture industry, commodity groups, and nonprofit organizations who share common objectives and contribute in-kind and matching funds to the program, up to a total of 10 organizations. Research findings will be communicated broadly, after a waiting period for exclusive access to program participants, to create shared knowledge on enteric methane mitigation. The Greener Cattle Initiative is expected to award up to $5 million in research grant funding in a 5-year period, which will contribute to advancing the voluntary greenhouse gas reduction goals established by both the United States and global dairy sectors.
Key words: dairy, enteric methane, funding

INTRODUCTION

Enteric methane is a major source of greenhouse gas emissions from milk and beef production systems that contribute to global warming. Enteric fermentation is the second largest source of methane emissions after natural gas and petroleum systems, and the second largest source of agricultural greenhouse gas emissions in the United States after nitrous oxide emissions from managed soils (US EPA, 2021). Mitigation of enteric methane emissions is a major focus of farmer-led voluntary efforts by the dairy sector in the United States to meet environmental stewardship goals announced publicly in the U.S. Dairy Stewardship Commitment (Innovation Center for US Dairy, 2020). Similar goals to accelerate climate change action and reduce greenhouse gas emissions were announced recently by the global dairy sector (Global Dairy Platform, 2021).

Mitigation of enteric methane from ruminants is not a novel field of research. However, the number of scientific publications in this area increased rapidly in the last 2 decades due to the emphasis placed on the effects of greenhouse gas emissions on climate change (Beauchemin et al., 2020). Many articles reviewed the scientific literature on enteric methane mitigation options (Hristov et al., 2013a; Knapp et al., 2014; Negussie et al., 2017; Beauchemin et al., 2020; Lassen and Difford, 2020). Arndt et al. (2022) recently conducted a meta-analysis to examine 98 enteric methane mitigation options from a comprehensive data set of treatment means from 425 peer-reviewed studies published between 1963 and 2018. They found that most of the options (63 out of 98, or 64%) were not successful in

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mitigating enteric methane. These authors also found that only 5 options reduced enteric methane production (g/d) and emissions intensity (g/kg of ECM or ADG) without negatively affecting milk production (ECM), and only 3 options reduced emissions intensity while increasing animal productivity (ADG). This suggests that many challenges remain in identifying, developing, and validating effective enteric methane mitigation options that result in net emissions reductions for milk and beef production that will also meet farmers' and broad socioeconomic needs.

Detailed discussion of enteric methane mitigation options is beyond the scope of this article. The contents of this article were presented at the ADSA symposium titled "Production, Management and the Environment Fall Webinar: Advances in Enteric Methane Mitigation in Dairy Cattle—The Last Decade and Future Prospects." Its objectives are to review and synthesize research challenges presented at the symposium and describe a program developed to address these challenges by funding enteric methane mitigation research, called the Greener Cattle Initiative (https://foundationfar.org/consortia/greener-cattle-initiative/; last accessed on Feb. 25, 2022).

ENTERIC METHANE AND OPPORTUNITIES TO ADDRESS CLIMATE CHANGE

Unlike other sources of greenhouse gas emissions, such as those from fossil fuel extraction and distribution that only contribute to atmospheric greenhouse gases, milk production systems are part of the biological carbon cycle and can function as a sink for greenhouse gases, thereby contributing to reverting climate change (Le Quéré et al., 2018). During the symposium, F. Mitloehner (University of California, Davis) emphasized that methane has a substantially shorter atmospheric lifetime than carbon dioxide and nitrous oxide. Because emitted methane is continuously removed from the atmosphere by hydroxyl oxidation, its atmospheric warming effects depend on the rate of emissions increase or decrease over the last 20 years rather than the total cumulative amount emitted over that period (Allen et al., 2018). The consequence of this behavior is that mitigation of enteric methane production at rates greater than its natural rate of oxidation reduces atmospheric methane concentrations, effectively reverting climate change effects (Lynch et al., 2020). In other words, mitigating enteric methane production has an effect on atmospheric warming similar to removing a fixed amount of carbon dioxide from the atmosphere by sequestering it in soil or plant matter (for example, by afforestation). Cain et al. (2019) found that sustained annual reductions of 0.3% in methane production are sufficient for atmospheric warming from methane to remain stable over time. The implication is that mitigation of enteric methane production greater than 0.3% annually that is sustained over time (i.e., year-over-year) could be used to offset the atmospheric warming effects of carbon dioxide and nitrous oxide emissions from milk production systems. In this way, sustained mitigation of enteric methane production becomes a valuable tool for dairy value chains to meet their greenhouse gas reduction goals. This opportunity to revert climate change effects by focusing on mitigation of enteric methane production places milk production systems in a unique position to convert climate impact into societal benefit.

GREENER CATTLE INITIATIVE TO FUND ENTERIC METHANE RESEARCH

As presented by J. M. Tricarico (Innovation Center for US Dairy) during the symposium, the Foundation for Food and Agriculture Research (**FFAR**) and the Dairy Research Institute (**DRI**) jointly developed the Greener Cattle Initiative as a pre-competitive program to support collaborative research on enteric methane mitigation from ruminants. The FFAR is a 501(c)(3) nonprofit organization, created by the US Congress to complement the work of the United States Department of Agriculture. The FFAR builds unique public-private partnerships to support innovative science addressing today's food and agriculture challenges. The DRI is a 501(c)(3) nonprofit organization affiliated with the Innovation Center for US Dairy, created to strengthen access to and investment in the technical research required to drive innovation and demand for dairy products and ingredients domestically and abroad. Both FFAR and DRI have agreed to identify additional organizations from the food and agriculture industry, commodity groups, and nonprofits that share similar scientific and educational objectives for enteric methane mitigation and are willing to contribute financially to the initiative. The overall goal for the Greener Cattle Initiative is to leverage resources through in-cash and in-kind contributions to award multiple grants in response to requests for proposals. The research objectives are to identify, develop, and validate new and existing scientifically sound, commercially feasible, and socially responsible mitigation options for enteric methane emissions from dairy and beef cattle (Figure 1). The following critical areas for research were identified by FFAR and DRI to develop requests for proposals under the Greener Cattle Initiative:

- *Dairy and beef cattle nutrition* to incorporate compounds fed in low quantities (equal to or less than 1% dietary DM) that directly or indirectly inhibit enteric methane emissions without negative impacts on animal performance, and feed ingredients that alter ruminal metabolic pathways away from methanogenesis when they are fed at quantities that require diet reformulation,
- *Rumen microbiome* to understand how its composition and activity influences methane formation and its inhibition,
- *Sensing and data technology for enteric methane measurement and prediction* such as sensors, robots, artificial intelligence systems, and more, to monitor enteric methane emissions or related physiological indicators and markers and manage individual animals to reduce emissions,
- *Dairy and beef cattle genetics* to develop selection traits and programs that allow selective breeding of low methane-emitting cattle, and
- *Socioeconomic analysis* of enteric methane mitigation options.

The development of effective enteric methane mitigation options that also meet economic and social requirements for adoption requires research across these various disciplines and possibly others. The following section will briefly describe research needs and challenges specific to dairy cattle that are related to the research areas listed, and were presented during the symposium by A. N. Hristov (The Pennsylvania State University), D. Pitta (University of Pennsylvania), E. Kebreab (University of California, Davis), F. Mitloehner (University of California, Davis), Y. de Haas

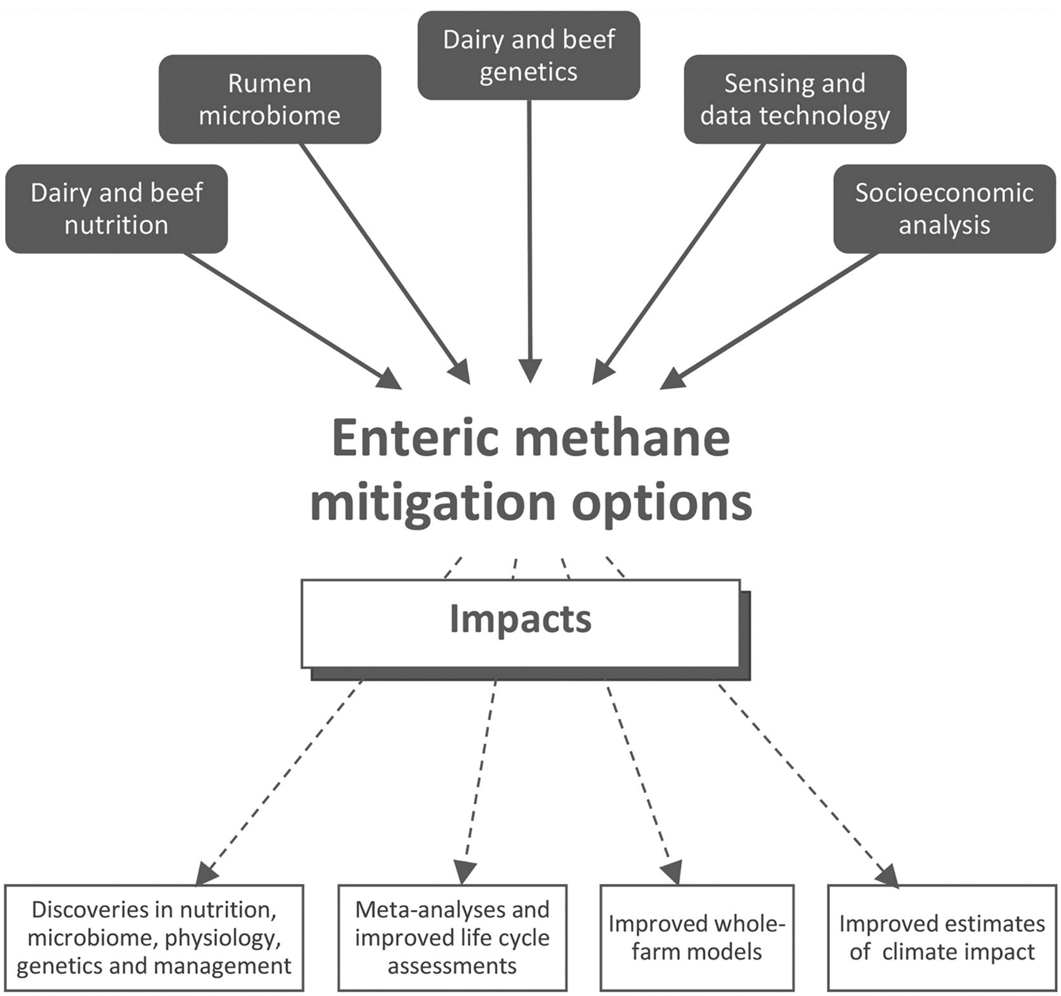

Figure 1. Areas of focus and expected impacts for research funds awarded by the Greener Cattle Initiative to identify, develop, evaluate, and validate enteric methane mitigation options for beef and dairy cattle.

(Wageningen University & Research), and J. M. Tricarico (Innovation Center for US Dairy).

RESEARCH NEEDS AND CHALLENGES FOR ENTERIC METHANE MITIGATION IN DAIRY CATTLE

Dairy Cattle Nutrition

Research on nutrition- and management-based enteric methane mitigation options must continue and expand to support identification and adoption of mitigation options and better understand their consequences on animal health, well-being, productivity, and product quality. Better delivery mechanisms are needed for nutritionally based mitigation options, especially under grazing conditions (Beauchemin et al., 2020). Long-term experiments are needed to examine the effects of mitigation options on animal health, well-being, and reproduction over a full lactation and multiple lactations. Long-term experiments are also needed to study adaptation by the ruminal microbiome and the animal to mitigation options. Appropriate experiments will also be valuable to examine the long-term effects of prolonged inhibition of methanogens or alteration of ruminal fermentation pathways. It is also important to understand the impacts nutritional mitigation options can have on milk composition, shelf life, sensory attributes, and consumer perception of dairy foods and how they are produced. Finally, research exploring the effects on dairy cow manure composition and manure and soil emissions resulting from mitigation options based on nutrition and feeding management, inhibition of methanogens, or alteration of fermentation pathways is also critically important.

Rumen Microbiome

Enteric methane is formed exclusively by methanogens that use fermentation end products, such as carbon dioxide and hydrogen, and keep the rumen in a reduced state, allowing microbial feed digestion to continue. Therefore, understanding how the ruminal microbiome affects enteric methane emissions by dairy cattle is another focus area for research that could deliver both short- and long-term benefits. Knowledge gaps in this area include improved understanding of the relationships between fungi, bacteria, protozoa, and archaea (i.e., methanogens) and how these interactions affect methanogenesis, microbe-animal (host) interactions, ruminal biochemical transactions including their thermodynamic regulation, and how the microbiome is influenced by the host, dietary reformulation, and feeding practices. Information on the production rates of volatile and branched-chain fatty acids resulting from ruminal fermentation is also warranted. Exploring methanogenic diversity and how their relative contributions to methanogenesis vary by breed and with fluctuating levels of forage and concentrate in the diet is desirable. This type of research will help explain differences in enteric methane emissions and the effectiveness of mitigation options between confined feeding and grazing systems. Also, determining the effect of different mitigation options on individual methanogen species (Pitta et al., 2021) and alternate hydrogen sinks (Greening et al., 2019) would allow identification of complementary options to further reduce methane formation in the rumen. For example, this type of research may help identify combinations of mitigation options that are more effective based on the expected methanogen diversity in animals under specific management and environmental conditions. Finally, research exploring the impact of applying interventions early in the life of the animal on enteric methane production later in life is also of interest (Meale et al., 2021).

Sensing and Data Technology for Enteric Methane Measurement and Prediction

The importance of measuring and accurately predicting both enteric methane emissions and the reductions due to the adoption of mitigation options cannot be overstated. Biophysical research to explore and develop new sensing technology or new uses for existing sensing technology is fundamental for accurate and robust enteric methane measurements and predictions (Negussie et al., 2017). Easily measured physiological indicators that can be used as robust estimates of enteric methane emissions and effects of mitigation options will be critical to test and validate these options in sufficiently large numbers of animals to provide confidence in the response (Patra, 2016). The main challenge with indicator variables is that accuracy is usually compromised, and more accurate methods, such as using respiration chambers, are laborious, slow, and expensive, thus limiting the number of mitigation options and animals that can be tested. The application of indirect indicator methods in large numbers of animals will be valuable to investigate the relationships between improving animal health and enteric methane abatement that currently have limited evidence (Hristov et al., 2013b). Data collection, aggregation, and synthesis are also crucial to increasing confidence in enteric methane mitigation estimates. Increased confidence in mitigation estimates is needed to develop socioeconomic innovation that encourages adoption of mitigation options. For example, the development of robust and verifiable methodologies to quantify enteric methane reductions is critical for the creation of enteric methane mitigation-based credits to be transacted in voluntary and compliance offset markets (Allen et al., 2021).

Dairy Cow Genetics

Selectively breeding dairy cattle that naturally produce lower enteric methane emissions is an attractive mitigation option that is cost-effective, permanent, and cumulative (de Haas et al., 2021). This is possible because enteric methane emissions are under a degree of genetic control and are therefore heritable (de Haas et al., 2021). Heritability estimates for methane emissions in dairy cows range between 0.05 and 0.27, but most estimates are >0.20 (Lassen and Difford, 2020). Selection indexes that include multiple traits will need to incorporate a methane emissions trait to ensure that breeding programs are balanced. This is not an easy task, as the methane emissions trait needs to be defined, recordable, affordable, heritable, and representative of the phenotypic variation onto which selection pressure is applied. In addition, its genetic correlations with other traits within the breeding goal need to be known to obtain EBV with reasonable accuracy. Four candidate phenotypes are currently available to potentially develop enteric methane emissions traits (de Haas et al., 2017). These are methane production (g/d), methane yield (g/kg of DMI), methane intensity (g/kg of ECM or ADG), and residual methane production (grams of methane regressed on DMI, BW, and ECM). Research is required to understand the advantages and limitations of each of these options. In addition, selective breeding takes advantage of genetic variation and therefore requires multiple generations for its effects to accumulate over time. Both pedigree-based selection and genomic-based selection will require phenotyping and genotyping large numbers of animals, which underscores the importance of developing sensor and indicator technologies, as described earlier. For example, de Haas et al. (2021) estimate that phenotypes from 15,000 cows are required to achieve the reliability necessary for genomic predictions on enteric methane production within the Dutch breeding goal. In summary, selective breeding can make a valuable contribution to a portfolio of enteric methane mitigation options that also include nutrition and management.

Socioeconomic Analysis

The discovery of new enteric methane mitigation options, by itself, is not enough for the dairy sector to meet its environmental stewardship goals on climate change. Mitigation options need to be deployed by a substantial number of dairy farmers to achieve the desired results. This task will become feasible when innovation in the biological and physical sciences, leading to the development of new enteric methane mitigation options, is accompanied by socioeconomic innovation to drive their adoption. Innovation in economic and social fields is critical to creating favorable environments, where adoption of enteric methane mitigation options by dairy farmers is incentivized. The desirable goal is to empower dairy farmers to incorporate mitigation options into their operations because they are environmentally and economically advantageous, recognized through measurement and recording, and reputationally rewarded.

Successful incorporation of enteric methane mitigation options into business models through pricing is essential, but this is not the only requirement to accelerate their adoption. The development of marginal abatement cost curves is a valuable approach to rank the cost-effectiveness of different enteric methane mitigation options and should be included in the socioeconomic analyses (Eory et al., 2018). Complexity of use associated with some mitigation options also represents a significant barrier to adoption (Owen et al., 2012). For example, the failure to adopt urea-ammonia treatment to increase the nutritive value of straws, as reported by Owen et al. (2012). This means that attention is also needed to develop and test alternative financial mechanisms, various modes of delivering technical assistance, and innovative approaches to partnerships to address existing barriers. Transparency concerning milk production practices and enteric methane mitigation efforts is indispensable to ensure that consumers trust the value chain that delivers nutritious milk and dairy foods to them. Innovation, consensus building, and clear communication are critical for dairy supply chains to meet their climate change goals and for the public to perceive them appropriately.

Innovation is also required in the regulatory environment in the United States because the current environment does not include clearly defined pathways specific for options that target enteric methane mitigation. For example, animal feed and health companies that develop enteric methane inhibitors currently need to pursue regulatory pathways that were developed to establish functional claims for drugs, such as compounds to cure, prevent, treat, or mitigate disease conditions or that change bodily structures or functions (United States Food and Drug Administration, 2022). Different regulatory mechanisms need to be developed that are specific for environmental claims to incentivize innovation in enteric methane mitigation.

Finally, the challenge of larger financial investments for enteric methane mitigation options is always present. Private companies are currently investing to develop enteric methane mitigation options without clarity on how and when they may capitalize on market opportunities, particularly if the options do not also offer additional economic benefits. Associations and nongovernmental organizations are investing in research to measure, test, and understand both the impacts and the opportunities afforded by options that promise enteric methane mitigation. Yet, simultaneously, public spending in the United States on agricultural research and development to address climate change while increasing food production is shrinking and is currently below the level of private sector investment (Clancy et al., 2016; Economic Research Service 2019). Government is a critical funder of research and in many cases represents the only funding available. As such, a need exists to increase, reorganize, and leverage research funding from public and private sources to encourage scientific pursuits that can build the basis for innovation by private funders looking to capitalize on marketplace opportunities.

EVALUATING ENTERIC METHANE MITIGATION OPTIONS

The accurate estimation of emissions and removals resulting from the adoption of enteric methane mitigation options by dairy farmers requires integrated systems approaches. For example, the quantification of net greenhouse gas emissions associated with the production and distribution of feed additives to mitigate enteric methane emissions requires following the guidelines developed by the Livestock Environmental Assessment and Performance Partnership (LEAP) of the Food and Agriculture Organization of the United Nations (FAO, 2020). A life cycle assessment approach is required to conduct cradle-to-farm gate environmental impact analyses to account for upstream and downstream effects of mitigation options according to these guidelines. Meta-analyses are also critical to quantify the effectiveness of enteric methane mitigation options. This is because the sign and magnitude of the response often depend on the context and landscape in which each dairy farm operates. The management and environmental conditions, such as the animal life stage and genetic makeup, additive dose, type of feeding, mitigation option delivery, and dietary composition, affect the expected mitigation response. Adequate research is needed for meta-analyses to be conducted for each mitigation option.

Quantifying the effects of adding mitigation options or changing milk production practices is extremely difficult without the ability to model whole-farm systems (Kebreab et al., 2019). Whole-farm models are also required to evaluate connections between system components that physical research cannot practically investigate and, in many instances, can provide information less expensively and more quickly than physical experimentation. Research is needed to support the development of integrated models that simulate the flows of carbon through the entire dairy farm under different management and environmental conditions. These models could benefit from the extensive amounts of data currently collected on commercial dairy farms (Cabrera et al., 2020). In addition, it is essential to understand the implications that enteric methane mitigation options could have on the local, regional, and global food systems. These different levels of aggregation represent an important challenge that can only be addressed through the development, validation, and application of whole-farm, landscape, and dairy sector models.

GREENER CATTLE INITIATIVE COLLABORATIVE STRUCTURE

The Greener Cattle Initiative was established to function over the course of 5 years, with the expectation that positive results will encourage funders to extend the timeline and funds available. The collaboration model for the program reflects the collaborative structure defined as a consortium by Pisano and Verganti (2008)—namely, a closed participation model with a flat governance. Focus on developing strong relationships within the participants and identifying and engaging with experts within their corresponding networks will be critical to address the limitations associated with the closed model involving few participants. In addition, flexible but clearly defined rules and processes are necessary to drive participant collaboration toward common goals that are sometimes challenging to achieve with flat governance structures.

A group of up to 10 participating organizations will comprise a steering committee. This steering committee will determine the scientific scope, the strategic direction, the project review and approval process, and new participant recruitment. Each organization will have one seat on the steering committee and will hold a single vote. All decisions affecting requests for proposals, projects awarded, or major decisions relative to the initiative's operations will be made by majority vote. Both FFAR and DRI will function as final arbiters when the decision-making process does not result in a clear outcome. The program director will be an individual hired by DRI to manage day-to-day operations of the initiative according to the direction set by the steering committee. The FFAR will act as disbursement facilitator for all project funds to grantees leveraging the infrastructure and processes it has already developed for this purpose. Specific information on how to submit proposals will become available after the program is launched and requests for proposals are announced. Steering committee members will receive knowledge of the results developed in all projects before publication, enabling early evaluation of their interests in licensing any corresponding intellectual property.

CONCLUSIONS

Global challenges, such as enteric methane mitigation and its contribution to climate change, cannot be solved by one organization. Addressing these challenges requires collaboration among many organizations and across different sectors. Collaboration under the Greener Cattle Initiative is meant to establish and articulate a clear path forward for coordinated action among stakeholders in the public and private sectors. Its purpose is to catalyze progress by pooling resources and utilizing them more effectively for experts to conduct research to identify, develop, and validate enteric methane mitigation options. This program represents an opportunity for participants across the beef and dairy sectors to collaborate toward a common goal. Involvement by farmers, feed companies, animal health and genetics companies, and other value chain stakeholders will result in research efforts that are informed by participants across the beef and dairy sectors, targeting mitigation options that are practical and implementable at scale. Focusing on pre-competitive research enables leveraging investments and resources to create shared knowledge that can be used as a platform for individual organizations and companies, including competitors, to develop new marketable mitigation options. This approach for pre-competitive, collaborative research aims to accelerate innovation on enteric methane mitigation and provide lasting value to businesses, society, and the environment.

Public-private partnerships represent the most attractive opportunity for strategic collaboration to address challenges facing the development of enteric methane mitigation options in a coordinated effort. Collaboration between the private and public sectors is critical for identifying mitigation options and encouraging action by dairy sector participants while continuing to improve the availability of safe and nutritious milk and dairy foods. The Greener Cattle Initiative is expected to award up to 5 million dollars in research grant funding within the next 5 years, which will contribute to advancing the voluntary greenhouse gas reduction goals established by both the United States and global dairy sectors.

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