Affordable and Scalable Non-intrusive Measurements of Bovine Methanogenesis

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Abstract

Ruminants—especially cattle—contribute significantly to global emissions of methane, being responsible for about 100 million tons each year.[3] By weight, "the comparative impact of CH_4 is more than 25 times greater than CO_2 [at trapping electromagnetic radiation in the atmosphere] over a 100-year period… When livestock and manure emissions are combined, the Agriculture sector is the largest source of CH_4 emissions in the United States."[4]

Approaches to reducing bovine methane production can include exploration of herd-wise dietary changes as well as studies of the origin of animal-to-animal differences in eructated methane. The measurements in these studies tend to concentrate on methane output from specific animals that can be tracked through the use of passive radio frequency identification (RFID) ear tags. The methane sensors for ruminants are often elaborate, expensive, and designed only for a research setting.[5] Nearly all techniques—instrumenting the access ports of restricted-access feed bunks, or training cattle to tolerate metabolic cages and head boxes—do not lend themselves to continuous, day-in, day-out measurements of large numbers of animals. Currently available systems are too expensive to be accessible to cattle producers hoping to monitor their own herds.

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[3] Ralf Conrad, "The global methane cycle: recent advances in understanding the microbial processes involved," Environment microbiology reports, 1:5, 285-292, DOI: 10.1111/j.1758-2229.2009.00038.x, 2009.
[4] U.S. Environmental Protection Agency, "Overview of Greenhouse Gases" (2017 data), https://www.epa.gov/ghgemissions/overview-greenhouse-gases, visited January 14, 2020.
[5] See, for example, A.L.F. Helwig et al., "Technical note: Test of a low-cost and animal-friendly system for measuring methane emissions from dairy cows," *Journal of Dairy Science* **95**, p. 6077, October 2012. We recently received a price quote for a small "non-dispersive infrared" methane detector that was approximately $1,700.

We propose to build a demonstrator system of three microcontroller-monitored strings of inexpensive MQ-4 compressed natural gas sensors,[6] with each microcontroller communicating with a base station through a radio link. Each string might comprise a radio-capable processor, ten MQ-4 sensors, and ten environmental sensors that would sample the temperature, atmospheric pressure, relative humidity, and total airborne volatile organic compound concentration near each MQ-4. We already have a small amount of experience with MQ-4 measurements in a closed barn,[7] and would like to extend these to other settings. We are also requesting support for two RFID devices and a pair of moderately sophisticated non-dispersive infrared methane detectors to cross check the data from the MQ-4s.

Project description

a. Project significance

Bovine methanogenesis is a major contributor to agricultural greenhouse gas emissions. Methane also represents an energetic inefficiency to animal production as a waste product from enteric fermentation. Therefore, reducing methane emissions from ruminants will improve sustainability and profitability of cattle production. While there has been extensive study of methane emissions from ruminants worldwide, nearly all of that has been limited to research settings with small numbers of animals. To date, the cost of methane monitoring technology has prevented its installation and use by commercial cattle operations. We will study the prospects for construction of an inexpensive, densely instrumented methane measurement system that can be deployed in commercial livestock operations. We believe such a system can quantify improvements in sustainability of cattle operations and be leveraged for precision monitoring and management of cattle. We are seeking seed funding to build a small demonstrator system; if our results show promise, we would seek external funding to increase the system scale and provide emissions monitoring access through partnerships with commercial producers.

Rather than building a system intended to make precise, expensive, and relatively infrequent measurements of methane from individual animals, we will concentrate primarily on densely instrumenting the air volume above the livestock in closed and open barns. The practical limitation on how frequently we can record methane levels is set by the settling time of MQ-4 sensors, which we know to be approximately ten seconds. As a result, we expect to be able to track methane levels, as well as environmental parameters

[6] See https://www.sparkfun.com/products/9404: the devices can detect methane concentrations in the range 200 ppm to 10,000 ppm and cost less than $5 per sensor.

[7] Sarah Popenhagen et al., "Measuring Methane Production of Cattle in a Semi-Closed Environment," December 6, 2019; https://courses.physics.illinois.edu/phys398dlp/sp2020/documents/398_methane_group_final_report.pdf.

like temperature and humidity, continuously for weeks at a time. We are requesting support for a small number of RFID devices, as well as a pair of non-dispersive infrared methane sensors, to investigate the feasibility of identifying signals from individual animals and gauging the actual airborne methane concentration for calibration purposes.

We already have on hand a small number of computer-readable anemometers that we can deploy in an open barn to track wind speed during the methane measurements.

b. Investigators

The proposal's principal investigators are Professor George Gollin (Physics), an elementary particle experimentalist with extensive experience in design and construction of distributed systems of instrumentation, and Assistant Professor Josh McCann (Animal Sciences), whose research focuses on the influence of nutrition on metabolism and growth of feedlot cattle. Their biographical sketches are attached to this proposal.

c. Innovation

The proposed system's most innovative features are

- its flexibility: methane sensors can be deployed above stalls in barns with restricted animal movement, or in open barns in arrays of arbitrary geometry that can be reconfigured as suggested by analysis of incoming data;
- the rate at which (and the duration for which) the system can be interrogated: data can be pulled from each string's microcontroller as frequently as desired; reading each string every few minutes is entirely feasible;
- real-time availability of data: by equipping the base station with an inexpensive WIFI card it will be possible to offload the system's most recent data to a remote computer for on-demand analysis.
- its low cost: the availability of inexpensive sensors and microcontrollers makes feasible a low cost-per-string so that the technology is available to cattle producers (see our budget figures, below);
- its extensibility and scalability: software improvements and the possibility to retrofit additional sensors will permit the extension of each sensor string's capabilities, while the 1 km range of a string's 900 MHz radio will allow a single base station to communicate with strings scattered over hundreds of acres.

d. Approach and future potential

The basic unit of the system will be a microcontroller-monitored sensor string. The components in one string are likely to be

- a 900 MHz radio-capable microcontroller

- a real time clock module
- a microSD card read/writer device
- ten MQ-4 gas sensors
- ten environmental parameter sensors

We list suitable devices in the budget, below.

Our plan is to install a system of three strings in a semi-open cattle barn that is part of the Beef and Sheep Research Field Laboratory. We already have some experience with MQ-4 sensors in a closed laboratory setting.[8] One of our first goals, once the strings are in place, will be to determine the effect of environmental conditions—in particular, wind speed and temperature—on data quality and system efficacy. Results permitting, we will then investigate the relationship between sensor placement and methane signal.

We expect to validate the MQ-4 methane sensor performance based on considerably more precise measurements from the NDIR sensors listed in our budget, and from known rates of release of methane from livestock. If we obtain sufficient precision and reliability, we will want to study how well we can relate methane concentrations at the feed bunk to the food intake and behavior of individual animals.

If our demonstrator system performs well, we do not expect there to be any fundamental barriers to scaling the system to cover a 1,000 animal barn complex. From our initial studies we hope to understand the issues (if any, other than cost) of deploying a very dense, very large system at "enterprise scale." Building such a large system, however, is best done by seeking commercial partnerships. Initially, we believe large commercial cattle enterprises will have the greatest interest as their commitment to sustainability affects messaging to their consumers and operational profitability.

We believe that this project can serve as an excellent multi-disciplinary training exercise for students in both physics and animal sciences.

Achieving these objectives will position us well to garner additional external funding. The planned work has been conceived to provide a wide range of subsequent funding mainly along two lines of research and application: 1. Direct measurement of methane from cattle in various environments; 2. Use of methane data and other environmental data for precision animal management. Direct measurement of methane fits with the Seeding Solutions RFP by the Foundation for Food and Agriculture Research (FFAR)[9] as it

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[8] Op. cit., Popenhagen.
[9] https://foundationfar.org/2019/03/01/ffar-seeks-pre-proposal-applications-for-2019-seeding-solutions-grants/, visited January 20, 2020.

encourages cooperation with multiple sectors. Use of the methane data to improve precision cattle management, nutrition, and profitability fits more closely with the USDA AFRI Foundation Programs for Animal Nutrition, Growth, and Lactation and the Engineering for Agricultural Production Systems. A new USDA program, Inter-Disciplinary Engagement in Animal Systems, would particularly be a good fit for our research as it seeks bridge disciplinary divides to improve livestock management and production.[10]

e. Environment

The environmental impact of the methane sensor strings is minimal. Since the information obtained might allow herd-scale experiments on methane reduction through dietary modification, we might see significant environmental benefits to developing and deploying a large sensor grid based on our findings.

[10] https://nifa.usda.gov/program/agriculture-and-food-research-initiative-afri, visited January 20, 2020.

References cited

Ralf Conrad, “The global methane cycle: recent advances in understanding the microbial processes involved,” *Environment microbiology reports,* 1:5, 285-292, DOI: 10.1111/j.1758-2229.2009.00038.x, 2009.

U.S. Environmental Protection Agency, “Overview of Greenhouse Gases” (2017 data), https://www.epa.gov/ghgemissions/overview-greenhouse-gases, visited January 14, 2020.

A.L.F. Helwig et al., “Technical note: Test of a low-cost and animal-friendly system for measuring methane emissions from dairy cows,” *Journal of Dairy Science* **95**, p. 6077, October 2012.

https://www.sparkfun.com/products/9404

Sarah Popenhagen et al., “Measuring Methane Production of Cattle in a Semi-Closed Environment,” December 6, 2019; https://courses.physics.illinois.edu/phys398dlp/sp2020/documents/398_methane_group_final_report.pdf

https://foundationfar.org/2019/03/01/ffar-seeks-pre-proposal-applications-for-2019-seeding-solutions-grants/, visited January 20, 2020.

https://nifa.usda.gov/program/agriculture-and-food-research-initiative-afri, visited January 20, 2020.

Budget and budget justification

We hope to build a three-string (plus base station) proof-of-concept system. The proposed investigation offers excellent interdisciplinary pedagogical possibilities, so we seek funds to hire two physics undergraduates. Crop sciences undergraduates who might work with us will be paid from a separate USDA grant.

Cost of one sensor string:

items for one sensor string	price
Adafruit Feather M0 microcontroller with RFM95 LoRa Radio (processor controlling the system and communicating with base station processor)	32.
Adafruit BME680 T/P/RH/VOC sensor breakout (10) (measures environmental parameters: temperature, pressure, humidity, airborne volatile organics.)	180.
Adafruit DS3231 real time clock (maintains UTC time even when system is unpowered)	13.
Adafruit microSD card breakout (onboard backup data storage)	7.
Sparkfun MQ-4 methane sensors (10) (inexpensive methane detectors used by project)	45.
Lithium ion battery, 3.7V, 2000 mAh (provides power for microcontroller)	12.
3D-printed enclosures (protects components from minor environmental hazards)	25.
mounting hardware and cables (we will need to hold sensor positions fixed)	35.
printed circuit board (holds the components, provides interconnects)	10.
1A, 5V "cell phone charger" (powers the sensors and recharges the Feather M0 battery)	10.
total	369.

Cost of base station:

items for one base station	price
Adafruit Feather M0 microcontroller with RFM95 LoRa Radio (runs the system)	32.
Adafruit DS3231 real time clock (maintains UTC time even when system is unpowered)	13.
Adafruit microSD card breakout (onboard data storage)	7.
Lithium ion battery, 3.7V, 2000 mAh (provides power for microcontroller)	12.
3D-printed enclosure (protects components from minor environmental hazards)	5.
printed circuit board (holds the components, provides interconnects)	10.
5V, 1A power supply (recharges the Feather M0 battery)	10.
total	89.

System hardware cost

N	items for complete demonstrator system	price
1	printed circuit board fabrication one-time setup charge (charged by PCB fabricator)	100.
3	sensor strings @ $369 each	1107.
1	base station (queries the sensor stations, receives and stores their data)	89.
2	Sparkfun simultaneous RFID reader @ $225 each (for studies of possible association of detected methane with individual animals)	450.
2	GHG analytical GasCard 0 – 1% methane sensor @1,750 each (precise, highly selective NDIR methane sensor for calibrating our MQ-4s)	3500.
1	miscellaneous hardware (nuts, bolts, cable ties, and so forth)	50.
	total	5296.

PI summer salaries, ½ month

who	cost
George Gollin	7,000.
Josh McCann	4,700.
total	11,700.

Summer undergraduate research assistants: 8 weeks, 35 hours per week, $15/hour

N	Undergraduate research assistants	price
2	$4,200 per student	8,400.

Total funds requested: $5,296 + $11,700 + $8,400 = $25,396