Methane emissions from beef cattle bred for low residual feed intake

Project number : 2014R073R

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Project completion date: 31 December 2017

Total ERA funds received and amount of hold back:

Submission date: 31 March 2018

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1.1. Table of Contents

1.2. List of Tables

1.3. List of Figures

Abbreviations: **GHG** = greenhouse gas; **RFI_{fat}** = residual feed intake adjusted for off-test backfat; **DMI** = dry matter intake; **CH_4** = methane; **CO_2** = carbon dioxide; **LRDC** = Lacombe Research and Development Centre; **KIN** = Roy Berg Kinsella Research Station; **GEM** = Greenfeed Emissions Monitoring; **FTIR** = Fourier Transform Infrared Spectrophotometer.

2.0. Executive Summary

- **The project**
  - Alberta is among the largest beef producing region in North America, having 42% of the beef cows and bred heifers and 70% of the beef feeding capacity in Canada.
  - Alberta produces 32% of Canada's agricultural greenhouse gas (GHG) emissions and is ranked first among provinces (Environment Canada, 2016). About 20% of the methane emissions in Alberta are from enteric methane, and 75% of this methane originates from cow-calf operations.
  - Since cattle are vital to the grassland ecosystem, rural community growth, and a safe and secure food supply, it is imperative to find solutions to reduce methane and GHG emissions from the beef cow-calf herds in Alberta.
  - **Objectives were to;**

    i) assess the GreenFeed Emissions Monitoring (GEM) system and open-path concentration sensors (e.g., Fourier-transform infrared spectroscopy, FTIR) for their ability to accurately measure enteric methane (CH_4) emissions under on farm grazing and wintering conditions;

    ii) compare feed intake, CH_4 and carbon dioxide (CO_2) emissions from high and low RFI (residual feed intake) beef heifers and cows under grazing and winter drylot conditions using GEM and respiration chambers;

    iii) quantify enteric methane emissions, feed intake, RFI and various biometrics in yearling beef heifers and cows during winter in drylot; and

    iv) quantify enteric methane emissions, feed intake, RFI and various biometrics in pregnant yearling beef heifers during summer grazing.

- **Results**
  - The GEM system functioned well in outdoor drylot environments through four Alberta winters where night time temperature often dropped below -30 ^{o}C. It was determined that averaging over 7 to 14 d with minimum of 20 spot samples was needed to produce repeatable and reliable averaged CH_4 and CO_2 emissions (Manafiazar et al. 2016, Can. J. Animal. Sci. 97: 118–126).
  - The GEM and respiratory chambers were compared at the Lethbridge Research Centre. It was concluded that, when intake of animals is known, GEM offers a robust and accurate means of measuring CH_4 emissions from animals under field conditions (Alemu et al. 2017, J. Anim. Sci., 95(8):3727-3737).
  - The FTIR laser combined with inverse-dispersion micrometeorological techniques and using a narrow paddock design and a robotic motor to aim and rotate the FTIR provided a flexible and accurate method for measuring CH_4 emissions from grazing cattle (**Flesch et al. 2017, Agricultural and Forest Meteorology,** http://dx.doi.org/10.1016/j.agrformet.2017.10.012**).**
  - Enteric CH_4 emissions from high (inefficient) and low (efficient) RFI_{fat} pregnant heifers were measured using FTIR in six summer grazing trials. In five of six trials, low RFI_{fat} heifers emitted 4-13% less methane per day as compared with their high RFI_{fat} pasture mates. In addition in two fall swath grazing trials, low RFI_{fat} cows emitted 6-9% less methane per day than high RFI_{fat} cows. Low RFI_{fat} heifers and cows consumed 7.0% and 5.2%, respectively, less forage DM/day as compared with their high RFI_{fat} cohorts, and had similar methane yields (g/kg DMI).

- Enteric CH_4 and CO_2 emissions from high and low RFI_{fat} heifers and cows were measured in 13 trials using the GEM system. Low RFI_{fat} cattle emitted 1.9% to 9.7% less methane per day compared with high RFI_{fat} cattle in 7 of 8 trials where forage diets (barley or triticale silage) were fed and five of five grazing trials. Low RFI_{fat} cattle also emitted 0.6% to 5.1% less CO_2 per day compared with high RFI_{fat} cattle in 7 of 8 drylot trials and 5 of 5 grazing trials. These results are due to lower feed intake, lower CO_2 from feed fermentation and higher metabolic efficiency in low compared with high RFI_{fat} cattle**.**
- Remote sensors (GEM, GrowSafe feed intake and GrowSafe Beef® systems) were used to monitor daily animal partial body weight, water intake, drinking behaviour, feed intake, and feeding behaviours. These data were combined with climatic observations and diet quality information. GrowSafe Beef® measures partial body weights many times during the day (high frequency, HF) when the animal is consuming water. These partial body weights are then converted to whole body weight. The GrowSafe feed intake system measures individual animal feed intake and feeding behaviours in a drylot, group setting.
- Whole body weight, as measured by a manual weigh scale, was highly related to HF body weight as measured by GrowSafe Beef®, such that HF body weight accounted for 95% of the variation in manual scale body weight for pregnant heifers and 3-year old cows. A similar strong (R^2 = 0.971) linear relationship was observed between manual scale body weight and GrowSafe Beef® HF body weight for yearling heifers and mature cows in drylot during their winter feed intake test. An advantage of HF partial body weight is that a weighing episode could occur 3-4 times per day in a non-stressed environment, while manual weights are associated with moving animal to a central processing area several times during a grazing period, usually in the morning. We conclude that HF partial body weight, as measured by GrowSafe Beef®, has great potential as a non-invasive, low stress, low labor method for measuring daily body weight under grazing and drylot conditions and may also be an indirect indicator of other important traits in beef cattle.
- GrowSafe Beef® biometrics such as daily HF partial body weight, water intake, and drinking and feeding behaviours combined with climatic observations and forage quality data (25 variables) had moderate (R^2 = 0.45-0.46) predictive accuracy for daily grazed forage intake and CH_4 emissions from individual animals on pasture. In addition, daily HF partial body weight combined with other climatic observations and diet quality data had strong relationships (R^2 = 0.885 and 0.823) to animal average daily feed intake and CH_4 emissions under drylot feeding conditions.
- Genetic selection for low RFI_{fat} will result in cattle with lower feed intake at the same level of production, and reduced daily CH_4 and CO_2 emissions compared with high RFI_{fat} cattle. Selection emphasis should be placed on production efficiency traits rather than CH_4 emissions per se as combining nutritional intervention, management, breeding strategies (e.g., maintain high herd heterosis) and genetic/genomic selection are more effective in reducing enteric methane emissions and carbon footprint (30-50% reduction).

- **Project Outcomes**
  - This project quantified the mitigation potential of low-RFI cattle under conditions representative of the Alberta beef herd. In terms of the volume of measurements, the conditions in which the measurements were made, the number of techniques used, and the scientific standards that were applied, this was a world-class effort.

- The GEM system and the FTIR laser technique for measuring CH_4 and CO_2 emissions from cattle were evaluated. This resulted in the development of cutting edge FTIR methodology and rigorous scientific protocols for the GEM system. These are two less invasive, less expensive, less labor intensive and accurate methods for measuring CH_4 emission from beef cattle under on-farm conditions compared with respiratory chambers and FS_6 tracer methodology.

- A world-class team was assembled that has the expertise and techniques to measure the GHG footprint of beef cattle production. This team includes two newly trained Masters of Science students and three post-doctorate fellows, which will help to advance Alberta's leadership role in GHG mitigation.

- This project team also trained scientists from the University of Alberta that are using the GEM system to measure methane emissions in dairy cattle as part of Genome Canada's Large Scale Applied Research Program on RFI and methane emissions in dairy cattle (PI, Filippo Miglior).

- Five peer reviewed papers have already been published in the Canadian Journal of Animal Science (1), American Journal of Animal Science (1), and Agricultural and Forest Meteorology (3). Two more manuscripts are in preparation.

- Forty presentations were made by team members at conferences (17), universities to undergraduate students (6), and to industry at field day and workshops (17). In addition four YouTube videos were produced, along with two newsletter articles, seven radio interviews (e.g., Canadian Geographic, CBC radio, CBC TV) and two presentations at the Five Country Fall Forum on Climate Change, and Sustainability as related to plants and livestock genomics (CAN, NZ, USA, Ireland, Northern Ireland).
- **The team was acknowledged at the Alberta Legislative Assembly;** 23 November 2016, Members' Statement as reported by Alberta Hansard: Dr. David Bailey and Dr. John Basarab introduced at Alberta's Legislative Assembly by "The hon. Member for Leduc-Beaumont. Mr. S. Anderson, as related to genomics and GHG emissions in beef cattle.
- **The Beef Cattle Methane Emissions data base** is operational and contains more than 23,000 individual animal daily enteric CH_4 and CO_2 emissions, with daily feed intake and feeding behaviours, HF partial body weight, water intake and drinking behaviours, climatic observations and diet quality information. All cattle (~700) in this data base have 50K or LD genotypes which are being used to identify SNPs, indels (genetic mutation; insertions and deletions) and functional genomic variants associated with CH_4 emissions and yield.

- **Results provide validation for the carbon footprint of a feed efficient beef herd simulated with HOLOS by Beauchemin, Little and Basarab (2013). The simulation assumed a comprehensive genetic selection program, an annual rate of genetic progress in RFI of 0.8%, a multi-trait selection index approach and 25 year of selection.** After full selection of a beef cattle herd for RFI, the estimated GHG intensity from beef production were 14.0% lower than for the non-selected baseline herd. Due to the lower feed intake of the RFI herd, the farm area required for grazing and feed production was 13.2% lower than for the baseline herd.

3.0. Introduction and Project Overview

Alberta is among the largest beef producing region in North America, containing 42% of the beef cows and bred heifers and 70% of the beef feeding capacity in Canada (Canfax Research Services, September 2015). In addition, Alberta is the only jurisdiction in North America that has an active carbon trading registry (Alberta Carbon Offset program, July 2007, http://aep.alberta.ca/climate-change/programs-and-services/alberta-carbon-offset-system.aspx). Three protocols for reducing GHG emissions from beef cattle production have been registered with Alberta Environment, namely; 1) reducing days on feed of beef cattle, 2) reducing age at harvest of beef cattle, and 3) selection for low residual feed intake (RFI) in beef cattle. It has been estimated that reducing age at harvest in Alberta's 2.4 million feeder cattle by one month would reduce GHG emissions by 681,000 t CO2e annually (Basarab et al. 2008). Similarly, in a simulation study using the HOLOS whole farm model, Basarab et al. (2013) reported that after 25 years of selection for low RFI, GHG emissions were 0.844 t CO_2e/cow/year lower compared with the average herd, or 1.64 Mt CO_2e/year lower for Alberta's 1.945 million beef cows and bred heifers and 3.89 Mt CO_2e/year lower for Canada's 4.613 million beef cows and bred heifers. However, these model estimates are not based on rigorous emission measurements in real-world conditions. Thus the mitigation potential of low RFI herds – which looks very promising – is not actually known.

The measurement of gas emissions to the atmosphere is a difficult challenge. It is an even greater challenge in the case of livestock emissions, where animals are typically handled in a restrictive measurement environment (e.g., large chambers) or subjected to atypical management during measurement. Such "unnatural" situations alter the feeding behavior of the animals and change their emissions. To further complicate the problem, cattle emissions are not uniform over time. Because emission rates vary within and between days and seasons, measurements should simultaneously be made with high temporal resolution and over long time periods. Can cattle emissions be measured from real-world production settings, and over long enough periods to confidently understand the implications of any mitigation strategy?

Respiratory chambers are often referred to as the "gold standard" for emission measurements, with individual animals studied for 1-3 days. However, inside the chamber the animal's feed intake is reduced, feeding behaviours are altered and short-term CH_4 measurement is unlikely to reflect longer-term CH_4 emissions in real production systems (Hegarty, 2004; Harper et al., 2011). The Sulphur hexafluoride (SF6) tracer technique can be used under practical conditions but requires rumen boluses, docile animals, daily animal handling, and laboratory gas analyses and is labor intensive. The GreenFeed™ system (https://www.c-lockinc.com/ ; C-Lock Inc., Rapid City, SD, USA) is an automated, individual animal feeding or "bait" station (e.g., feed pellets) that measures carbon dioxide (CO_2; useful in estimating energy balance or efficiency) and CH_4 over 3-5 minutes, 4-5 times per day over many days. Preliminary results have reported similar CH_4 emissions (within 1-10%) from cattle as measured by respiratory chambers, GreenFeed™ and SF_6 techniques (Hammond et al. 2013; Waghorn et al. 2011). While these standard measurement techniques have advantages either in terms of simplicity or cost, historical track record and precision may be limited by animal interference, unproven accuracy, or difficulty in making multi-day measurements.

As an alternative, micrometeorological techniques offer the potential for measuring cattle emissions in real world conditions without animal handling or altering animal behavior (Harper et al, 2011). While most of these techniques are either inappropriate or difficult to adapt to the grazing environment, technological developments in the last decade have advanced a new and powerful micrometeorological technique for studying animal emissions. Open-path gas sensors coupled with inverse dispersion calculations allow the measurement of emissions with much fewer restrictions than other techniques. With an open-path sensor one measures the "fence-line" concentration in the air between the sensor and a distant reflector (e.g., 50 to 1000 m apart). Lasers and Fourier Transform Infrared Spectrophotometers are two types of open-path sensors (OP-Laser & OP-FTIR). With two fence-line measurements one can isolate a paddock and study emissions in real-world beef production settings, and with high resolution (e.g., 15-min average emission rates throughout the day). Canadian researchers have been active in the adapting open-path technology to study gas emissions from agriculture. In a collaborative project with Vern Baron of Agriculture and Agri-Food Canada (AAFC) and John Basarab with Alberta Agriculture and Forestry (AAF), John Wilson and Thomas Flesch at the University of Alberta have been deploying OP-Laser and OP-FTIR sensors to look at cattle emissions in grazing situations. The OP-Laser is a compact one-gas sensor that is environmentally robust and allows enteric methane measurements in Canadian winter conditions. Alternatively, the OP-FTIR detector has multi-gas capability, making it possible to study a suite of GHGs as well as other pertinent gases such as ammonia. The OP-FTIR also improves on the sensitivity of the laser. However, the OP-FTIR is bulkier than the laser and its winter performance is unproven.

The primary purpose of this study is to measure the CH_4 emissions from beef cattle measured for feed efficiency, specifically residual feed intake (RFI). This effort will rely on application of the new FTIR-laser technology, which will allow us to study emissions in real-world Alberta beef production situations. We will “push the envelope” on this technique towards smaller number of animals. In the past the technique has been used with groups of 10 or more animals. If we can push this down to 5-6 animals, we can focus on the extremes of RFI animals and better judge the bounds of possible CH_4 reduction due to low RFI selection.

This leads to a second objective of this project: determining the reliability of alternative CH_4 measurement techniques. Do we need the precision and repeatability of chamber measurements to identify low-emission animals? How about a “sniffer” method like GreenFeed or a biometric method like GrowSafe Beef®, with their inherent simplicity and ability to monitor individual animals? Our goal will be to identify reliable technologies.

Because even the simplest of direct emission measurement techniques is a substantial undertaking, requiring specialized equipment and expertise, can we instead estimate emissions using simple indirect measurement? A third set of objectives will be to examine the use of indirect biometrics such as feeding and water behaviours and intake in relationship to CH_4 production (g CH_4/animal/day) and yield (g CH_4/kg DMI). This aspect can be measured using GrowSafe Beef® (GrowSafe Systems Ltd., Calgary, Alberta, Canada; http://growsafe.com/).

3.1. Project goals

3.1.1. Determine the repeatability of short-term spot measurements of CH_4 and CO_2 emissions from beef cattle using GreenFeed Emissions Monitoring (GEM) system.

3.1.2. Compare CH_4 emissions from high and low RFI beef heifers using GreenFeed and respiration chambers.

3.1.3. Assess open-path concentration sensors (e.g., lasers, FTIR) and inverse-dispersion micrometeorological techniques using different field configurations for measuring methane emissions from grazing and wintering cattle.

3.1.4: Methane measurements from low (efficient) and high (inefficient) residual feed intake (RFI) heifers using Fourier-transform infrared spectroscopy (FTIR, laser).

3.1.5: Methane measurements from low (efficient) and high (inefficient) residual feed intake (RFI) heifers using GreenFeed Emissions Monitoring (GEM) System.

3.1.4. Quantify enteric methane emissions (CH_4), feed intake, RFI and various biometrics in yearling beef heifers and cows during drylot winter feeding (confinement) at the Lacombe Research and Development Centre (LRDC) and the Roy Berg Kinsella Research Station (KIN).

3.1.5: Methane measurements from low (efficient) and high (inefficient) residual feed intake (RFI) heifers using GreenFeed Emissions Monitoring (GEM) System

3.1.6. Quantification of the relationships between various daily measured biometrics and daily forage intake and methane emissions from pregnant heifers grazing summer pasture and cows grazing swathed annuals (triticale).

3.1.7. Quantify relationships of CH_4 and CO_2 emissions with feed intake, RFI and various biometrics in heifers and cows during winter drylot feeding.

3.2. Results and Discussion

Objective 3.1.1: Repeatability and variability of short-term spot measurement of methane and carbon dioxide emissions from beef cattle using GreenFeed emissions monitoring (GEM) system; published in the Can. J. Animal. Sci. 97: 118–126 (Manafiazar et al. 2017).

The purpose of this study was to determine the repeatability of CH_4 and CO_2 emissions from beef cattle using the GEM system and as affected by sampling frequency and measurement periods. Twenty-eight crossbred replacement beef heifers were monitored using the GEM system over 59 d to collect their CH_4 and CO_2 emissions data. Heifers' feed intake was recorded by eight automated feeding stations. The standardized dry matter intake (SDMI), CH_4 and CO_2 emission and yield (g/kg SDMI) were averaged over 1, 3, 7, and 14 d periods. On average, animals emitted 204.7 g/day (SD = 36 g/day) and 6408 g/day (SD = 780 g/day) of CH_4 and CO_2, respectively. Between-animal coefficients of variation for all variables decreased with an increasing averaging period (from 1 to 14 d). The coefficient of determination (R^2) between CH_4 emission and SDMI was increased from 0.25 to 0.73 as averaging period increased from 1 to 14 d. Similarly, the R^2 between CO_2 emission and SDMI increased from 0.39 to 0.79 as averaging period increased from 1 to 14 d. **It was determined that averaging over 7 to 14 d with minimum of 20 spot samples was needed to produce repeatable and reliable averaged CH_4 and CO_2 emissions and correlated with SDMI. In addition, the GEM system functioned in a feedlot environment through an Alberta winter where night time temperatures often dropped below -25 °C.**

Objective 3.1.2: Enteric methane emissions from low- and high-residual feed intake beef heifers measured using GreenFeed and respiration chamber techniques; published in J. Anim. Sci., 95(8):3727-3737 (Alemu et al. 2017).

The objectives of this study were to evaluate the relationship between RFI and enteric CH_4 production (g/d; g/kg DM) and to compare CH_4 and CO_2 emissions measured using respiration chambers (RC) and GEM system (C-Lock Inc., Rapid City, USA). Sixteen crossbred replacement heifers (8 low RFI and 8 high RFI) with mean initial BW of 377 ± 30 kg were used to measure enteric CH_4 and CO_2 emissions (g/d). Heifers were group-housed in a pen and fed barley silage *ad libitum* and their feed intakes were recorded by 5 automated GrowSafe feed intake bunks (GrowSafe Systems Ltd., Calgary, AB, Canada). Enteric CH_4 and CO_2 emissions were measured over two 25-d periods using RC (2 days/period) and GEM systems (all days when not in chambers). Metabolic BW tended to be greater ($P \leq 0.09$) for high RFI heifers but ADG tended ($P = 0.09$) to be greater for low RFI heifers. As expected, high RFI heifers consumed 6.9% more feed ($P = 0.03$) compared to their more efficient counterparts (7.1 *vs* 6.6 kg

DM/d). Average CH_4 emission was 202 and 222 g/d (*P* = 0.02) from the GEM system, and 156 and 164 g/d (*P* = 0.40) in RC for the low and high RFI heifers, respectively. When adjusted for feed intake, CH_4 yield (g/kg DMI) was similar for high and low RFI heifers (GEM: 27.7 and 28.5, *P* = 0.25; RC: 26.5 and 26.5, *P* = 0.99). However, CH_4 yield for the high RFI group (*P* = 0.01) differed for the two measurement techniques, but did not differ for the low RFI cattle (*P* = 0.13). Estimates of CO_2 yield (g/kg DMI) also differed between the two techniques ($P \leq 0.03$). Our study found that high and low efficiency cattle produce similar CH_4 yields but different daily CH_4 emissions. The two measurement techniques differ in estimating CH_4 and CO_2 emissions, partially due to differences in conditions (lower feed intakes of cattle while in chambers, fewer days measured in chambers) during measurement. **We conclude that, when intake of animals is known, GEM offers a robust and accurate means of estimating CH_4 emissions from animals under field conditions.**

Objective 3.1.3: Methane emissions from cattle grazing under diverse conditions: An examination of field configurations appropriate for line-averaging sensors; published in Agricultural and Forest Meteorology, http://dx.doi.org/10.1016/j.agrformet.2017.10.012 (Flesch et al. 2017).

Micrometeorological techniques offer the possibility of a non-interfering measurement of enteric emissions from cattle in their natural environment, where animals do not need to be encumbered or handled. However, the grazing environment is a difficult application for these techniques. This study reports on an experimental design using an inverse dispersion method (IDM) to measure enteric methane (CH_4) emissions, and its application to 15 rather distinct cattle trials in three types of feeding situations: summer grazing, winter swath grazing, and winter feeding. The IDM design was based on long and narrow animal paddocks with line-averaging sensors measuring CH4 concentration alongside the long axes of the paddock. Emissions were calculated based on the difference in concentration between the two measurement paths. The narrow paddock has many advantages for an IDM calculation: it avoids the need to monitor animal positions; it helps ensure measurable downwind concentration; and it increases the range of useable wind directions. Four different sensor configurations were used in the trials, differing in the number of concentration sensors (one or two) and sensor paths (two or four). Some configurations used sensor aiming motors to give multiple measurement paths and others used mirrors to create segmented paths (i.e., to go around a paddock corner). Cattle emissions measured with the IDM design showed good agreement across the 15 trials, consistent with high forage diets. When expressed in terms of CH4 yield (g/kg dry matter intake), the three feeding situations averaged 21.3 (summer grazing), 23.4 (winter grazing), and 23.9 (winter feeding). **Based on the trial-to-trial consistency of the results, the similarity with other literature studies, and the success of a previous tracer-release study, we conclude that the narrow paddock IDM design provides a flexible and accurate method for calculating CH_4 emissions from grazing cattle.**

Objective 3.1.4: Methane measurements from high (inefficient) vs. low (efficient) residual feed intake (RFI) heifers using open-path lasers (e.g., FTIR); manuscript in progress (Flesch et al. 2018 unpublished).

Methane emissions, daily dry matter intake (DMI), and methane yield (g CH_4 / kg DMI) from high and low RFI pregnant heifers and 3-yr old cows were measured in eight grazing trials (Tables 1 and 2). In each trial emissions were measured over five consecutive days using open-path concentration sensors (e.g., lasers, FTIR) and a micrometeorological technique as described by Flesch et al. (2017). Emissions from high and low RFI animals were measured concurrently using a robotic motor to aim sensors back and forth between high and low RFI paddocks, continuously throughout the day. Feed intake from the pregnant heifers was based on the alkane technique as described by Manafiazar et al. (2015), while feed intake of the cows was based on quadrat forage disappearance measurements. In all grazing trials (6 summer, 2 fall) a strong diurnal cycle in emissions was observed from the ensemble of 30-min measurement periods, with the highest emissions occurring during the late-morning through evening, and the lowest emissions during the early morning (Figure 1). The diurnal variability means that care is needed when estimating a daily average emission rate: a snapshot of daytime observations will overestimate the average, while the opposite would be true of a nighttime snapshot. The emission data over the multi-day trials were grouped into eight 3-h blocks covering the 24-h day (i.e., 0:00 – 3:00, 3:00 – 6:00, …), and the average emission rate from each block was summed to give the daily average rate. In five of six trials, low RFI heifers emitted 4-13% less methane per day as compared with their high RFI pasture mates (Table 1), and in two of two trials low RFI cows emitted 6-9% (mean=7.5%) less methane per day than high RFI cows (Table 2). Low RFI heifers and cows consumed 7.0% and 5.2%, respectively, less forage DM/day as compared with their high RFI cohorts, having similar methane yields (g/kg DMI). High uncertainties of CH_4 emission for 2016 Kinsella heifers (Table 1) was due poor wind conditions and few valid measurements, while high uncertainties for 2016 Lacombe cows (Table 2) was due to extremely wet fall grazing conditions.

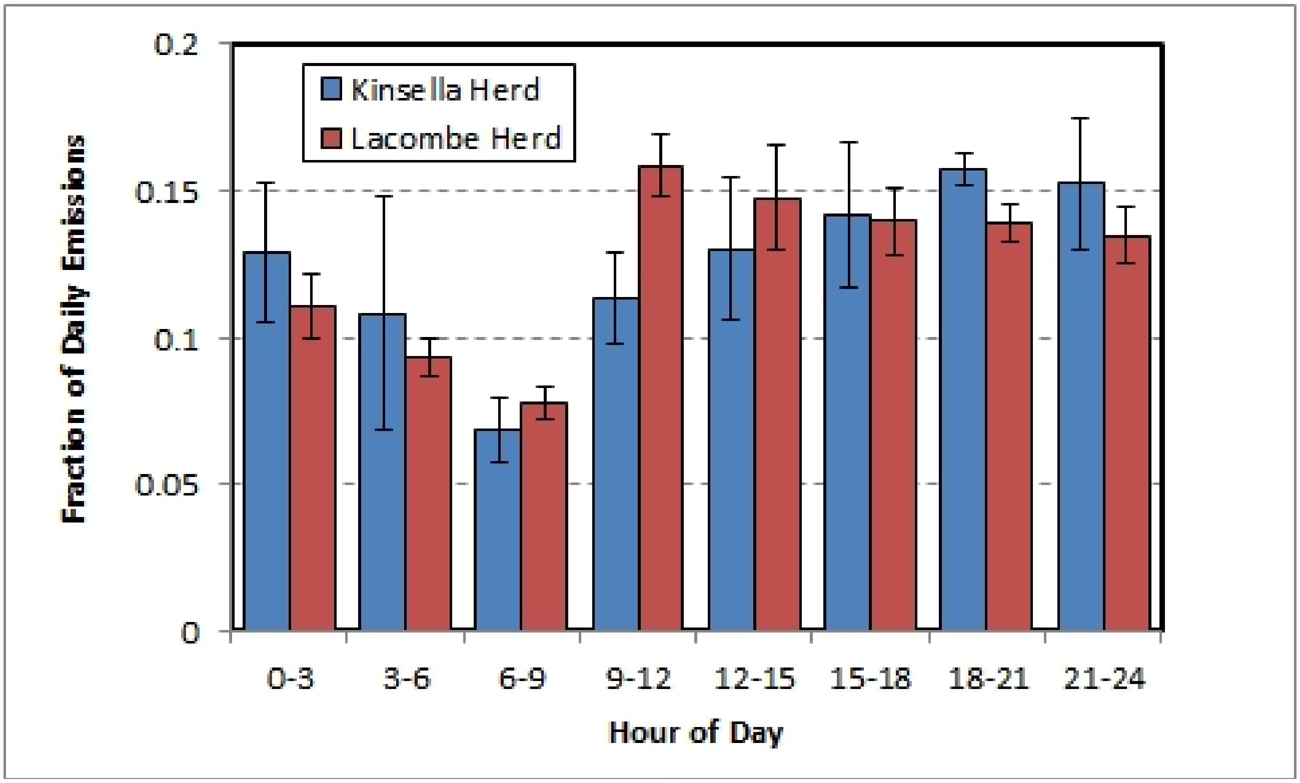


Figure 1. Daily CH_4 emission patterns for heifers from Kinsella and Lacombe grazed at the Lacombe Research and Development Centre. This is a composite of all three years of summer grazing data, combining the high and low RFI animals.

Table 1. Methane (CH_4) emission, feed intake and CH_4 yield from high and low RFI beef heifers grazing summer pasture at the Lacombe Research and Development Centre, 2015-2017.

		High RFI (inefficient)				**Low RFI (efficient)**				High to low RFI ratio	
Year and herd	Hours of obs.	n	CH_4 emission[z] g/animal/d	Feed intake[y] kg DM/d	CH_4 yield[y] g/kg DMI	n	CH_4 emission[z] g/animal/d	Feed intake[y] kg DM/d	CH_4 yield[y] g/kg DMI	CH_4 emission	CH_4 yield
2015 Kinsella	34	5	250±12	12.7	19.7	5	221±12	10.8	20.5	1.13	0.96
2015 Lacombe	37	6	268± 8	11.2	23.9	6	247±10	9.6	25.7	1.09	0.93
2016 Kinsella	22	5	310±24	12.1	25.6	5	283±25	11.8	24.0	1.10	1.07
2016 Lacombe	49	5	265±10	11.5	23.0	5	268±9	11.2	23.9	0.99	0.96
2017 Kinsella	30	4	208±11	12.0	17.3	4	188±7	11.8	15.9	1.10	1.09
2017 Lacombe	24	3	300±24	9.7	30.9	3	288±18	9.2	31.3	1.04	0.99
Overall mean				11.5				10.7		1.08±0.05	1.00±0.07

[z] Numbers are ± standard error. [y] Feed intake was based on the alkane technique as described by Manafiazar et al. (2015).

Table 2. Methane (CH_4) emission, feed intake and CH_4 yield from high and low RFI 3-yr old beef cows grazing triticale swaths in the fall (October) at the Lacombe Research and Development Centre.

		High RFI (inefficient)				**Low RFI (efficient)**				High to low RFI ratio	
Year and herd	Hours of obs.	n	CH_4 emission[z] g/animal/d	Feed intake[y] kg DM/d	CH_4 yield[y] g/kg DMI	n	CH_4 emission[z] g/animal/d	Feed intake[y] kg DM/d	CH_4 yield[y] g/kg DMI	CH_4 emission	CH_4 yield
2015 Lacombe	25	9	222 ± 15	9.4	23.6	9	209 ± 11	8.7	24.0	1.06	0.98
2016 Lacombe	18	6	275 ± 40	13.5	20.4	6	253 ± 26	13.1	19.3	1.09	1.06
Overall				11.5				10.9		1.075	1.02

[z] Numbers are ± standard error. [y] Feed intake was based on quadrat disappearance measurements.

Objective 3.1.5: Methane measurements from low (efficient) and high (inefficient) residual feed intake (RFI) heifers using GreenFeed Emissions Monitoring (GEM) System.

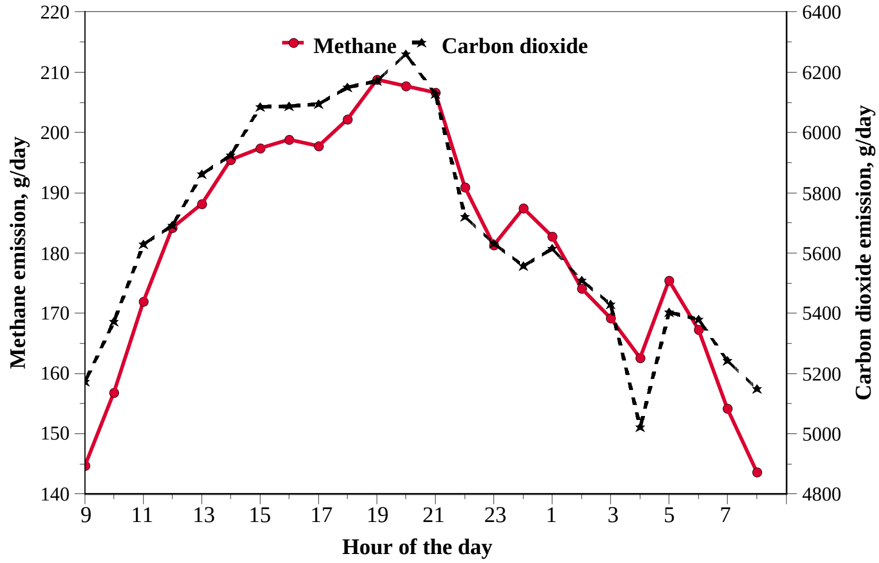
Twenty-three (23) trials were conducted from 2015-2017 and included crossbred yearling heifers and cows from the Lacombe Research and Development Centre (LRDC), and Roy Berg Kinsella Research Station. Average daily CH_4 and CO_2 emissions for yearling heifers during winter feeding as recorded by the GEM system were 182.0 g CH_4/day (SD=45.8, n=8725 animal days) and 5824 g CO_2/day (SD=1558, n=8725 animal days). Similar values for pregnant heifers grazing summer pasture were 239.3 g CH_4/day (SD=46.7, n=674 animal days) and 8103 g CO_2/day (SD=1329, n=674 animal days), while mature cows in winter drylot emitted 229.2 g CH_4/day (SD=68.1, n=5411 animal days) and 7925 g CO_2/day (SD=1791, n=5411 animal days). Three-year old cows grazing triticale swaths in the fall emitted 200.9 g CH_4/day (SD=54.1, n=529 animal days) and 6847 g CO_2/day (SD=1555, n=529 animal days). Thus, considerable variability was observed in daily CH_4 and CO_2 emissions due to animal, diet quality, animal type, and feed efficiency group, thus suggesting potential for genetic and genomic selection for reduced CH_4 emissions.

Diurnal patterns for CH_4 and CO_2 in beef cattle

Daily CH_4 and CO_2 emissions were averaged across animals within drylot, summer grazing, and swath grazing trial by hour of day to generate diurnal patterns (Figures 2-5). Methane and CO_2 emissions for heifers fed a high forage diet in drylot begin to increase rapidly around 9 am, coinciding with feed delivery to the pen bunks at 0830 to 0900 hours (Figure 2). Peak emissions occurred between 1800-2200 hours due to second feed delivery around 1530-1630 hr. Peak CH_4 and CO_2 emissions for pregnant heifers grazing high quality grass pasture occurred around 0900-1000 hours and this was likely associated with initiation of daily grazing around sunrise which at LRDC in August occurred between 0556 to 0645 hours (Figure 3). Peak CH_4 and CO_2 emissions for cows fed triticale silage in drylot occurred between 1200 and 1700 hours which was primarily driven by feed delivery to the cows at 0830-0900 hours (Figure 4). Cows grazing swathed triticale in the fall exhibited peak emission around 1200-1400 hours, which was initiated by the beginning of daily grazing coinciding with sunrise which at LRDC in October occurs at 0737 to 0830hours (Figure 5). These diurnal patterns and their associated equations will be useful in further refinement to the procedure for calculating daily emissions from 3-5 min visit measurements. Presently visit measurements for 3-hour intervals within a day (0-0300, 0300-6000, …) are averaged and then the interval are averaged to obtain daily emissions.

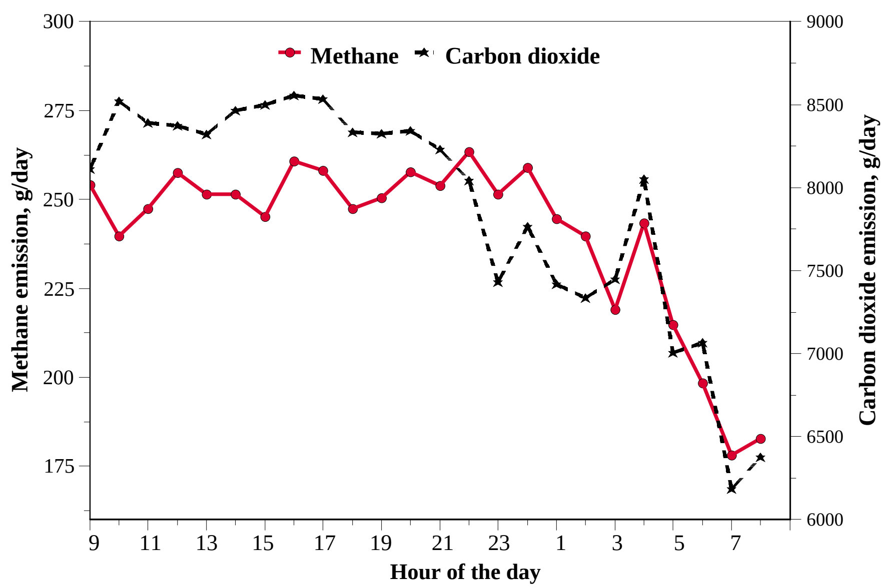
As expected, the CO_2 emissions were less variable than CH_4 emissions because the primary source of CO_2 is related to metabolic energy requirements that remain more stable compared with ruminal gas emissions that vary with feed intake, diet composition, and feeding strategy (Jentsch et al. 2009; Hegarty, 2013; Knapp et al. 2014). Our results of CH_4 emission pattern are comparable with previous studies. For example, Crompton et al. (2010) performed controlled experiments in open-circuit respiration chambers to continuously measure CH_4 emissions from lactating cows fed at different intervals. They reported variability that for once a day feeding, variability in diurnal pattern was 2.5; however, this decreased to 1.6 when animals were fed four times a day. In other studies, with ad libitum fed diets, CH_4 variability of diurnal pattern varied from 1.8 (Jonker et al. 2014) to 2.0 (Grainger et al. 2007). In a review of variability of diurnal CH_4 patterns using the GEM system, Zimmerman et al. (2013) reported values ranging from 1.2 to 1.6. More variable CH_4 diurnal patterns have been noted in chamber studies (up to 5.0), but diurnal patterns are associated with restricted feed intake or pelleted concentrate diets (Jonker et al. 2014) because CH_4 emission is affected by the amount and type of feed and time of feeding. Overall, CH_4 and CO_2 emission patterns from cattle vary depending on rate of methanogens which is a function of time and level of feeding, type of feed, and short-term sporadic emission of gas released from the rumen (Hegarty 2013).

Figure 2. Diurnal distribution of enteric methane and carbon dioxide emissions from replacement beef heifers fed a high forage diet in drylot as measured by the GEM system.



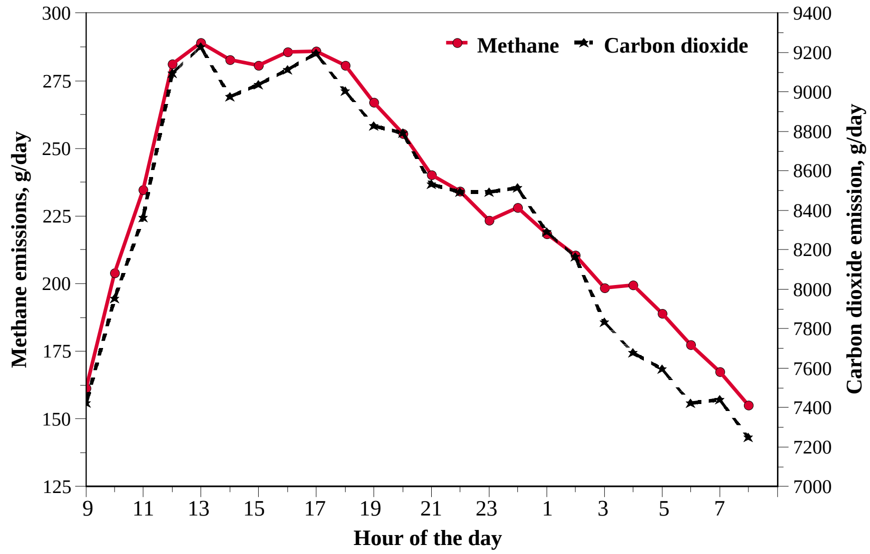
Diurnal patterns are represented by the following equations:
CH_4: y=145.38±4.06 + 14.8390±1.5613x – 1.1208±0.1597x^2 + 0.0212±0.0046x^3, R^2= 0.924, RMSE=5.77, n=26753. CO_2: y = 5095±91 + 301.87±35.01x – 26.24±3.58 x^2 + 0.58±0.01x^3, R^2=0.893, RMSE=129.30, n=26753; x refers to hour of the day where 9=0 hours in the equation.

Figure 3. Diurnal distribution of enteric methane and carbon dioxide emissions from pregnant beef heifers grazing high quality meadow brome grass as measured by the GEM system.



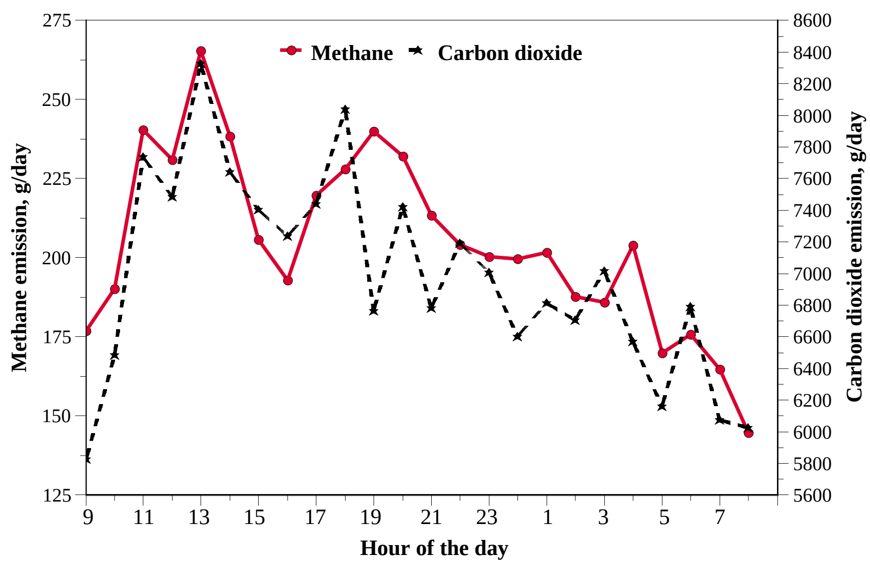
Diurnal patterns are represented by the following equations:
CH_4: y=249.89±5.76 – 1.3500±2.2162x + 0.4240±0.2267x^2- 0.0222±0.0065x^3, R^2= 0.899, RMSE= 8.18, n=3504. CO_2: y=8276±150 + 66.98±30.12x – 6.47±1.26x^2, R^2= 0.867, RMSE= 271.24, n=3504; x refers to hour of the day where 9 = 0 hours in the equation.

Figure 4. Diurnal distribution of enteric methane and carbon dioxide emissions from cows fed a forage diet in winter drylot as measured by the GEM system.



Diurnal patterns are represented by the following equations:
CH_4: y = 180.21±9.07 + 33.1970±3.4914x – 3.0748±0.3572x^2 + 0.0703±0.0102x^3, R^2=0.925, RMSE = 12.89, visit fluxes = 11913. CO_2: y = 7641±126 + 458.56±48.38x – 40.99±4.95 x^2 + 0.89±0.14x^3, R^2=0.934, RMSE = 178.66, visit fluxes=11913; x refers to hour of the day where 9 = 0 hours in the equation.

Figure 5. Diurnal distribution of enteric methane and carbon dioxide emissions from cows grazing triticale swaths during the fall as measured by the GEM system.



Diurnal patterns are represented by the following equations:
CH_4: y = 196.58±12.86 + 10.4542±4.95x – 0.9373±0.5061x^2 + 0.0179±0.0145x^3, R^2=0.643, RMSE = 18.27, visit fluxes = 1365. CO_2: y = 6418±305 + 395.04±117.17x – 37.78±11.99 x^2 + 0.89±0.34x^3, R^2=0.602, RMSE = 432.69, visit fluxes=1365; x refers to hour of the day where 9 = 0 hours in the equation.

Methane and CO_2 emissions from beef cattle using the GEM system

Performance, feed intake, and CH_4 and CO_2 production as measured by the GEM system for yearling heifers during winter feeding (9 trials), cows during winter feeding (6 trials), and pregnant heifers during summer grazing (6 trials) are summarized in Table 3. Average feed efficiency of low and high RFI_{fat} cattle of different animal types differed by 0.76 to 1.24 kg DM/day (P<0.001) at equal levels of body weight, gain and backfat thickness. Age on test, mid-point body weight during test period (except drylot cows) and off-test backfat thickness were similar between low and high RFI_{fat} groups across all animal types. Efficient animals (low RFI_{fat}) consistently consumed less feed (8.9% for yearling heifers; 10.1% for cows; 5.1% for pregnant heifers on pasture) as compared with their inefficient (high RFI_{fat}) pen or pasture mates (P<0.001). This consistency is clearly illustrated in Figure 6, where the n-alkane tracer method was used to estimate individual animal grazed forage intake from Day 8-12 of a 12-day grazing trial.

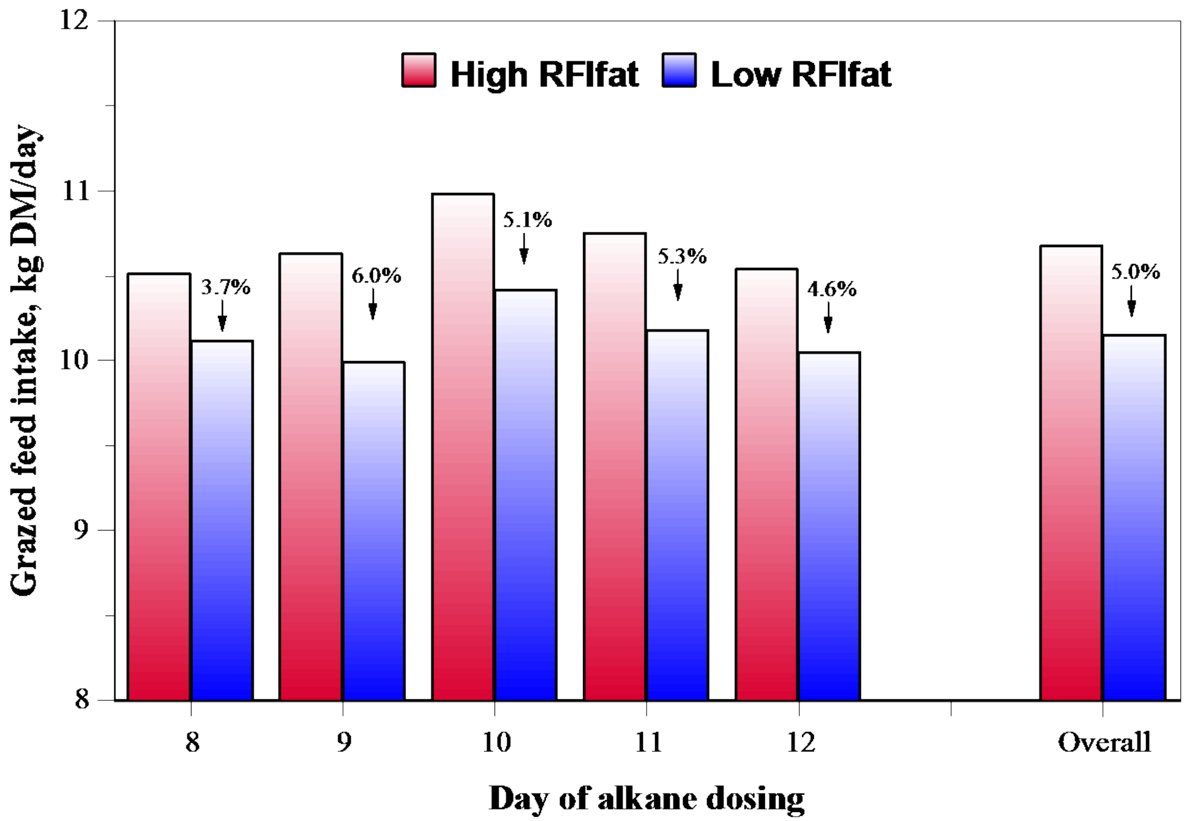


Figure 6. Forage intake of high and low RFI_{fat} pregnant heifers grazing meadow brome grass over three summers at LRDC (summary of 6 trials and 60 heifers from LRDC and 60 from KIN).

Low RFI_{fat} yearling heifers and cows in winter drylot and pregnant heifers during summer grazing emitted 3.8%, 4.1% and 3.7% less CH_4 per day, respectively, than their high RFI_{fat} pen or pasture mates (Table 3). In addition, low RFI_{fat} yearling heifers and cows in winter drylot and pregnant heifers during summer grazing emitted 2.2%, 4.2% and 4.5% less CO_2 per day, respectively, as compared to high RFI_{fat} cattle. This reflects lower feed intake and possibly lower metabolic rate in low vs. high RFI_{fat} cattle in this study. A portion of the lower CH_4 emissions (g/day) in efficient cattle is offset by longer rumen retention time, improved digestibility (1-2 percentile points previously report in the literature), and more hydrogen ions available for methanogenesis. This is shown by the higher CH_4 and CO_2 yields (g/kg DMI) in low vs. high RFI_{fat} yearling heifers and cows in winter drylot, but not in pregnant heifers grazing summer pastures.

Table 3. Performance, feed intake and methane and carbon dioxide production of yearling heifers, cows, and pregnant heifers summarized over 21 trials.

Trait	RFI_{fat} group	Drylot- yearling heifers	Drylot- Cows	Pasture Intake- Pregnant heifers
Number of trials	21	9	6	6
Number of animals	High	156	57	60
	Low	137	58	60
RFI_{fat}, kg DM/d	High	0.39±0.03	0.54±0.05	0.59±0.04
	Low	-0.37±0.03	-0.45±0.05	-0.65±0.04
	P level	<0.001	<0.001	<0.001
On-test age, mon	High	9.5±0.04	53.2±0.3	16.2±0.1
	Low	9.6±0.05	53.3±0.3	16.3±0.1
	P level	0.400	0.582	0.756
Test mid-point weight, kg	High	352.2±2.3	681.9±4.6	462.8±3.8
	Low	349.8±2.6	672.1±4.9	459.8±3.8
	P level	0.486	0.033	0.597
Off-test backfat, mm	High	6.0±0.1	10.05±0.3	7.6±0.2
	Low	5.6±0.2	10.1±0.3	7.5±0.2
	P level	0.073	0.088	0.807
Feed intake, kg DM/d	High	8.23±0.07	13.32±0.06	10.75±0.09
	Low	7.50±0.08	11.98±0.06	10.20±0.09
	P level	<0.001	<0.001	<0.001
CH_4 emission, g/d	High	185.3±0.8	245.8±1.5	248.7±3.0
	Low	178.2±1.9	235.8±1.4	239.4±2.8
	P level	<0.001	<0.001	0.045
CO_2 emission, g/d	High	5722±19	8535±35	7950±84
	Low	5596±21	8173±34	7591±82
	P level	<0.001	<0.001	0.002
CH_4 yield, g/kg DMI	High	22.9±0.2	19.2±0.2	23.3±0.4
	Low	24.2±0.2	20.7±0.2	23.8±0.3
	P level	<0.001	<0.001	0.355
CO_2 yield, g/kg DMI	High	707±5	662±4.7	745±10
	Low	759±5	711±4.5	754±10
	P level	<0.001	<0.001	0.608

Respiratory chamber (Alemu et al. 2017) and FTIR (Flesch et al. 2018 unpublished) results from some of these same cattle reported no difference in CH_4 yields between low vs. high RFI_{fat} yearling heifers in drylot or pregnant heifers during summer grazing.

Forage intake of 3-yr old cows during two swath grazing trials (20 cows per year) was not reported for several reasons: 1) field conditions during the fall of 2016 were very wet resulting in cattle tramping the swaths into the ground and muddy holes developing in front of the GEM system and, 2) the alkane profiles of swath triticale heads and stems were very different, thus negating the usefulness of the n-alkane methodology to estimate grazed forage intake. This in itself was a valuable result and will result in the publication of a paper on "Alkane profiles in fall grazed annuals".

In conclusion, low RFI_{fat} animals consume less feed at equal levels of body weight and production, emit less CH_4 and CO_2 (g/day), but may have variable CH_4 and CO_2 yields (g/kg DMI) depending on their physiological stage and diet (e.g., grazing high quality summer pasture, consuming barley silage during winter feeding). **Thus genetic selection for low RFI_{fat} will result in cattle with lower feed intake at the same level of production, and reduced daily CH_4 and CO_2 emissions without comprising production traits, though methane and carbon dioxide yield per unit of feed may increase due to improved digestibility. Selection emphasis should be on production efficiency traits rather than CH_4 emissions per se as nutritional intervention, management and breeding strategies are shorter term and more effective in reducing the carbon footprint of beef production.**

Objective 3.1.6: Quantification of the relationships between various daily measured biometrics and daily forage intake and methane emissions from pregnant heifers grazing summer pasture and cows grazing swathed annuals (triticale).

The objective of this study was to determine whether daily high frequency (HF) partial body weight, water intake, drinking behaviors and daily climatic variables could be used to predict individual animal daily feed intake and methane emissions of grazing cattle. Daily HF partial body weight, water intake and drinking behaviours (duration, headdown time and frequency) were measured using the GrowSafe Beef® System (http://www.growsafe.com/) and climatic data were obtained for LRDC and KIN from AAF's Current and Historical Alberta Weather Station Data Viewer (http://www.agric.gov.ab.ca/acis/alberta-weather-data-viewer.jsp). Twenty pregnant beef heifers per year for three years from LRDC, 20 pregnant beef heifers per year for three years from KIN, and 20 and 12 cows per year from LRDC were used. Thus a total of six short duration (12 days) summer grazing trails with pregnant heifers were conducted at LRDC in 2015, 2016 and 2017, and two short duration fall grazing trails with 3-year old cows were conducted at LRDC in 2015 and 2016. Summer grazing trials are as described in detail by Manafiazar et al. (2015). Descriptive statistics by trial are given in Table 4 for manual scale whole body weight and HF partial body weight, and shows that a maximum of 456 possible manual scale weights are available for correlation to HF partial body weights.

Table 4. Descriptive statistics on number of manual scale whole body and high frequency partial body weights taken during eight grazing trails conducted at Lacombe Research and Development Centre[z].

Trial[y]	No. of cattle	Days on test	Possible no. of manual scale weights[x]	Total no. of high frequency partial body weights		High frequency partial body weight, kg		
				Possible	Actual	Mean (SD)	min	max
KIN-15-h	20	12	60 (3)	240	209	407.5 (23.4)	350.1	471.3
LRDC-15-h	20	12	60 (3)	240	240	470.3 (27.7)	406.6	540.2
KIN-16-h	20	12	60 (3)	240	198	433.6 (34.6)	364.0	541.2
LRDC-16-h	20	12	60 (3)	240	217	488.4 (29.5)	420.2	568.6
KIN-17-h	20	12	60 (3)	240	128	392.0 (26.0)	302.5	441.1
LRDC-17-h	20	12	60 (3)	240	163	464.8 (35.6)	397.7	542.5
LRDC-15-c	20	12	60 (3)	240	158	630.2 (52.9)	524.1	742.9
LRDC-16-c	12	12	36 (3)	144	91	603.0 (33.8)	500.8	665.1

[z] A Morand chute with load bars and a Reliable Scale M75 scale head as used for manual scale weights, while high frequency partial body weights were taken with the GrowSafe Beef® system (GrowSafe Systems Ltd., Calgary, AB, Canada).
[y] Trials are described by source of animal (LRDC, KIN), year (2015-2017) and animal type (h=heifer; c=cow).
[x] Numbers in parenthesis refer to scale weights per animal.

Figure 7 illustrates a strong (R^2 = 0.95) linear relationship between whole body weight and HF partial body weight for pregnant heifers and 3-yr old cows, such that HF partial body weight accounted for 95% of the variation in manual scale body weight. High frequency partial body weight was consistently higher than manual body weight by 10-20 kg, and likely reflects lower gut fill associated with manual weighing due to the stress of moving cattle off pasture and through a processing facility. Since animals usually begin grazing at sunrise (August at LRDC, 0556-0646 hours), this results in more and variable gut fill loss when the animals are weighed sometimes around 0830-0930 hours. An advantage of HF partial body weight is that a weighing episode could occur 3-4 times per day in a non-stressed environment. A similar strong (R2 = 0.971) linear relationship was observed between whole body weight and HF partial body weight for yearling heifers and mature cows in drylot during their winter feed intake test. **Thus, HF partial body weight, as measured by GrowSafe Beef®, has great potential as a non-invasive, low stress, low labor method for measuring daily body weight under grazing condition and may also be an indirect indicator of other important traits in beef cattle (feed intake, methane emissions).**

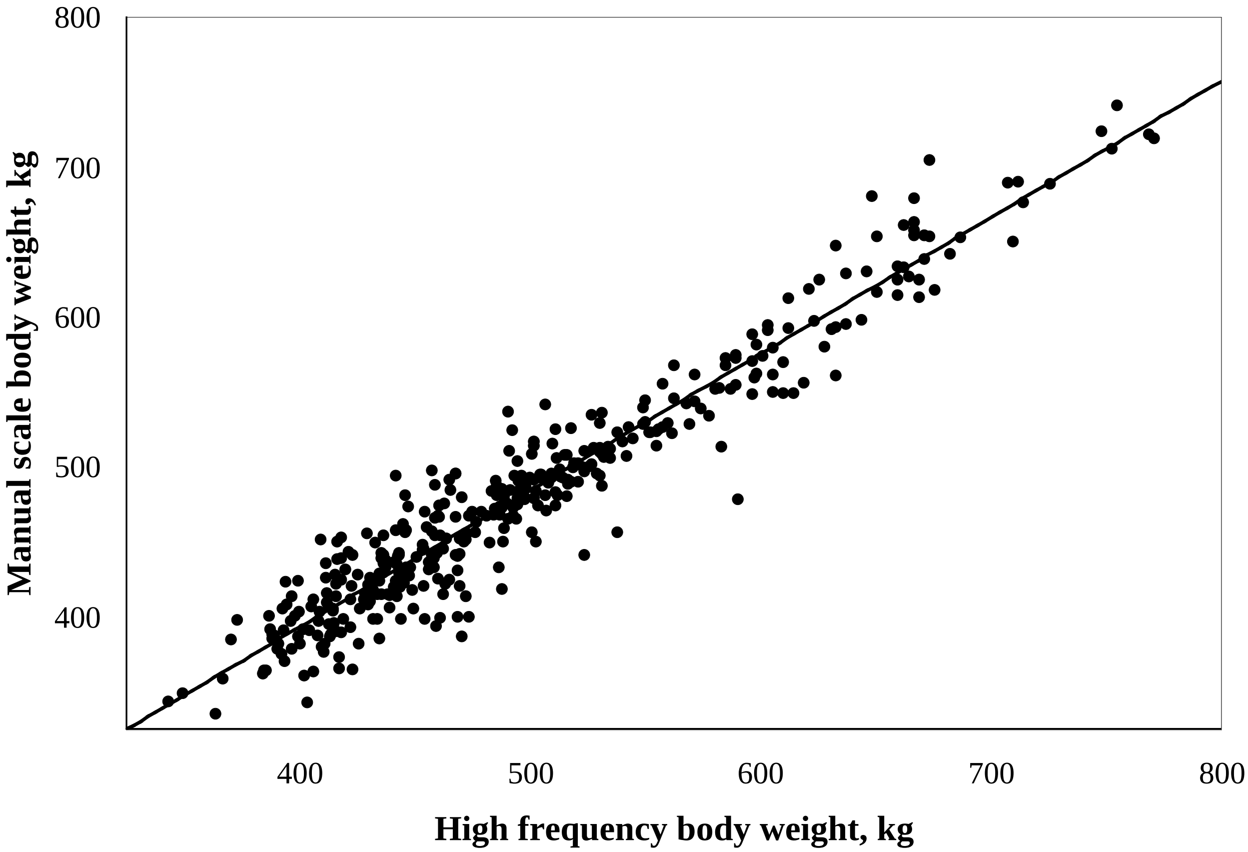


Figure 7. Relationship between body weight recorded by a manual scale vs. high frequency partial body weight recorded by the GrowSafe Beef® system during 8 grazing trials from 2015-2017 (6 pregnant heifer grazing trials; 2 cow swath grazing trials; Day 0, Day 8, Day 12 and end manual body weights). Y = -10.23±6.01 + 1.0509±0.0120x, n = 383, R^2 = 0.952, RMSE = 18.67.

Predicting of heifer grazed forage intake and CH_4 emissions: Phenotypic correlation coefficients (r_p) between daily measured biometrics from the GEM and GrowSafe Beef® systems and individual animal daily forage intake and CH_4 emissions are given in Table 5. These correlation coefficients are combined with daily mean climatic and forage quality variables. Noteworthy, are the relationships between grazed forage intake and CO_2 emission (r_p = 0.23), drinking event frequency (r_p = -0.17), and daily climatic variables (r_p = 0.22-0.24), and CH_4 emissions and daily HF partial body weight (r_p = 0.41) and several daily climatic variables. Multiple stepwise linear regression analysis revealed that four of 25 variables accounted for 45.9% of the variation in animal average daily grazed forage intake, and four of 25 variables accounted for 44.7% of the variation in animal average daily CH_4 emissions (Table 6). **These results indicate that several daily measured biometrics such as daily HF partial body weight, water intake, climatic observations and forage quality data may have use in predicting daily grazed forage intake and CH_4 emissions of individual animals. However, it must be cautioned that forage intake was**

only measured for 5 days on 118 animals using the alkane tracer technique. Other variables such as dry matter yield and forage allocation (area grazed) may provide extra information for predicting grazed forage intake and CH_4 emissions.

Table 5. Correlation coefficients between various biometrics measured daily using remote sensors supplemented with daily climatic and forage quality data, and daily forage intake and methane emissions from pregnant heifers grazing summer pasture[z].

Parameters	Grazing feed intake kg DM/d			CH_4 emission g/d		
	n	r	Sign.	n	r	Sign.
Heifer RFI_{fat}, kg DM/d	512	0.18	<0.001	3205	0.04	0.041
GreenFeed Emissions Monitoring System						
CH_4 emission, g/d	512	0.11	0.010	-----	-----	------
CO_2 emission, g/d	512	0.23	<0.001	3205	0.44	<0.001
CH_4/CO_2 ratio	512	0.10	0.029	3205	-0.60	<0.001
CH_4 yield, g/kg DM/d	512	-0.51	<0.001	512	0.78	<0.001
CO_2 yield, g/kg DM/d	512	-0.53	<0.001	512	0.32	<0.001
Visits, visits/d	512	0.05	0.271	3205	0.05	0.010
Visit time, min/d	512	0.08	0.088	3205	0.07	<0.001
GrowSafe Beef® **System**						
Daily HF weight, kg	468	0.10	0.033	3022	0.41	<0.001
Water intake, L/d	402	0.03	0.510	2676	-0.01	0.677
Drinking event duration, min/d	402	-0.10	0.037	2676	0.02	0.326
Drinking event headdown, min/d	402	-0.02	0.636	2676	0.04	0.038
Drinking event frequency, events/d	402	-0.17	<0.001	2676	-0.05	0.006
Daily mean climatic variables						
Daily air temperature, ^oC	505	0.02	0.587	3197	-0.19	<0.001
Daily air temperature max., ^oC	505	-0.07	0.114	3197	-0.14	<0.001
Daily air temperature min., ^oC	505	0.24	<0.001	3197	-0.22	<0.001
Daily humidity, %	505	0.22	<0.001	3197	-0.00	0.838
Daily wind speed, km/hr	296	0.13	0.020	1719	0.21	<0.001
Daily precipitation, mm	505	0.23	<0.001	3197	-0.06	<0.001
Forage quality variables						
Dry matter, %	505	-0.17	<0.001	1458	0.07	0.005
Crude protein (CP), %	505	0.16	<0.001	1458	-0.15	<0.001
Acid detergent fiber (ADF), %	505	0.02	0.711	1458	0.14	<0.001
Neutral detergent fiber (NDF), %	505	0.03	0.505	1458	0.03	0.315
Total digestible nutrients (TDN)[y], %	505	-0.02	0.699	1458	-0.14	<0.001
Metabolizable energy[x], MJ/kg DM	505	-0.02	0.695	1458	-0.14	<0.001

[z] Remote sensors used were GreenFeed Emission Monitoring GrowSafe Beef® systems

[y] TDN, % = 96.03 – [1.034 x ADF, %].

[x] ME, MJ kg^{-1} DM = {(TDN,%/100) x 4.4 Mcal kg^{-1} TDN} x 4.184 MJ DE $Mcal^{-1}$ x 0.82 MJ ME MJ^{-1} DE (NRC 1996).

Table 6. Linear effects between variables measured daily using remote sensors combined with daily climatic observations and diet quality information, and daily forage intake and methane emissions from pregnant heifers grazing meadow brome grass[z].

Variables	Daily forage intake, kg DM/d		Variables	CH_4 emission g/d	
	Effects±SE	Sign.		Effects±SE	Sign.
HF partial weight, kg	0.010±0.003	0.001	HF weight, kg	0.477±0.107	<0.001
Heifer RFI_{fat}, kg DM/d	0.388±0.121	0.002	Water intake, L/d	0.751±0.399	0.063
Air temperature, ^oC	-0.359±0.194	0.068	Daily precipitation, mm	14.87±7.38	0.047
Diet NDF, %	-0.245±0.141	0.085	Diet DM, %	-2.748±1.146	0.019
Overall equation R^2	0.459	<0.001	Overall equation R^2	0.447	<0.001

[z] Remote sensors used were GreenFeed Emission Monitoring and GrowSafe Beef® systems.
Data were adjusted for contemporary group or trial. Variables exited the regression analysis when P >0.10.

3.1.7. Quantify relationships of CH_4 and CO_2 emissions with feed intake, RFI and various biometrics in heifers and cows during winter drylot feeding.

Predicting of heifer and cow feed intake and CH_4 emissions during winter drylot feeding: Phenotypic correlation coefficients (r_p) between daily measured biometrics from the GEM and GrowSafe Beef® systems and individual animal daily feed intake and CH_4 emissions from heifers and cows during winter drylot feeding are given in Table 7. These correlation coefficients are combined with daily mean climatic observations and diet quality information. Noteworthy, are the moderate to high relationships between feed intake and CH_4 and CO_2 emission (r_p = 0.51 and 0.61), daily HF partial body weight (r_p = 0.85), and feeding event duration (r_p = 0.42). Methane emissions were most highly related to CO_2 emission, and daily HF partial body weight (r_p = 0.69). Multiple linear regression analysis revealed that three of 29 variables accounted for 88.5% of the variation in animal average daily feed intake, and three of 29 variables accounted for 82.3% of the variation in animal average daily CH_4 emissions (Table 8). **These results indicate that daily HF partial body weight combined with other observations (e.g., climatic) may be useful in predicting average animal daily feed intake and CH_4 emissions under drylot feeding conditions.**

Table 7. Correlation coefficients between various biometrics measured daily using remote sensors[z] supplemented with climatic observations and diet quality information and daily feed intake and methane emissions from beef heifers and cows during winter dylot feeding (15 trials).

Parameters	Feed intake kg DM/d			CH_4 emission g/d		
	n	r	Sign.	n	r	Sign.
Heifer RFI_{fat}, kg DM/d	10542	0.11	<0.001	12990	0.02	0.011
GrowSafe Feed Intake Systems						
Feeding event duration, min/d	11022	0.42	<0.001	11026	0.15	<0.001
Feeding event headdown time, min/d	11022	0.28	<0.001	11026	0.06	<0.001
Feeding event frequency, events/d	11022	-0.00	0.826	11026	-0.07	<0.001
GreenFeed Emissions Monitoring System						
CH_4 emission, g/d	11022	0.51	<0.001	-----	-----	------
CO_2 emission, g/d	11022	0.66	<0.001	13618	0.73	<0.001
CH_4/CO_2 ratio	11022	0.23	<0.001	13618	-0.33	<0.001
CH_4 yield, g/kg DM/d	11022	-0.48	<0.001	11022	0.29	<0.001
CO_2 yield, g/kg DM/d	11022	-0.39	<0.001	11022	0.16	<0.001
Visits, visits/d	11022	-0.14	<0.001	13609	-0.09	<0.001
Visit time, min/d	11022	-0.16	<0.001	13618	-0.09	<0.001
GrowSafe Beef® system						
Daily HF weight, kg	2191	0.85	<0.001	2250	0.69	<0.001
Daily HF metabolic weight, kg	2191	0.85	<0.001	2250	0.69	<0.001
Water intake, L/d	na	na	na	na	na	na
Drinking event duration, min/d	1798	-0.34	<0.001	1856	-0.26	<0.001
Drinking event headdown, min/d	1798	-0.31	<0.001	1856	-0.24	<0.001
Drinking event frequency, events/d	1798	-0.30	<0.001	1856	-0.26	<0.001
Daily mean climatic variables						
Daily air temperature, ^oC	11022	-0.15	<0.001	12410	0.11	<0.001
Daily air temperature max., ^oC	11022	-0.19	<0.001	12410	0.09	<0.001
Daily air temperature min., ^oC	11022	-0.13	<0.001	12410	0.11	<0.001
Daily humidity, %	11022	0.02	0.099	12410	-0.10	<0.001
Daily wind speed, km/hr	10639	0.12	<0.001	12023	0.05	<0.001
Daily precipitation, mm	11022	0.01	0.129	12410	0.00	0.882
Forage quality variables						
Dry matter, %	11022	-0.16	<0.001	12588	0.09	<0.001
Crude protein (CP), %	11022	-0.08	<0.001	12588	-0.16	<0.001
Acid detergent fiber (ADF), %	11022	0.03	<0.001	12588	0.10	<0.001
Neutral detergent fiber (NDF), %	11022	-0.07	<0.001	12588	-0.01	0.412
Total digestible nutrients (TDN)[z], %	11022	-0.25	<0.001	12588	-0.22	<0.001
Metabolizable energy[y], MJ/kg DM	11022	-0.25	<0.001	12588	-0.22	<0.001

na The GrowSafe Beef® system in drylot was positioned in front of and tight to a Richie waterer and measured individual animal partial body weight, duration, headdown time and frequency of drinking episodes.

Table 8. Linear effects between variables measured daily using remote sensors combined with daily climatic observations and diet quality information, and daily feed intake and methane emissions from heifers and cows during winter drylot feeding[z].

Variables	Daily forage intake, kg DM/d		Variables	CH_4 emission g/d	
	Effects±SE	Sign.		Effects±SE	Sign.
HF body weight, kg	-0.036±0.026	<0.001	HF body weight, kg	-1.342±0.494	<0.001
HF body weight $^{0.75}$, kg	0.318±0.162	<0.001	HF body weight $^{0.75}$, kg	9.533±3.240	<0.001
Daily humidity, %	-0.031±0.015	<0.001	Feed intake, kg DM/d	7.455±2.831	<0.001
Overall equation R^2	0.885	<0.001	Overall equation R^2	0.823	<0.001

[z] Remote sensors used were GreenFeed Emission Monitoring and GrowSafe Beef® systems.
Data were adjusted for contemporary group or trial Variables exited the regression analysis when P >0.10.

Predicting of trial feed intake and CH_4 emissions:
Individual animal daily biometrics such as HF partial body weight, water intake, drinking and feeding behaviours, climatic observations and diet quality information may also be useful in predicting trail average feed intake and CH_4 emissions. This has practical use for grazing situations where measuring feed intake and CH_4 emissions are difficult, laborious and expensive. The relationship between trial average CO_2 emission and trial average daily feed intake in 20 trials is shown in Figure 8. Trial average CO_2 emission accounted for 70.2% of the variation in trial average DMI. This relationship is described by the following equation:
Trial DMI, kg DM/day = 1.87±1.29 + 0.0012±0.0002x, R^2 = 0.702, RMSE = 1.23, n=20 trials.

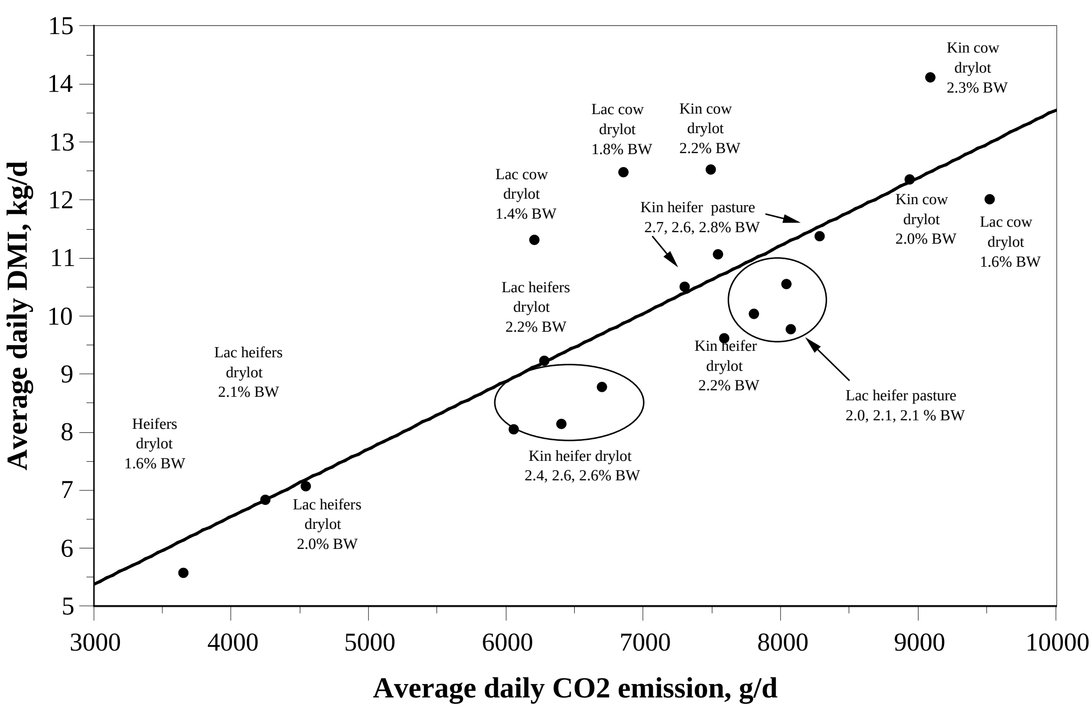


Figure 8. Relationship between trial average feed intake and trial average carbon dioxide emissions in beef heifers and cows over 20 trials conducted at the Lacombe Research and Development Centre and the Roy Berg Kinsella Research Station.

Addition of HF partial body weight to the equation increased the amount of variation accounted for to 84.6%, where, Trial DMI, kg DM/day = 0.88±0.98 + 0.0008±0.0002 (CO_2, g/day) + 0.0069±0.0017 (HF body weight, kg), R^2 = 0.846, RMSE=0.92, n=20 trials.

Alternatively, HF partial body weight (partial R^2 = 0.587), diet ADF (partial R^2 = 0.113) and diet NDF (partial R^2 = 0.137) accounted for 83.7% of the variation in trial average daily feed intake.

Prediction of trial average CH_4 emissions also showed promise with trial average DMI accounting for 55.4% of the variation in trial average CH_4 emission (Figure 9). This relationship is described by the following equation: Trial CH_4, g/day = 82.06±29.43 + 13.50±2.86x, R^2 = 0.554, RMSE = 27.37, n=20 trials.

Addition of HF partial body weight to the equation accounted for 83.3% of the variation in trial average CH_4 emission, where Trial CH_4, g/day = 14.21±39.37 + 12.81±4.60 (DMI, kg DM/day) + 0.91±0.57 (HF partial body weight, kg), R^2 = 0.833, RMSE=19.94, n = 20 trials.

Alternatively, HF partial body weight (partial R^2 = 0.437), average daily air temperature (partial R^2 = 0.323) and feeding event duration (partial R^2 = 0.045) accounted for 80.5% of the variation in trial average CH_4 emissions.

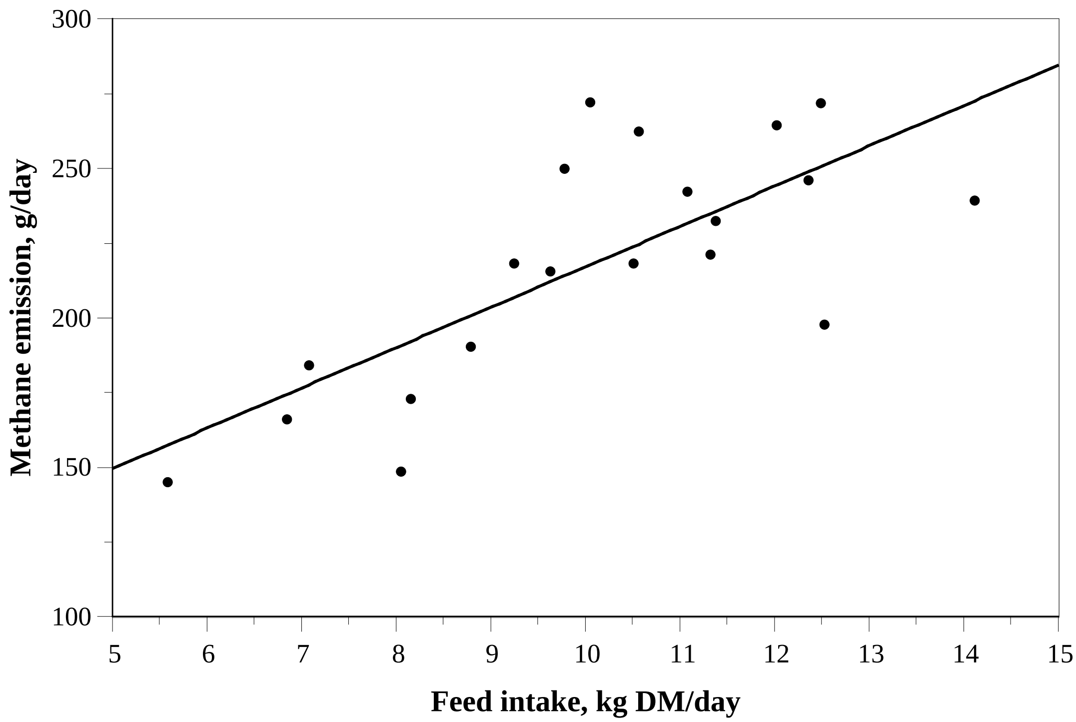


Figure 9. Relationship between trial average methane emission and trial average feed intake in beef heifers and cows in 20 trials conducted at the Lacombe Research and Development Centre and the Roy Berg Kinsella Research Station.

Thus predicting trial average DMI and CH_4 emissions using remote sensors such a GEM GrowSafe Beef® combined with climatic observations and diet quality information has practical application as the coefficients of determination (R^2) were high (0.805 - 0.846).

4. Scientific Achievement.

4.1. Potential patents, licence agreements

- **Beef Cattle Methane emissions data base** contains more than 23,000 daily enteric CH_4 and CO_2 emissions, with individual animal daily feed intake and feeding behaviours, HF partial body weight, water intake and drinking behaviours, climatic observations and diet quality information. All cattle (~700) in this data base have 50K or low density (GGP LD) genotypes which are being used to identify SNPs, indels (insertions and deletions) and functional genomic variants associated with CH_4 emissions and yield.

4.2. Published peer-reviewed papers, abstracts and proceedings

Manafiazar, G., Zimmerman, S, and. Basarab, J. A. 2017. Repeatability and variability of short-term spot measurement of CH_4 and CO_2 emissions from beef cattle using GreenFeed Emissions Monitoring System. Can. J. Animal. Sci. 97: 118–126 (2017) dx.doi.org/10.1139/cjas-2015-0190.

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Flesch, T.K., Baron, V.S., Wilson, J.D., Griffith, D.W.T., Basarab, J.A., and Carlson, P.J. 2016. Agricultural gas emissions during the spring thaw: Applying a new measurement technique. Agricultural and Forestry Meteorology, 217 (Supp. 1): 111-121. https://doi.org/10.1016/j.agrformet.2016.02.010

Flesch, T., et al. 2017. Large Nitrous Oxide Emissions during Spring Thaw in Alberta. J. Envir. Quality, JEQ-2017-03-0129-TR, submitted.

Flesch, T.K., Basarab, J.A., Baron, V.S., Wilson, J.D., Hu, N., Tomkins, N.W., and Ohama, A.J. 2017. Methane emissions from cattle grazing under diverse conditions: An examination of field configurations appropriate for line-averaging sensors. Agricultural and Forestry Meteorology, Available online 14 October 2017, https://doi.org/10.1016/j.agrformet.2017.10.012

Flesch, T.K., Baron, V.S., Wilson, J.D., Basarab, J.A., Desjardins, R.L., Worth, D., and Lemke, R.L. 2018. Micrometeorological Measurements Reveal Large Nitrous Oxide Losses during Spring Thaw in Alberta. Atmosphere, accepted 27 March 2018.

Hu, N., Flesch, T.K., Wilson, J.D., Baron, V.S., Basarab, J.A. 2016. Refining an inverse dispersion method to quantify gas sources on rolling terrain. Agriculture and Forest Meteorology, 225: 1-7.

Meng, X. Extrusion of a beef heifer diet containing dotriacontane. 2017. Final Report. Food Science and Technology Centre, Food and Bio-Processing Division, Alberta Agriculture and Forestry, 301 Horticultural Station Road E, Brooks AB T1R 1E6.

4.3. Presentations, workshops, newsletters, articles, videos

Basarab, J.A., 2015-2017. Residual feed intake and greenhouse gas emissions in beef cattle, Animal Science 474, University of Alberta. Each year gave a presentation to ANSC 474 class.

Basarab, J.A. 2017. Keep Your Cow Herd Vigor Up, BeefTech, November 8-9, 2017, Edmonton, AB, Canada

Basarab, J.A. 2017 Genomic tools for commercial beef cattle, Tools to Build Your Cow Herd, Fall Workshop Series, 23-26 October 2017, Lethbridge, Olds, Pollackville and Vermillion.

Basarab, J.A. 2017. Genomic tools for commercial beef cattle. 8th Annual Livestock Gentec Conference, 17-18 October 2017, Edmonton AB.

Basarab, J.A., J. Crowley and D. Berry. 2017. Develop and deploy gEPDs and profit indices that perform well in commercial beef cattle. Alberta Beef, Forage and Grazing Centre Advisory Meeting, 22 August 2017, Lacombe, AB.

Basarab, J.A. 2017. Genomic tools for commercial beef cattle. COW-FORAGE GENTEC FIELD DAY, 22 August 2017, Lacombe, AB.

Mckeown, L. 2017. Demonstration of the Greenfeed Emissions Monitoring (GEM) system for remote measurement of methane and carbon dioxide from beef cattle. COW-FORAGE GENTEC FIELD DAY, 22 August 2017, Lacombe, AB.

Basarab, J.A. 2017. Genomic tools for commercial beef cattle. UCVM Beef Cattle Conference, 23 June 2017, Calgary, AB, Canada.

C. Ekine-Dzivenu, E. C. Akanno, L. Chen, L. McKeown, B. Irving, L. Baker, M. Vinsky, S. Miller, Z. Wang, J. Crowley, M. Colazo, D. Ambrose, M. Juarez, H. Bruce, M. D. MacNeil, G. Plastow, J. Basarab, C. Li, C. Fitzsimmons. 2017. Performance evaluation for feed efficiency and growth in progeny of parents selected for low residual feed intake - The "Kinsella Breeding Project", results following two years of selection. Livestock Gentec Conference, 17-18 October, 2017, Edmonton, AB, Canada

C. Ekine-Dzivenu, E. C. Akanno, L. Chen, L. McKeown, B. Irving, L.Baker, M.Vinsky, S.Miller, Z. Wang J. Crowley, M. Colazo, D. Ambrose, M. Juarez, H. Bruce , M. D. MacNeil, G. Plastow, J. Basarab,C. Li and C. Fitzsimmons. 2017. Improvement of cow feed efficiency using molecular breeding values for residual feed intake - The "Kinsella Breeding Project". World Congress on Genetics Applied to Livestock Production (New Zealand, February 11-16, 2018).

Johnson, J.R., G. E. Carstens, S. D. Prince, K. H. Ominski, K. M. Wittenberg, M. Undi, T. D. A. Forbes, A. N. Hafla, D. R. Tolleson, and J. A. Basarab. 2017. Evaluation of fecal NIRS profiling technology to predict forage intake estimated using n-alkane markers in grazing cattle. **ASAS-CSAS Annual Meeting, Baltimore, MD, July 8 to July 12, 2017.**

ALMA 2016. Collaboration Provides Cattle Industry with Potential to Reduce Methane Emissions. ALMA, Newsletter, February 2016.

Beil, L. 2015. Getting creative to cut methane from cows: Less-burpy bovines means fewer greenhouse gases, Science News, Vol. 188, No. 11, November 28, 2015, p.22. Article and video. https://www.sciencenews.org/article/getting-creative-cut-methane-cows

McKeown, L. 2016. Greenfeed system for measuring methane emissions from cattle. Workshop at the Lethbridge Research Centre, 10 March 2016.

Zimmerman, S., Ghader Manafiazar, Nico Peiren and J.A. Basarab. 2016. ESTIMATES OF THE POTENTIAL OF GREENFEED ERRORS USING A MODELING APPROACH WITH VARIED VISITATION PATTERNS. 6th Greenhouse Gas and Animal Agriculture Conference, 14-18th February 2016, Melbourne, Australia, PO43, a*bstract and poster*.

Manafiazar, G. 2016. Research progress report- RFI Methane project. Livestock Gentec lab meeting. March 4th. Edmonton, Canada. *Presentation.*

Manafiazar G., S. Zimmerman, and J. Basarab. 2016. Methane, CO_2, O_2 emissions variability and repeatability and feed intake comparisons in beef cattle. Workshop on Metabolic Gas Measurements for GreenFeed, 13-14th February 2016, Melbourne, Australia, *presentation*.

Hu, N., Flesch, T., Basarab, J.A., Baron, V., Wilson, J. 2016. EXPERIMENTAL DESIGN FOR MEASURING CATTLE EMISSIONS FROM TREATMENT AND CONTROL PADDOCKS USING OPEN-PATH CONCENTRATION

SENSORS. PO19, 6th Greenhouse Gas and Animal Agriculture Conference, 14-18th February 2016, Melbourne, Australia.

Manafiazar G., S. Zimmerman, and J. Basarab. 2016. Sampling frequency and measurement period for short-terms spot measurements of methane emissions from cattle using GreenFeed Emissions Monitoring System. 6th Greenhouse Gas and Animal Agriculture Conference, 14-18th February 2016, Melbourne, Australia, P044, a*bstract and poster*

Hailemariam, D., G. Manafiazer, F. Miglior, J. Basarab, G. Plastow, C. Grelet, N. Petreny and Z. Wang. 2015. Improving feed efficiency and reducing methane emissions from dairy cows using milk Mid-infrared spectroscopy to support "green Alberta milk". Research progress report, Dairy Breeding and Genetics Committee meeting. http://cgil.uoguelph.ca/dcbgc/Dagnachew%20DCBGC%20-%20Progress%20report%20-%20Feed%20Efficiency%20UofA.pdf

Basarab, JA. 2015. Making beef cattle more feed efficient: Impact on performance, carcass and meat quality and methane emissions. II Symposium of Animal Science and Food Engineering, Pirassununga/SP/Brazil, 21-23 Oct 2015, *presentation*.

Basarab, J.A. 2015. Feed efficiency and Impact on performance, carcass and meat quality and methane emissions. II Intl. Symposium of Meat Science, Pirassununga/SP/Brazil, 21-23 Oct 2015.

Basarab, J.A., Manafiazar G. McKeown˙, L. 2015. Real-time demonstration of Greenfeed for producers, Livestock Gentec Field day. August 19th , Lacombe Research Center.

Basarab, J.A., Manafiazar G. McKeown˙, L. 2015. Real-time demonstration of GrowSafe Beef for producers, Livestock Gentec Field day. August 19th , Lacombe Research Center.

Basarab, J.A. and Flesch,TK, 2015. Real-time demonstration of FTIR methane measurement fro producers, Livestock Gentec Field day. August 19th , Lacombe Research Center.

Manafiazar, G., McKeown˙, L., Baron, V., Plastow, G., Ominski, K., and Basarab, J. 2015. Methane and carbon dioxide emissions from high and low residual feed intake beef heifers, Gentec Conference, Edmonton, 13-14 October 2015.

Basarab, J.A. 2015. Residual feed intake and greenhouse gas emissions in beef cattle. Dr. Masahito Oba's international class, University of Alberta, Lacombe Research Centre, 21 August 2015.

Basarab, J.A. 2015. Selection for feed efficiency: Impact on climate change and methane production. Sustainable Agri-Food Production and Health – 21st Century Solutions Edmonton, 14-16 Oct 2015.

Baron, V.S. and J.A. Basarab. 2015. Will RFI Studies Mean a Lower Carbon Footprint for Cattle Producers? https://www.youtube.com/watch?v=GeQcMjTRoko
Flesch, T. 2015. New Technology for Measuring Methane Emissions - What it Means for Cattle Producers. https://www.youtube.com/watch?v=VUjO4yCjsFM
Flesch, T. 2015. Cattle and Methane Emissions - Are we the problem, or the solution? https://www.youtube.com/watch?v=xKji8i2OIcM

Basarab, J.A. 2017. Sustainable beef production global challenge. January 23-24, 2017. University of Calgary's new College of Discovery, Creativity and Innovation, led by Dr Jay Cross, developed the course to bring creativity to Global Challenges such as feeding up to 9 billion people next 20-30 years.

Alberta Legislative Assembly; 23 November 2016, Members' Statement as reported by Alberta Hansard: Dr. David Bailey and Dr. John Basarab introduced at Alberta's Legistative Assembly by "The hon. Member for Leduc-Beaumont. Mr. S. Anderson.

Beef Cattle CH_4 emissions data base: containing more than 21,000 animal-days of enteric methane and CO2 visit fluxes with individual animal feed intake, body weight, water intake and behaviour and climatic data.

Repeatability and variability of short-term spot measurement of methane and carbon dioxide emissions from beef cattle using GreenFeed Emissions Monitoring System. Poster. Roy Berg Kinsella Research Station Field Day, 20 July 2016

Demonstration on GreenFeed Emission Monitoring and GrowSafe systems for producers. Roy Berg Kinsella Research Station Field Day, 20 July 2016

Completed six interviews on "Research on Measuring Methane Emissions from Cattle":

i) Canadian Geographic, July 2016; ii) 840 CFCW, Alberta, July 2016; iii) 910 CFCW, Alberta, July 2016; iv) Bellmedia 610 CKTB, St. Catherines, Ontario, 30 August 2016; v) CBC radio, 25 August 2016; vi) CBC TV, 25 August 2016

Feed efficiency (RFI) traits from beef: What can we learn? Dairy section, Livestock Gentec Conference, 19 October 2016, Edmonton, AB, Canada.

gEPDs for commercial cattle: Project Update, Livestock Gentec Conference, 18 October 2016, Edmonton, AB, Canada. Methane data will be shared with this project.

Basarab, J.A. 2016. Methane in beef cattle. Interview with Mark Connolly, CBC Radio Edmonton am and David Gary, Calgary EyeOpener, May 25, 2016

Hailemariam, D., Manafiazar, G., Miglior, F., Basarab, J., Plastow, G and Wang, Z. 2016. Estimating CH_4 and CO_2 emission from lactating dairy cows using GreenFeed system. **2016 Joint Annual Meeting (ADSA, ASAS, WSASAS, CSAS), Salt Lake City, Utah, July 19-23, *abstract.***

Manafiazar, G. 2016. Repeatability and variability of short-term spot measurement of CH_4 and CO_2 from beef cattle using GEM system. Carbon Offsets and Livestock Methane Update. Edmonton, July 2016, *presentation*.

4.4. Students involved and level

Brittany Byron, MSc., Relationship between RFI classification and individual animal intake on pasture, using prediction equations, fecal NIRS and *n*-alkane techniques to measure intake. University of Manitoba. The RFI-Methane Project provided data to Brittany's project. Brittany also traveled from Winnipeg to Lacombe for two weeks each summer to assist with the summer grazing trials and is the student that completed our alkane analyses at the University of Manitoba.

Nicky Lansink, MSc., Performance and methane emissions of RFI-selected cattle in drylot and on range. University of Alberta, Defense completed October 20, 2017. The RFI-Methane project provided Nicky with the alkane pellets and procedures for determining feed intake on pasture. In addition 60 heifers from her project were tested at Lacombe Research and Development Centre for feed efficiency and methane emissions.

Ghader Manafiazar, PDF on project, University of Alberta. Dr. Manafiazar was directly involved with data analyses and write-up of project.

Lisa McKeown, Research Technician with John Basarab, Alberta Agriculture and Forestry. Lisa was responsible for calibration of GEM systems at LRDC and KIN and held workshops at the Lethbridge Research Centre and University of Alberta to teach other scientists and technicians.

A.W. Alemu, PDF for Karen Beauchemin, Lethbridge Research Centre. Dr. Alemu was responsible for carrying out the activity on "Enteric methane emissions from low- and high-residual feed intake beef heifers measured using GreenFeed and respiration chamber techniques".

Amir Behrouzi, Research assistant with Carolyn Fitzsimmons, University of Alberta. Amir was responsible for weekly reporting and quality control of Greenfeed Emissions monitoring System at the Roy Berg Kinsella Research Station.

4.5 Greenhouse Gas Impact.

Carbon footprint of a feed efficient beef herd (adapted from Beauchemin, Little and Basarab)

The results of the present study are consistent with a previous life cycle assessment (LCA) of selecting for low RFI cattle conducted by Beauchemin et al. (2013) and presented at the Greenhouse Gas and Animal Agriculture conference in Dublin. Briefly, a baseline LCA established the whole farm GHG emission intensity for beef production in western Canada (Beauchemin et al., 2010). A RFI scenario was then applied to the baseline scenario and its impact on GHG emissions was assessed. The beef production operation was comprised of 120 cows, 4 bulls, and their progeny. Progeny were fattened in a feedlot and marketed at 18 months of age. The farm also included cropland and native pasture for grazing to supply the feed requirements. The LCA was conducted over 8 years to account for lifetime GHG emissions from all animals. Beef was marketed from cull cows, cull bulls, and progeny reared for market. The fully selected RFI herd assumed 25 yr of selection. Annual rate of genetic progress was assumed to be 0.8% per year as per Alford et al. (2006). The proportion of feed intake of the RFI herd, relative to the unselected baseline herd, was 0.8207 for calves, replacement heifers, and backgrounding cattle, 0.8282 for finishing cattle, and 0.8544 for cows (0.8804 for pre-slaughter cows). GHG emissions were estimated using Holos, a whole-farm model based on the IPCC methodology, modified for Canadian conditions and farm scale. The model considers all significant CH_4, N_2O, and CO_2 emissions and removals (C sequestration in soils) on the farm, as well as emissions from manufacture of inputs (fertilizer, herbicides) and off-farm emissions of N_2O derived from nitrogen applied on the farm. Results are given as CO_2 equivalent, using the global warming potentials of the individual gases: CH_4, 25; N_2O, 298; and CO_2, 1. After full selection of a beef cattle herd for RFI, the estimated GHG intensity from beef production were 14.0% lower than for the non-selected baseline herd (19.8 vs. 23.1 kg CO2e/kg carcass beef). Due to the lower feed intake of the RFI herd, the farm area required for grazing and feed production was 13.2% lower than for the baseline herd.

5.0 Conclusions

This project has developed cutting edge FTIR methodology and rigorous scientific protocols for the GEM system to measure CH_4 and CO_2 in beef cattle under on-farm grazing and drylot conditions. The GEM and FTIR systems are less invasive, less expensive, less labor intensive and accurate methods for measuring CH_4 emission compared with respiratory chamber methodology. In addition, a world-class team has been assembled that has the expertise and techniques to quantify GHG footprints of beef cattle production systems, and to reduce carbon footprint of cattle production. Selection for low RFI as a GHG reduction strategy has been verified. Next steps will include using the large phenotype-genotype data base from this project to identify rumen and genomic biomarkers for low methane emitters and to develop a project on RFI and adapting to climate change for submission to the 2018 Large Scale Applied Research Program of Genome Canada. Large reduction (e.g., 30-50%) in the carbon intensity of beef production are possible by combining nutritional, management, grazing, and genomic interventions such as using feed additives (e.g., 3NOP, biochar), improving diet quality, using grasses and legumes with methane reducing attributes, breeding strategies to optimize hybrid vigor, genomic selection for low methane emitters, and improving general production efficiency.

6.0. Project Budget

Reporting period	Source	Type	Personnel	Travel	Capital Assets	Supplies	CDL*	Other	Total
Period 1	ALMA	Budgeted	$30,000.00			$15,000.00			$45,000.00
Dates: 2014/03/01		Spent	$43,562.15			$9,454.13			$53,016.28
to 2015/05/31	Gov't	Cash							$0.00
		In-kind	$50,050.00						$50,050.00
	Industry	Cash							$0.00
		In-kind			$36,633.00				$36,633.00
Total Spent for Period 1			**$93,612.15**	**$0.00**	**$36,633.00**	**$9,454.13**	**$0.00**	**$0.00**	**$139,699.28**
Period 2	ALMA	Budgeted	$148,003.00			$56,666.00			$204,669.00
Dates: 2015/06/01		Spent	$136,155.17			$64,043.00			$200,198.17
to 2016/03/31	Gov't	Cash							$0.00
		In-kind	$210,480.00					$56,050.00	$266,530.00
	Industry	Cash							$0.00
		In-kind			$56,000.00				$56,000.00
Total Spent for Period 2			**$346,635.17**	**$0.00**	**$56,000.00**	**$64,043.00**	**$0.00**	**$56,050.00**	**$522,728.17**
Period 3	ALMA	Budgeted	$233,999.00	$13,000.00		$56,666.00			$303,665.00
Dates: 2016/04/01		Spent	$222,134.25	$3,184.30		$73,699.58			$299,018.13
to 2017/03/31	Gov't	Cash							$0.00
		In-kind	$210,480.00					$56,050.00	$266,530.00
	Industry	Cash							$0.00
		In-kind			$56,000.00				$56,000.00
Total Spent for Period 3			**$432,614.25**	**$3,184.30**	**$56,000.00**	**$73,699.58**	**$0.00**	**$56,050.00**	**$621,548.13**
Period 4	ALMA	Budgeted	$139,999.00			$56,666.00			$196,665.00
Dates: 2017/04/01		Spent	$101,205.75			$76,406.12			$177,611.87
to 2017/12/31	Gov't	Cash							$0.00
		In-kind	$210,480.00					$56,050.00	$266,530.00
	Industry	Cash							$0.00
		In-kind			$56,000.00				$56,000.00
Total Spent for Period 4			**$311,685.75**	**$0.00**	**$56,000.00**	**$76,406.12**	**$0.00**	**$56,050.00**	**$500,141.87**
Period 5	ALMA	Budgeted							$0.00
Dates: yyyy/mm/dd		Spent							$0.00
to yyyy/mm/dd	Gov't	Cash							$0.00
		In-kind							$0.00
	Industry	Cash							$0.00
		In-kind							$0.00
Total Spent for Period 5			**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**
CUMULATIVE ALMA CASH SPENT			$503,057.32	$3,184.30	$0.00	$223,602.83	$0.00	$0.00	$729,844.45

***Communication, Dissemination, and Linkage**

Budget Commentary

Period 2:

ALMA Spent Personnel: $9908 (TF); $7596 (GM); $73,889 (LM); $2762 UofA administrative staff; **$42,000 AAFC salary and benefits** = $136,155 (to March 23, 2016)

ALMA Spent Supplies: $45,000 Univ. of Manitoba, alkane analysis; $1575 pellets AF; $15,000 AAFC pasture development costs; 2468 other = $64,043.

The $42,000 in salary and benefits listed in the first sentence is categorized as ALMA personnel, but due to University of Alberta's accounting system it appears under Supplies and Other-BL in their Financial Overview statement. Actual ALMA Personnel=$136,155 (variance=8.0%) and Supplies=$61,565 (variance=8.6%). **Period 2 variance = 3.4%.**

Period 3:
ALMA Spent Personnel: $9098.78 (GM); $16691.39 (tehnicans); $26188.48 (TF); $ 8155.60 DGAC UofA administrative staff; $45000 University of Manitoba; **$117000 AAFC salary and benefits** = $222134.25 (to March 17, 2017).

Travel: $3184.30.

ALMA Spent Supplies: $5699.58 pellets Brooks Food Processing Centre for pellets; $68,000 to AAFC Lethbridge for respiratory chamber user fees = $73699.58.

The $45,000 and $117000 in salary and benefits listed in the second sentence is categorized as ALMA personnel, but due to University of Alberta's accounting system it appears under Supplies and Other-BL in their Financial Overview statement. **Period 3 budget variance = 1.5%.**

Period 4:
ALMA Spent Personnel: $28292.00 (GM); $13578.57 (technicans RM); $39643.48 (TF); $11471.85 (TDSV); $1019.90 (MER); $ 7199.96 DGAC UofA administrative staff = $101205.76.

ALMA Spent Supplies: $4370.94 pellets Brooks Food Processing Centre for pellets; $991.09 trucking; $925 insurnace; $79.09 other; $40.00 software; $45000 University of Manitoba; $25000 AAFC = $76406.12

Period 4 budget variance = 9.7%. Surplus is due to lower costs of salary and benefits.

Overall budget variance = 3.0%.

Surplus is due to lower costs of salary and benefits as post-doctorate fellows were often shared between projects and thus projects were charged accordingly.

7.0. Funding contributions

Estimated total resources allocated to the project

Sources	Amount	Percentage of total project cost
Alberta Agriculture and Forestry	$750,000	28.2%
Other government sources: Cash	$0	0.0%
Other government sources: In-kind	$849,640	32.0%
Industry: Cash	$851,354	32.1%
Industry: In-kind	$204,633	7.7%
Total project cost	$2,655,627	100%

External sources of funding for the project. Clearly indicate any changes to confirmed sources of funding as well as any new sources of funding. (Additional rows may be added if necessary).

Government sources		
Name (no abbreviations unless stated in Section 3)	Amount cash	Amount in-kind

Industry sources		
Name (no abbreviations unless stated in Section 3)	Amount cash	Amount in-kind
Climate Change and Emission Management Cooperation (CCEMC)	$851,354	
GrowSafe System Ltd. (Calgary, AB, Canada)		$204,633

15. Principal Investigator’s Signature and Authorised Representative’s Approval

The Principal Investigator and an authorised representative from the Principal Investigator’s organisation of employment MUST sign this form.

By signing as an authorised representative of the Principal Investigator’s employing organisation, the undersigned hereby acknowledges submission of the information contained in this interim report to the funder(s).

Principal Investigator	
Name: **John Basarab**	**Title/Organisation:** Senior Reserach Scientist, Alberta Agriculture and Forestry & Adjunct Professor, Agricultural, Food and Nutritional Sciences, University of Alberta
Signature:	**Date:** **March 22, 2018**
Principal Investigator’s Authorised Representative’s Approval	
Name: Ruurd Zijlstra	**Title/Organisation:** AFNS University of Alberta
Signature:	**Date:** **March 22, 2018**

Principal Investigator	
Name: **John Basarab**	**Title/Organisation:** Senior Reserach Scientist, Alberta Agriculture and Forestry & Adjunct Professor, Agricultural, Food and Nutritional Sciences, University of Alberta
Signature:	**Date:** **March 22, 2018**
Principal Investigator’s Authorised Representative’s Approval	
Name: Ruurd Zijlstra	**Title/Organisation:** AFNS University of Alberta
Signature:	**Date:** **March 22, 2018**

Appendix A. **CCEMC Budget and Project Financing Schedule, March 2014 to 31 December 2017**

CCEMC Budget and Project Financing Schedule as of 31 May 2015

Milestone	Task	Start Date	End Date	Expense Category	ALMA Actuals	CCEMC Funds	CCEMC Actual	CCEMC Variance
1.0 Year 1 Import two Greenfeed Systems from USA, install & valid. Install and valid GSB system. Prepare monoculture pasture at one location.	1.1 **YEAR 1.** Develop monoculture pastures and pasture infrastructure at Lacombe.	**May 1, 2014**	**Sept 30, 2014**	**Supplies** (planting, fencing, water, power, site preparations)	$15,000 transferred to AAFC-Lacombe on July 3, 2015	$15000	CCEMC $12851	$2149
	1.2a **YEAR 1.** Develop RFP, import and install two GreenFeed™ systems. Attend workshop on measuring CH4 & CO2 using the Greenfeed System; install GrowSafe Beef systems at Lacombe	**May 1, 2014**	**Dec 1, 2014**	**Capital** – Greenfeed		151967	$154469	$-2502
		Apr 1, 2014	**Dec 1, 2014**	**Travel**		$5000	$3434	$1566
		Sept, 2014	**Oct, 2014**	**Workshop (2 people): measure CH4 & CO2 using Greenfeed, Rapid City, SD, USA**		$10000	$8970	$1030
		April 1, 2014	**Dec 1, 2014**	**Services** - GSB systems at Lacombe - Installation & delivery -site prep & broad cost **Salaries/Benefits** Tech/PDF 42k/yr; **DGAC**	$43562 $9454	$30000 $20000	$50000	$0
	1.2b YEAR 1. Purchase C32	**April 1, 2014**	**Dec 1, 2014**	Import C32 ($1600/kg) from France		$2500	$2500	$0
	YEAR 1 Overhead	**April 1, 2014**	**May 31, 2015**	**20% to UofA**	0	$46893	$46445	$448
	YEAR 1 Total	**April 1, 2014**	**May 31, 2015**		$53016	$281360	$278669	$2691

1. Overall the CCEMC budget variance is 0.96%.

CCEMC Budget and Project Financing Schedule for 1 June 2015 to 31 March 2016

Milestone	Task	Start Date	End Date	Expense Category	ALMA Funds	CCEMC Funds	CCEMC actual	CCEMC variance
Year 2 Measure ~220 growing heifers and 80 cows under drylot conditions for RFI. Measure heifers for biometrics & CH4 emissions under drylot (n=80) and grazing (n=60) conditions. Measure 40 cows for CH4 emissions under drylot and grazing conditions.	1.3 YEAR 2. Purchase sampling supplies and feed ingredients for alkane labeled feed pellet. Make alkane pellets	**June 1, 2015**	**Mar 31, 2016**	**Supplies;** Sampling-feed, forage, fecal, blood beeswax, barley & wheat flour, canola meal and oil, DDGs		$1,500 $1,850	$1,500 $1,850	$0
		June 1, 2015	**Mar 31, 2016**	**Services:** -alkane pellets ($5k/site/yr) Alkane analysis ($27/samples * 3000)	$37,000 $10k AAFC $27k to UofM			
	1.4 YEAR 2. Measure ~220 heifers (2 locations) for RFI.	**June 1, 2015** Monitor one pen (42-45 hd)/location using the Greenfeed and GS	**Dec 31,2015**	**Services** - GSB user fee or purchase cost - feed cubes		$34,000 $15,000	$34,000 $2894 trk $9332 geno	$2774
	1.5 YEAR 2. Setup FTIR and measure CH_4, etc.	**June 1, 2015**	**Dec 1, 2015**	**Salaries/Benefits** (Partial TKF salary/ PDF/grad stud. 3.5 yr.)	$77,003 9063 lm 7,551 gm 10299 tf ($47K to AAFC)			
		June 1, 2015	**Dec 1, 2015**	**Supplies FTIR** Repair, calibration, purchase		$23,317	$10183 reflectors $9,063	$4,071
		June 1, 2015	**Dec 1, 2015**	**Travel**		$14,000	$12,095	$ 1,905
	1.6 YEAR 2. Summer grazing: Conduct feed intake on pasture trial at Lacombe; 30 heifers per yr.	**June 1, 2015**	**Mar 31, 2016**	**Salaries/Benefits** Tech or PDF 42k/yr & Ph.D 23k/yr;	$65,000 $65000 lm			
		July 1, 2015	**Oct 31, 2015**	**Services:** **Travel-**		$5,000	$5,000	$0
	2.1 YEAR 2. Install GreenFeed™, GrowSafe Beef and OP_FTIR systems in drylot pens and swath locations	**Sept 1, 2015**	**Mar 31, 2016**	**Services** - GSB user fee or purchase cost - Installation & delivery -site preparation		$17,000 $7,000	$16,000 $5787	 $2,213
	2.2 YEAR 2 Measure 40 cows for RFI in two locations	**Nov 1, 2015**	**Mar 31,2016**	**Services** Alkanes-C32 Alkane analysis ($27/sample)	$1,666 $18,000 $1,576 $18,000 to UofM			
	2.3 YEAR 2 Conduct trial in each of three years	**June 1, 2015**	**Mar 31, 2016**	**Salaries/Benefits** (partial TKF salary/ PDF/grad stud 3.5 yr.)	Covered under 1.5	$23,665	$18211 tf $6238 eo	$ -784
		June 1, 2015	**Mar 31, 2016**	**DGAC**	$6,000 $5,500			
	Year 2 overhead	**June 1, 2015**	**Mar 31, 2016**	**20% to UofA**		$28,466	$26,342	$2,124
	YEAR 2 Total	**June 1, 2015**	**Mar 31, 2016**		$204,669 $200,989	$170,798	$158,495	$12,303

ALMA Funds column: Highlighted are actual expenditures; not highlighted are projected expenditures.
Year 2 **ALMA variance=1.8%. Year 2 CCEMC variance=7.2%.**

CCEMC Budget and Project Financing Schedule for 1 April 2016 to 31 March 2017

Milestone	Task	Start Date	End Date	Expense Category	ALMA Funds	CCEMC Funds	CCEMC actual	Total
Year 3 Measure an additional ~220 growing heifers and 80 cows under drylot conditions for RFI. Measure heifers for biometrics & CH4 emissions under drylot (n=80) and grazing (n=60) conditions. Measure 40 cows for CH4 emissions under drylot and grazing conditions.	1.3 YEAR 3. Purchase sampling supplies and feed ingredients for alkane labeled feed pellet. Make alkane pellets	**April 1, 2016**	**June 30, 2016**	**Supplies;** Sampling-feed, forage, fecal, blood beeswax, barley & wheat flour, canola meal and oil, DDGs		$1,500 $1,850	$3,350	$3,350
		April 1, 2016	**June 30, 2016**	**Services:** -alkane pellets ($5k/site/yr) Alkane analysis ($27/samples * 3000)	$10,000 $27,000 27k UofM 5713 goa			$37,000
	1.4 YEAR 3. Measure ~220 heifers (2 locations) for RFI.	**Jan 2016** Monitor 1 pen (~40hd per location)using the Greenfeed & GS	**May 2016**	**Services** - (4) GSB user fee at $8,500/unit/yr. - Feed cubes for cows		$34,000 $15,000	$34,000 $15,000	$49,000
	1.5 YEAR 3. Setup FTIR and measure CH_4, etc. at two locations	**April 1, 2016**	**Dec 1, 2016**	**Salaries/Benefits** (Partial TKF salary/ PDF/grad stud. 3.5 yr.)	$17,999 2000 gm 16691 tec 10k aafc	$68,000	24,227 tf 43,773 lm	$85,999
		April 1, 2016	**Dec 1, 2016**	**Supplies FTIR** Repair, calibration		$23,316	25,369	$23,316
		April 1, 2016	**Dec 1, 2016**	**Travel-FTIR**		$13,000	$13,000	$13,000
Measure CH_4 emissions from 10 high and 10 low RFI beef heifers using GreenFeed compared to respiration chambers	1.6 YEAR 3. Summer grazing: Conduct feed intake on pasture trial Lacombe/Kins; 30 heifers per year/location.	**April 1, 2016**	**Mar 31, 2017**	**Salaries/Benefits** Tech or PDF42k/yr & Ph.D 23k/yr;	$42,000 $23,000 7000gm 25483 tf 32k aafc			$65,000
		July 1, 2016	**Oct 31, 2016**	**Services:** **Travel-Lac/Kinsella**	$13,000 3,184	$5,000	$5,176	$18,000
	2.1 YEAR 3. Install GreenFeed™, GrowSafe Beef and OP_FTIR systems in drylot pens and swath at two locations	**Sept 1, 2016**	**Mar 31, 2017**	**Services** - (4) GSB user fee at $8,500/unit/yr. - Installation & delivery -site preparation		$17,000 $7,000	$16,000 $4,126 $1,216	$24,000
	2.2 YEAR 3 Measure 40 cows for RFI in two locations	**Nov 1, 2016**	**Feb 28,2017**	**Services** Alkanes-C32 Alkane analysis ($27/sample)	$1,666 $18,000 18kUofM			$19,666
	2.3 YEAR 3 Conduct trial in each of three yrs	**April 1, 2016**	**Mar 31, 2017**	**Salaries/Benefits** (partial TKF salary/ PDF/grad stud. 3.5 yr.)	Covered under 1.5	$14,665	14582	$14,665
	3.1 Calibrate systems and measurements	**April 1, 2016**	**May 31,2016**	**Services** Equip Fee ($500/hd)	$68,000 $68k aafc			$68,000
		April 1, 2016	**June 30, 2016**	**Salaries/Ben-Tech** 0.6 FTE	$75,000 75kaafc			$75,000
		April 1, 2016	**Mar 31, 2017**	**DGAC**	$8,000 $8156			$8,000
	Year 3 Overhead	**April 1, 2016**	**Mar 31, 2017**	**20% to UofA**		$40,066	$40,051	$40,066
	YEAR 3 Total	**April 1, 2016**	**Mar 31, 2017**		$303,665 $298,227	$240,397	$239,870	$544,062 $538,097

ALMA Funds column: Highlighted values in "ALMA Funds" refers to actual ALMA expenditures.

Year 3 ALMA variance=1.8%.

Year 3 CCEMC variance=0.2%. Year 3 Total variance=1.1%.

CCEMC Budget and Project Financing Schedule for 1 April 2017 to 31 December 2017

Milestone	Task	Start Date	End Date	Expense Category	ALMA Funds	CCEMC Funds	Total
YEAR 4 Measure an additional ~220 growing heifers and 80 cows under drylot conditions for RFI. Measure heifers for biometrics & CH4 emissions under drylot (n=80) and grazing (n=60) conditions. Measure 40 cows for CH4 emissions under drylot and grazing conditions	1.4 YEAR 4. Measure ~220 heifers (2 locations) for RFI.	**April 1, 2017**	**June 30, 2017**	**Services:** -alkane pellets ($5k/site/yr) Alkane analysis ($27/samples * 3000)	$10,000 $27,000 $27k UofM $6366 +40		$37,000 $33406
		Jan 2017 Monitor one pen (42-45 hd)/ location using the Greenfeed and GS	**May 2017**	**Services** - (4) GSB user fee at $8,500/unit/yr. -Feed cubes		$34,000 $15,000 $34,000 $10,125	$49,000 $44,125
	1.5 YEAR 4. Setup FTIR and measure CH_4, etc. at Lacombe	**April 1, 2017**	**Dec 1, 2017**	**Salaries/Benefits** (Partial TKF salary/ PDF/grad stud. 3.5 yr.)	$85,999 $39643 tkf $11472 tv $25000 ac $1020 mer		$85,999 $77,135
	1.6 YEAR 4. Summer grazing: Conduct feed intake on pasture trial Lacombe/Kins; 20 heifers per year/location.	**April 1, 2017**	**Dec 1, 2017**	**Supplies FTIR** Repair, calibration, purchase		$23,317 $2,753	$23,317 $2,753
		April 1, 2017	**Dec 1, 2017**	**Travel-FTIR**		$13,000 $3,408 $1,821	$13,000 $5,229
		April 1, 2017	**Dec 31, 2017**	**Salaries/Benefits** Tech or PDF 42k/yr & Ph.D 23k/yr;	$25,000 $23,000 $13579 rm 28292 gm		$48,000 $41,871
	2.1 YEAR 4. Install GreenFeed™, GrowSafe Beef and OP_FTIR systems in drylot pens at LRC.	**July 1, 2017**	**Oct 31, 2017**	**Services:** **Travel-Lac/Kinsella**		$5,000 $4,193	$5,000 $4,193
		Sept 1, 2017	**Dec 1, 2017**	**Services** - (4) GSB user fee at $8,500/unit/yr. - Installation & delivery -site preparation		$17,000 $7,000 $17,000 $1,318	$24,000 $18,318
	2.2 YEAR 4 Measure 40 cows for RFI in two locations	**Nov 1,2017**	**Dec 31, 2017**	**Services** Alkanes-C32 Alkane analysis ($27/sample)	$1,667 $18,000 $18k UofM		$19,667 $18,000
	2.3 YEAR 4 Conduct trial in each of three years	**April 1, 2017**	**Dec 31, 2017**	**Salaries/Benefits** (partial TKF salary/ PDF/grad stud. 3.5 yr.)	Covered under 1.5	$14,666 $14666 tf	$14,666 $14,666
		April 1, 2017	**Dec 31, 2017**	**DGAC**	$6,000 $7200		$6,000 $7200
	Year 4 Overhead	**April 1, 2017**	**Dec 31, 2017**			$26,466 $17857	$26,466 $17857
	YEAR 4 Total	**April 1, 2017**	**Dec 31, 2017**		$196,666 $177,612	$158,799 $107,141	$355,465 $284,753
	Year 1-4	**April 1, 2014**	**Dec 31, 2017**		$750,000 $729,844	$851,354 $784,175	$1,601,354 $1,514,019

ALMA Funds column: Highlighted values in "ALMA Funds" refers to actual ALMA expenditures.

Total project variance=5.5%. Unspent funds were due to lower costs of repair and maintenance costs (e.g., FTIR laser), salary and benefits (sharing of PDFs between projects), and feed (no cubes purchased in Year 4 as triticale silage was used and paid for by AAFC).