

1 **METHANE EMISSIONS FROM ALBERTA’S BEEF CATTLE**

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3 **Methane emissions from enteric fermentation in Alberta’s beef cattle population**

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16 Date accepted: June 2005

1 Basarab, J.A., Okine, E.K., Baron, V., Marx, T., Ramsey, P., Ziegler, K. and Lyle, K. 2005.
2 Methane emissions from enteric fermentation in Alberta's beef cattle population Can. J. Anim.
3 Sci. XXXX: This study determined methane emissions from enteric fermentation in Alberta's
4 beef cattle population by using three methodologies: 1) Intergovernmental Panel on Climate
5 Change (IPCC), Tier 2 guidelines for cattle, 2) actual methane emission factors, expressed as a
6 percentage of gross energy intake, from Canadian research trials and; 3) CowBytes[®] plus the basic
7 equation developed by Blaxter and Clapperton (1965). Methane emissions, in carbon dioxide
8 equivalents (CO₂-E), from Alberta's beef cattle were determined for 1990, 1996 and 2001.
9 Census of Agriculture numbers for Alberta (Statistics Canada; www.statcan.com) were used and
10 beef cattle were subdivided into 31 distinct categories based on animal type, physiological status,
11 gender, weight, growth rate, activity level and age. Emission of greenhouse gases (GHG) from
12 Alberta's beef cattle population, based on IPCC Tier 2 guidelines, were 4.93, 6.57 and 7.01 Mt
13 CO₂-E yr⁻¹ in 1990, 1996 and 2001, respectively. Emissions based on methane emission factors
14 from Canadian research trials were 6.23, 8.26 and 8.77 Mt CO₂-E yr⁻¹ in 1990, 1996 and 2001,
15 respectively. Estimated methane emissions based on CowBytes[®] and Blaxter and Clapperton's
16 (1965) equation were 6.24, 8.35 and 8.94 Mt CO₂-E yr⁻¹ in 1990, 1996 and 2001, respectively.
17 The IPCC Tier 2 values were 25.2-26.5% lower than the GHG emissions calculated using
18 emission factors from western Canadian research and 26.7-27.6% lower than GHG emissions
19 calculated from CowBytes[®] and Blaxter and Clapperton's equation. IPCC Tier 1 values, which
20 were calculated by multiplying total beef cattle in Alberta by four single value emission factors
21 (beef cows=72 kg CH₄ yr⁻¹; bulls=75 kg CH₄ yr⁻¹; replacement heifers=56 kg CH₄ yr⁻¹; calves,
22 steer and heifer calves for slaughter=47 kg CH₄ yr⁻¹), were 4.83, 6.40 and 6.83 Mt CO₂-E in

1 1990, 1996 and 2001, respectively. Thus, IPCC Tier 1 GHG emissions from enteric fermentation
2 in beef cattle were 2.0-2.7%, 28.6-29.1% and 29.2-31.0% lower than those calculated from IPCC
3 Tier 2, western Canadian research trials, and CowBytes[®] plus Blaxter and Clapperton's equation,
4 respectively. These results reflect the uncertainty associated with estimating methane emissions
5 from enteric fermentation in cattle and suggest that further research is required to improve the
6 accuracy of methane emissions, particularly for beef cows in their second and third trimester of
7 pregnancy and fed in confinement. They also indicate that a more robust methodology may be to
8 combine CowBytes[®] predicted dry matter intake with regional specific methane emission factors,
9 where methane loss is expressed as a percentage of gross energy intake.

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19 **Key words:** Cattle, enteric fermentation, greenhouse gas, methane

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21 **Abbreviations:** GHG, greenhouse gas, IPCC, intergovernmental panel on climate change; Mt,
22 million tonnes

1 In April 1998 Canada signed the Kyoto Protocol committing to reduce greenhouse gas
2 (GHG) emissions to 6% below 1990 levels by 2008 to 2012 (Environment Canada 2005). The
3 Canadian Government ratified the agreement in December 2004. Canada's greenhouse gas
4 (GHG) emissions, based on Intergovernmental Panel on Climate Change (IPCC) Tier 1
5 calculations, were 609, 675, 716 and 731 megatonne (Mt) CO₂-E for 1990, 1996, 2001 and 2002,
6 respectively, indicating that GHG emissions have increased by 20.0% or by 122 Mt from 1990 to
7 2002 (Matin et al. 2004). The energy sector is responsible for 97.8% of the increase in GHG
8 emissions, with the largest contributors to the increase being electricity and steam generation
9 (33.7 Mt), vehicles (34.2 Mt) and fossil fuel industries (21.9 Mt). The 2002 figure represents
10 about 2% of the total global GHG emissions. On a per capita basis, Canada ranks second in the
11 G8 nations and ninth in the world for CO₂ emissions, primarily due to its energy intensive
12 economy (Olsen et al. 2002). In 2002, the energy sector was responsible for 81.0% of the
13 emissions, with 74.0% resulting from the combustion of fossil fuel and 8.0% resulting from
14 fugitive emissions from mining and oil and gas production (Matin et al. 2004). Other sectors
15 contributing to GHG emissions were agriculture (8.0%), industrial processes (6.8%), waste and
16 waste management (3.2%), land use change and forestry (0.8%) and solvents and other product
17 use (0.1%). Carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) are the major GHG
18 gases, contributing 78.8%, 12.9% and 7.2% to the total emissions, respectively (Matin et al.
19 2004).

20 Alberta's GHG emissions were 171, 203, 220 and 221 Mt CO₂-E for 1990, 1996, 2001 and
21 2002, respectively (Matin et al. 2004). This represents 28.1-30.7% of Canada's total output of
22 GHG. The emissions of GHG from enteric fermentation in Alberta's livestock were 5.1, 6.2, 7.2

1 and 7.2 Mt CO₂-E for 1990, 1996, 2001 and 2002, respectively, representing 3.0-3.3% of
2 Alberta's total output of GHG emissions and 0.8-1.0% of Canada's total output of GHG
3 emissions (Matin et al. 2004). These GHG emissions are based on the IPCC Tier 1 guidelines
4 that use single value methane emission factors for beef cattle in North America (IPCC 1997).
5 Alberta calves (under one yr of age) and beef steers and heifers raised for slaughter purposes
6 (one yr of age and older) from Census of Agriculture numbers (Statistics Canada) are multiplied
7 by 47.0 kg CH₄ hd⁻¹ yr⁻¹ (http://www.ec.gc.ca/pdb/ghg/1990_00_report/appd_e.cfm#link10) to
8 obtain total methane emission from enteric fermentation in beef calves, and steers and heifers for
9 slaughter. Beef cows, breeding bulls (one yr of age and older) and replacement heifers (one yr of
10 age and older) are multiplied by 72, 75 and 56 kg CH₄ hd⁻¹ yr⁻¹, respectively. This approach
11 ignores animal type (calf vs. steers for slaughter), diet, physiological status, gender, weight,
12 growth rate, activity level, age and environmental factors, all of which affect enteric methane
13 production.

14 The objectives of this study were to calculate methane emissions from enteric fermentation in
15 Alberta's beef cattle population at distinct physiological stages of production and growth by
16 three methodologies: 1) IPCC Tier 2 guidelines (IPCC 2000) for beef cattle; 2) methane emission
17 factors for beef cattle obtained from Canadian research trials and; 3) CowBytes[®] plus the basic
18 equation developed by Blaxter and Clapperton (1965). These calculations were conducted for
19 Alberta's beef cattle population in 1990, 1996 and 2001.

20 **MATERIALS AND METHODS**

21 Alberta beef cattle inventories were taken from the Census of Agriculture numbers,
22 which is an inventory of Canadian agriculture taken once every five years, as required by the

1 federal Statistics Act (Statistics Canada, www.statcan.com; Table 1). National in scope, the
2 Census uses a survey approach to capture data from all Canadian agricultural operations. The
3 survey is taken on May 15 of the census year (i.e., 1991, 1996, and 2001) by Statistics Canada.

4 **Methane estimations**

5 Three methods were used to calculate methane emissions from enteric fermentation in Alberta's
6 beef cattle population.

7 Method 1 used IPCC Tier 2 guidelines (IPCC 2000; [http://www.ipcc-](http://www.ipcc-nggip.iges.or.jp/public/gp/gpgaum.htm)
8 [nggip.iges.or.jp/public/gp/gpgaum.htm](http://www.ipcc-nggip.iges.or.jp/public/gp/gpgaum.htm)) that required subdividing the beef cattle populations by
9 animal type, physiological status (pregnant or lactating), gender, weight, growth rate, activity
10 level and age. This resulted in 31 distinct categories of beef cattle (Table 2). The cattle weight
11 loss equation (Equation 4.4b, IPCC 2000) was assumed to be zero for all categories of beef cattle
12 except cows in their second trimester of pregnancy (Category 3). Average milk production and
13 milk fat content was assumed to be 7.0 kg d⁻¹ and 4.8%, respectively (Butson and Berg 1984).
14 This average milk production is similar to the value of 7.3 kg d⁻¹ reported by Jenkins and Ferrell
15 (1992) who determined the lactation characteristics of nine breeds of cattle representing diverse
16 biological types. Gross energy intake (GEI; MJ) was converted to dry matter (DM) intake by
17 dividing GEI by 18.45 MJ kg⁻¹ DM (IPCC 2000). Energy lost as methane, expressed as a
18 percentage of GEI for North America are 6% of GEI for all cattle except those fed diets
19 containing 90% or more concentrates for which conversions are 4% of GEI (IPCC 2000).

20 Method 2 used methane emission factors from western Canadian research studies,
21 expressed as a percentage of GEI, and adapted them to the 31 categories of beef cattle outlined in
22 Table 2. In all but two of the studies chosen, methane production from enteric fermentation was

1 measured using either the sulphur hexafluoride (SF₆) tracer gas technique or indirect calorimetry
2 utilizing a hood collection system. For these studies, methane emission factors were adjusted
3 upwards by 3% since the SF₆ tracer gas technique and the hood collection system account for 95-
4 98% of the total methane produced by the animal and do not account for all hindgut methane
5 production (Murray et al. 1976; Johnson et al. 1994). Murray et al. (1976) reported that methane
6 produced in the rumen is 87% of total methane produced by the animal, while methane produced
7 in the hindgut is largely (89%) absorbed into the portal blood and excreted through the lungs,
8 which can then be collected at the mouth. The remaining two studies used a complete animal
9 chamber system to measure methane emissions and were not adjusted for hindgut methane
10 production. The studies used and the categories of beef cattle to which each study was applied
11 are as follows:

12 *1) Beef cows (Category 1, 2 and 3):* In this category calculations were based on a study using
13 first-calf lactating beef heifers (515 kg) grazing alfalfa-grass (78%: 22%) or meadow brome-
14 grass (100%) pasture (McCaughey et al. 1999). Beef heifers averaged 0.76 ± 0.02 L CH₄ kg⁻¹
15 body weight (BW) d⁻¹, 391.4 ± 10.1 L CH₄ d⁻¹ or 102.5 kg CH₄ yr⁻¹. Average DMI and energy lost
16 through eructation of methane by these first-calf heifers was 10.5 ± 0.4 kg d⁻¹ and $8.4 \pm 0.4\%$ of
17 GEI, respectively. The methane value was derived using the SF₆ tracer gas technique and was
18 adjusted upward by 3% (8.65% of GEI).

19 *2) Breeding bulls in confinement (Category 4 and 6):* Calculations were based on a study using
20 Hereford steers (531 kg) fed at maintenance, a diet consisting of 50% brome grass and 50%
21 alfalfa hay (DM basis; Okine et al. 1989). These steers were fed indoors in a thermal neutral
22 environment and produced 0.36 ± 0.01 L CH₄ kg⁻¹ BW d⁻¹, 188.8 ± 7.8 L CH₄ d⁻¹ or 49.4 kg CH₄ yr⁻¹

1 ¹. Average DMI and energy lost through eructation of methane by steers was 7.4 kg d⁻¹ and
2 5.7±0.3% of GEI, respectively. The methane value was derived through indirect calorimetry
3 utilizing a hood collection system and was adjusted upward by 3% (5.87% of GEI).

4 *3) Breeding bulls, replacement heifers, stocker heifers and steers on pasture (Category 5, 7, 16,*
5 *20, 24, 26 and 29):* Calculations in this category were based on a study using steers (397.8 kg)
6 grazing pastures comprised of 60.0% alfalfa, 28.6% meadow brome-grass and 4.9% Russian
7 wildrye for 140-d, and producing 0.69±0.06 L CH₄ kg⁻¹ BW d⁻¹, 273.2±24.2 L CH₄ d⁻¹ or 71.5 kg
8 CH₄ yr⁻¹ (McCaughey et al. 1997). The average DMI and energy lost through eructation of
9 methane by steers grazing alfalfa/grass pastures was 13.9±0.9 kg d⁻¹ and 4.5±1.4% of GEI,
10 respectively. In a similar study, steers (387 kg) grazing legume-grass pasture during early, mid
11 and late-season averaged 0.80±0.06 L CH₄ kg⁻¹ BW d⁻¹, 310.5±25.9 L CH₄ d⁻¹ or 81.3 kg CH₄ yr⁻¹
12 (Boadi et al. 2002). Average DMI and energy lost through eructation of methane by steers
13 grazing legume-grass pastures was 11.1±0.3 kg d⁻¹ and 6.7±0.6% of GEI, respectively. The mean
14 of these studies, or 5.6% of GEI, was adjusted upward by 3% (5.77% of GEI) since methane
15 production was derived using the SF₆ tracer gas technique.

16 *4) Beef heifers and steers on finishing diets (Category 8, 9, 13, 14, 18, 21, 22, 25, 27, 28, 30 and*
17 *31):* Calculations were based on a study using Angus heifer (finishing period mid-point weight =
18 427 kg) calves fed a 91% concentrate and 9% barley silage diet (DM basis). These heifers
19 produced 0.35 L CH₄ kg⁻¹ BW d⁻¹, 150.5 L CH₄ d⁻¹ or 39.4 kg CH₄ yr⁻¹ (Beauchemin and McGinn
20 2005). Average DMI and methane produced as a percentage of GEI was 8.3 kg d⁻¹ and 4.0%,
21 respectively. The methane value was derived using a complete animal chamber to measure gas
22 emissions and was not adjusted for hindgut methane production.

1 5) *Beef replacement heifers in confinement (Category 10, 15 and 17)*: In this category
2 calculations were based on a study using Charolais x Simmental yearling heifers (319 kg; 12 mo)
3 fed various forage qualities under *ad libitum* confined feeding conditions and producing
4 0.81 ± 0.02 L CH₄ kg⁻¹ BW d⁻¹, 258.7 ± 11.9 L CH₄ d⁻¹ or 67.7 kg CH₄ yr⁻¹ (Boadi and Wittenberg
5 2002). Average DMI and energy lost through eructation of methane by yearling heifers in this
6 study was 8.4 ± 0.4 kg d⁻¹ and $6.7 \pm 0.3\%$ of GEI, respectively. The methane value was derived
7 using the SF₆ tracer gas technique and was adjusted upward by 3% (6.90% of GEI).

8 6) *Stocker heifer and steers in feedlot (Category 11, 12, 19 and 23)*: Calculations were based on
9 a study using steers fed a diet consisting of 70% barley silage, 25% steam-rolled barley and 5%
10 supplement (DM basis), and formulated to have the cattle gain at 0.9 kg d⁻¹ for 42-d (mid-point
11 weight=344 kg). These steers produced 0.75 L CH₄ kg⁻¹ BW d⁻¹, 257.9 L CH₄ d⁻¹ or 67.5 kg CH₄
12 yr⁻¹ (Beauchemin and McGinn 2005). The average DMI and energy lost through eructation of
13 methane by steers fed a 70:30% roughage concentrate diet was 7.6 kg d⁻¹ and 7.3% of GEI,
14 respectively. In this study, methane emissions were determined using a complete animal chamber
15 and no adjustment was made for hindgut methane production.

16 Method 3 used CowBytes[®] (CowBytes[®], Beef Ration Balancer, v 4.8, Alberta Agriculture,
17 Food and Rural Development, Edmonton, Alberta) to formulate a diet, determine daily DMI (kg)
18 and daily DMI required for maintenance (kg). CowBytes[®] was used to evaluate nutrient and feed
19 requirements of beef cattle depending on their physiological status (maintenance, growth,
20 lactation and gestation) and climatic conditions (temperature and wind speed). The model was
21 also used as a daily management tool for adjusting nutrient requirement and utilization over wide
22 variations in cattle, feed, management and environmental conditions. The effects of cold stress

1 and lower critical temperature (LCT) on maintenance requirements were also considered. The
2 NRC equations for predicting cattle energy and protein requirements have been published
3 previously (Fox et al.1988, 1992; NRC 1996). Computation of cattle requirements was based on
4 the following: 1). Maintenance requirements were determined from body weight, previous
5 nutritional status and level of production, and tissue and external insulation relative to effective
6 ambient temperature, wind, and other environmental conditions (NRC 1984, 1996). 2). Growth
7 requirements were based on empty body tissue composition of the expected gain. Factors that
8 influenced requirements for growth were assumed to be weight, stage of growth, growth rate,
9 and use of anabolic implants and use of ionophores. 3). Pregnancy requirements were predicted
10 from uterine and conceptus demand. 4). Lactation requirements were computed from the amount
11 and composition of milk. Peak milk yield was an input parameter or predicted based on observed
12 calf weaning weights for various mature cow sizes (Fox et al. 1988). Milk production was
13 predicted from lactation curves (Wood 1967). 5). Energy and protein reserves were estimated
14 from NRC (1996). From the energy balance, the change of cow body condition score (BCS) was
15 estimated. Methane emissions were based on the equation developed by Blaxter and Clapperton
16 (1965) and later corrected by Wilkerson et al (1995): %CH₄ loss (% of gross energy) = 1.30 +
17 (0.112DE) + LOI(2.37-0.05DE), where DE is percent digestible energy or percent total digestible
18 nutrients (TDN) and LOI is the level of daily DMI above that required for maintenance or daily
19 DMI (kg) divided by DMI required for maintenance (kg). Total daily DMI required for
20 maintenance included the energy required for empty body weight (EBW, 0.077 Mcal/EBW^{0.75},
21 NRC 1996), activity, pregnancy, lactation and heat and cold stress. Gross energy (GE) of diet
22 was 18.45 MJ kg⁻¹ DM (IPCC 2000). Methane loss in MJ d⁻¹ was determined as follows: CH₄

1 loss (MJ d⁻¹) = (diet GE x DMI) x (CH₄ loss as a % of gross energy/100). Methane loss in MJ d⁻¹
2 was converted to g d⁻¹ and kg yr⁻¹ using the relationship that one g CH₄ has 0.0555606 MJ energy
3 (Morrison and Boyd, 1961).

4 **Categorization of Alberta's Beef Cattle Population**

5 Alberta's beef cattle population as defined in Table 1 was divided into 31 categories
6 according to physiological status (e.g., pregnant, lactating), diet, age and time of year (Table 2).

7 All values for TDN and average daily gain are from E. Okine (pers. comm.).

8 *Category 1-3:* At the beginning of the census year Category 1 mature beef cows were assumed,
9 based on industry practice, to be fed high roughage diets (i.e., hay or barley silage, straw and
10 some barley grain; 63% TDN; gain=0.00 kg d⁻¹) for 4 mo, were in confinement, and were in their
11 third trimester of pregnancy (average=8 mo). Their start weight of 592 kg was estimated from
12 Alberta's average cow weight at weaning of 606 kg (October-November; Alberta Cow-Calf
13 Audit 2001) and assumed that cows lost weight slowly (0.15 kg d⁻¹) during the early winter
14 feeding period from October to the end of December. Mid-point weight (day 222 of pregnancy)
15 and weight at calving were calculated assuming the cows were in day 162 of pregnancy on
16 January 1, had an average gestation period of 282 days and using the equation relating time of
17 pregnancy to conceptus weight (NRC 1996): Conceptus weight (kg) = (43 x 0.01828) x e^{((0.02t) -}
18 ^(0.0000143t²)), where 43 is the assumed birth weight of calf (kg) and t is the number of days of
19 pregnancy. The difference between conceptus weights at day 222 and day 162 of pregnancy was
20 then added to start weight to obtain mid-point weight (611 kg). End weight was calculated by
21 subtracting weight of fetus (43 kg), fetal membranes and fluids (21 kg or 29.9% of gravid uterus
22 weight, Ferrell et al. 1976) from cow weight at calving (649 kg). Category 2 beef cows were

1 assumed to have calved, were, on average, in their third mo of lactation, one month pregnant and
2 were fed good quality pasture (65% TDN; gain=0.14 kg d⁻¹) for the next 5 mo. Average milk
3 production was assumed to be 7.0 kg d⁻¹ (Butson and Berg 1984), which is approximately
4 equivalent to 10.0 kg d⁻¹ at peak lactation using an equation derived from data by Jenkins and
5 Ferrell (1992; peak milk, kg d⁻¹ = 1.57 + 1.2 x average milk production, kg d⁻¹; n=9, R²=0.956,
6 P<0.001). Category 3 beef cows were assumed to be non-lactating, were in their second trimester
7 of pregnancy (average=5 mo), and were either grazing crop aftermath, fall pastures or fed stored
8 forages (58% TDN; gain = -0.15 kg d⁻¹) on pasture for the next three months.

9 *Category 4-6:* Within year, breeding bulls over one year of age from census data were grouped
10 according to diet and time of year. Category 4 bulls were assumed to be in confinement during
11 the winter months of January through April and fed roughage diets (i.e., hay or barley silage,
12 straw and some barley grain; 63% TDN; gain=0.50 kg d⁻¹). These bulls are termed Category 5
13 when they are grazing grass pastures (63% TDN; gain=0.50 kg d⁻¹) from May to October, and
14 Category 6 when they are in confinement (63% TDN; gain=0.50 kg d⁻¹) during November and
15 December.

16 *Category 7:* These were assumed to be local calves born within the census year during February,
17 March, April and May (Table 1), were less than 6-7 month of age on May 15 and grazed on
18 pasture with their dams (Category 3) until weaning in the fall. Their diet was assumed to consist
19 of forage and milk (57:43% on a DM basis; 91% TDN; gain=1.07 kg d⁻¹). In Alberta, most
20 calves are born during the last week in March and the first week in April and have an average
21 200-d weaning weight of 257 kg (Alberta Cow-Calf Audit 2001). Thus, calves grew at an
22 estimated 1.07 kg d⁻¹, assuming an average calf birth weight of 43 kg. It was noted that the

1 census numbers may include import stocker calves that are less than 9 mo of age and for this
2 reason an adjustment was made to the beef calves census numbers. The Alberta Cow-Calf Audit
3 (2001) indicated that the calf crop weaned from cows wintered approximated 94.4% (4.2% calf
4 death loss, birth to weaning; 1.4% of wintered cows not calving). Thus, if the census beef calf
5 number was greater than 94.4% of the census beef cow number, then the beef calves weaned was
6 set to 94% of the census beef cow number.

7 *Category 8-9:* These categories were assumed to be 8-9 mo. old imported steer and heifer calves
8 averaging 323 kg and 319 kg, respectively. Census beef calf numbers were adjusted using the
9 caveat that if the numbers were greater than 94% of census beef cows then import calves equaled
10 census beef calves minus 94% of census beef cows. This value was then split equally between
11 heifer and steer calves that went directly to feedlot for finishing in 6 mo. In the feedlot these
12 calves were fed a standard industry finishing diet (barley grain, barley silage, feedlot supplement
13 32% crude protein); 80% TDN, DM basis), and steer and heifer calves grew at 1.59 and 1.49 kg
14 d^{-1} , respectively.

15 *Category 10-14:* These categories assumed Alberta born calves (Category 7) were weaned in
16 October (Mathison 1993; Alberta Cow-Calf Audit 2001). Seventeen percent of these calves were
17 then selected as replacement heifers (Category 10; 65% TDN; gain = 0.68 kg d^{-1}), 16.5% as
18 stocker heifers (Category 11; 65% TDN; gain = 0.68 kg d^{-1}), 25% as stocker steers (Category 12;
19 65% TDN; gain = 0.71 kg d^{-1}), 16.5% as heifers for direct finishing (Category 13; 80% TDN;
20 gain = 1.22 kg d^{-1} and 25% as steers for direct finishing (Category 14; 80% TDN; gain = 1.36 kg
21 d^{-1}). These values were based on the assumption that 17% of the calf crop was required each year
22 for herd replacements (Johnson and Johnson 1995; Mathison 1993; Alberta Cow-Calf Audit

1 2001) and, of the remaining calves, 50% are placed in a feedlot at a slower rate of gain (stocker
2 calves) and 50% are placed in a feedlot at a faster rate of gain (finisher calves). Start weights for
3 each group are based on a 200-d weaning weight of 257 kg (Alberta Cow-Calf Audit 2001) and
4 the assumption that steer calves weigh 5% more than heifer calves at weaning (Basarab et al.
5 1984).

6 *Category 15-17:* Replacement heifers (9-10 mo of age) at the beginning of the census year were
7 estimated to be 17% of the previous year's calf crop. Calves born in the previous years for 1989,
8 1995 and 2000 were 1,421,000, 1,780,000 and 1,790,000 head, respectively (Statistics Canada).
9 Therefore, 9-10 mo. old replacement heifers were estimated at 241,570, 302,600 and 304,300 for
10 1990, 1996 and 2001, respectively. Within each year, these replacement heifers were assumed to
11 be fed a high forage diet for 5 mo (Jan.-May) in a confined area (Category 15; 65% TDN; gain =
12 0.68 kg d^{-1}), then grazed on pasture for four mo (Category 16; 65% TDN; gain = 0.68 kg d^{-1}),
13 and then fed a high forage diet in a confined feeding area for 3 mo (Category 17; 65% TDN; gain
14 = 0.68 kg d^{-1}).

15 *Category 18-21:* Heifers to be fed for slaughter were determined by subtracting the 9-10 mo old
16 replacement heifers from the census beef heifers over one year of age in Table 1 (i.e., $625,000 -$
17 $241,570 = 383,430$ heifers). Fifty percent of these heifers were assumed to have gone directly to
18 feedlot where they were fed a high concentrate diet until finished for slaughter (Category 18;
19 80% TDN; gain = 1.49 kg d^{-1}). The remaining heifers were then placed in feedlot for five mo
20 where they were fed and cared for in such manner that growth rather than finishing occurred
21 (Category 19; 65% TDN; gain = 0.68 kg d^{-1}). Once adequate pasture was available, these stocker
22 heifers were grazed for four mo on good quality pasture (Category 20; 65% TDN; gain = 0.68 kg

1 d^{-1}) and then into feedlot for three mo of finishing (Category 21; 80% TDN; gain = 1.49 kg d^{-1}).

2 *Category 22-25:* Steers to be fed for slaughter were taken directly from the census beef steers
3 over one year of age in Table 1. Fifty percent of these steers were assumed to have gone directly
4 to the feedlot (category 22; 80% TDN; gain = 1.59 kg d^{-1}). The remaining stocker steers were
5 placed in feedlot for five mo (Category 23; 65% TDN; gain = 0.71 kg d^{-1}). Once adequate
6 pasture became available, these stocker steers were grazed for four mo on good quality pasture
7 (Category 24; 65% TDN; gain = 0.68 kg d^{-1}) and then into feedlot for three mo of finishing
8 (Category 25; 80% TDN; gain = 1.59 kg d^{-1}).

9 *Category 26-31:* Net feeder cattle imports were estimated based on total fed cattle production in
10 Alberta for 1990 (1,385,156 head), 1996 (2,160,178 head) and 2001 (2,507,923 head) minus beef
11 calf imports (Category 8-9) minus heifers and steers fed for slaughter from Table 2. For example,
12 there were 1,385,156 feeder cattle fed to slaughter in Alberta in 1990, yet the census taken in
13 July only accounted for 951,430 head (625,000 beef heifers – 241,570 replacement heifers +
14 568,000 beef steers = 951,430). Thus, total fed cattle (1,385,156) minus feeder cattle counted in
15 census (951,430) minus beef calf imports (0) gives an estimate of net imports of feeder cattle to
16 Alberta or 433,726 head. These cattle were then divided into stocker heifers placed on pasture
17 (25%; Category 26; 65% TDN; gain = 0.68 kg d^{-1}) then into feedlot for finishing (Category 27;
18 80% TDN; gain = 1.49 kg d^{-1}), heifers placed directly into feedlot for finishing (25%; Category
19 28; 80% TDN; gain = 1.49 kg d^{-1}), stocker steers placed on pasture (25%; Category 29; 65%
20 TDN; gain = 0.71 kg d^{-1}) then into feedlot for finishing (Category 30; 80% TDN; gain = 1.59 kg
21 d^{-1}), and steers placed directly into feedlot for finishing (25%; Category 31; 80% TDN; gain =
22 1.59 kg d^{-1}).

1 **Comparison between Methods**

2 Methane emissions as determined by the three methodologies were converted to carbon
3 dioxide equivalents (CO₂-E) by multiplying methane emissions by 21 (Matin et al. 2004). This
4 allowed for easier comparison to provincial and national GHG emissions from all livestock and
5 other sources. Comparison between methods in total yearly production of GHG from Alberta's
6 beef cattle population was calculated as a percent difference ($[\text{Method 2} - \text{Method 1}] / \text{Method 1} \times$
7 100). IPCC Tier 1 was used as the baseline value for GHG emissions from Alberta's beef cattle
8 population and was determined by multiplying each beef category by its respective IPCC Tier 1
9 emission factor (cows=72 kg hd⁻¹ yr⁻¹, bulls=75 kg hd⁻¹ yr⁻¹, replacement heifers=56 kg hd⁻¹ yr⁻¹
10 and calves, steers and heifers for slaughter=47 kg hd⁻¹ yr⁻¹; IPCC 1997; Environment Canada
11 2002). DMI as predicted by IPCC Tier 2 and CowBytes[®] were compared using the General Linear
12 Models procedure (SAS 1996).

13 **RESULTS AND DISCUSSION**

14 **GHG Emissions from Alberta's Beef Cattle Population**

15 Methane emissions from Alberta's beef cattle population, as calculated by IPCC Tier 2
16 guidelines, were 4.93, 6.57 and 7.01 Mt CO₂-E in 1990, 1996 and 2001, respectively (Table 3).
17 The IPCC Tier 1 values, which used four different emission factors for the 31 beef cattle
18 categories in Table 1, were 4.83, 6.40 and 6.83 Mt CO₂-E in 1990, 1996 and 2001, respectively.
19 These IPCC Tier 1 calculations were only slightly lower (2.0 –2.7%) than the more complicated
20 IPCC Tier 2 calculations. From 1990 to 2001, both IPCC Tier 1 and IPCC Tier 2 calculations
21 show an increase in GHG emissions from Alberta's beef cattle population of 41.3% and 42.3%,
22 respectively.

1 Emissions of GHG from Alberta's beef cattle population as calculated by emission
2 factors from western Canadian research trials were 6.23, 8.26 and 8.77 Mt CO₂-E in 1990, 1996
3 and 2001, respectively (Table 4). These values are 25.2-26.5% higher than the values calculated
4 from IPCC Tier 2 and 28.6-29.1% higher than IPCC Tier 1 values. It is likely that the IPCC Tier
5 1 methane emissions factor for beef cows under western Canadian feeding practices (72 kg hd⁻¹
6 yr⁻¹; Environment Canada 2002) is set too low since IPCC Tier 2 (Method 1) and western
7 Canadian research trials gave methane emission factors of 61.7-103.0 and 97.5-135.2 kg hd⁻¹ yr⁻¹
8 ¹, respectively. In addition, methane emissions as calculated by Method 2 have a higher degree of
9 uncertainty since no Canadian study was available that reported methane production in beef
10 cows during the second and third trimesters of pregnancy and fed a roughage diet in
11 confinement.

12 Emissions of GHG from Alberta's beef cattle population based on CowBytes[®] and the
13 basic equation of Blaxter and Clapperton (1965) were 6.24, 8.35 and 8.94 Mt CO₂-E in 1990,
14 1996 and 2001, respectively (Table 5). These values were 29.2-31.0% and 26.7-27.6% higher
15 than values calculated from IPCC Tier 1 and IPCC Tier 2, respectively, and 0.1-1.9% higher than
16 GHG emissions calculated using western Canadian research trials. The differences in GHG
17 emissions between Method 3 and IPCC Tier 2 are partially due to differences in DMI calculated
18 by CowBytes[®] and IPCC Tier 2. The relationship between DMI predicted by CowBytes[®] and
19 IPCC Tier 2 is expressed by the following linear equation: $DMI_{CB} = -0.64 \pm 1.2 + 1.11 \pm 0.12$
20 DMI_{IPCC} , where DMI_{CB} is the predicted DMI from CowBytes[®] and DMI_{IPCC} is the predicted DMI
21 from IPCC Tier 2 in kg d⁻¹ ($R^2 = 0.73$, $P < 0.001$, $n = 31$). Depending on category, DMI values
22 calculated by CowBytes[®] were 48-49% higher for breeding bulls in confinement (Category 4 and

1 6) to 18.2% lower for 13-14 mo old replacement heifers (Category 16) compared to DMI values
2 calculated from IPCC Tier 2 (Table 3 vs. Table 5). Overall the DMI from CowBytes[®] was 3.1%
3 (SD=15.3%) higher than DMI calculated from IPCC Tier 2. These differences in DMI relate to
4 the constancy of coefficients for net energy for maintenance (non-lactating, 0.322; lactating,
5 0.335), activity (0.0, 0.17, 0.36), lactation (e.g., 7.0 kg of milk per day), weight loss (-0.8 times
6 net energy for gain) and pregnancy (0.10) used in IPCC Tier 2 (IPCC 2000), whereas in
7 CowBytes[®] these factors are continuous and CowBytes[®] accounts for cold stress. In addition,
8 Blaxter and Clapperton's equation resulted in methane losses that varied from 7.6% of gross
9 energy intake for cow on a high roughage diet to 6.0% of gross energy intake for young growing
10 cattle on a finishing diet. This result agrees with Johnson and Johnson (1995) who reported that
11 Blaxter and Clapperton predict methane production ranged from 6-10% with most points in the 6
12 to 8% range. They also reported a poor relationship ($R^2 = 0.23$) between observed and predicted
13 methane production (% of GEI) using Blaxter and Clapperton equation (1965). The gross energy
14 values resulting from Blaxter and Clapperton's equation for young growing cattle on a finishing
15 diet are questionable since McAllister et al. (1996) and Beauchemin and McGinn (2005) reported
16 that high-grain diets fed at near ad libitum have methane losses of 2 to 4% of gross energy
17 intake. Based on stoichiometric relationships (Hungate 1966) high ratios of propionic acid result
18 in decreased methane production. Factors such as high grain diets will increase propionic acid
19 concentrations and decrease methane production, but are not accounted for in Blaxter and
20 Clapperton's equation. A practical improvement to IPCC Tier 2 would be to combine the DMI
21 predicted by CowBytes[®] with regional specific methane emission factors (eg., McCaughey et al.
22 1999; Okine et al. 1989; McCaughey et al. 1997; Boadi et al. 2002; Beauchemin and McGinn

1 2005; Boadi and Wittenberg 2002), where methane loss is expressed as a percentage of GEI.

2 **Methane emission factors for enteric fermentation**

3 Depending on method of determination, methane emissions from enteric fermentation in
4 pregnant beef cows in confinement ranged from 61.7 to 114.3 kg CH₄ cow⁻¹ yr⁻¹, while methane
5 emissions for lactating beef cows on pasture ranged from 103.0 to 135.2 kg CH₄ cow⁻¹ yr⁻¹
6 (Table 6). On average, emission factors for cows, breeding bulls and calves as determined by
7 Method 2 and 3 were 32.0% (SD=32.8) and 39.8% (SD=33.7) higher, respectively, than
8 emission factors determined by IPCC Tier 2 guidelines. This range in methane emission factors
9 for beef cows made a difference to the yearly estimate of methane emissions from Alberta's cow
10 population. For example, in 1996 methane emission from Alberta's cow population was 165,416
11 (Table 3), 239,688 (Table 4) and 204,672 (Table 5) Mt CH₄ yr⁻¹ when determined by Method 1, 2
12 and 3, respectively. Beef cows emitted more methane (51.5-60.9%) than all other beef cattle
13 categories.

14 On average, methane emission factors in young growing beef cattle resulting from
15 Method 2 and 3 were 5.3% (SD=16.8) and 40.3% (SD=25.6) higher, respectively, than emission
16 factors determined by IPCC Tier 2 guidelines (Table 7). These results reflect the uncertainty
17 associated with estimating methane emissions from enteric fermentation in cattle and agree with
18 the degree of the uncertainty estimated in the IPCC guidelines ($\pm 20\%$; IPCC 2000). Sources of
19 uncertainty include incomplete reporting of beef cattle statistics by Statistics Canada such as beef
20 and dairy calves not reported separately, beef and dairy bulls not reported separately and calves
21 under one year of age containing significant number of import stocker and finisher cattle. In
22 addition, production practices such as culling rates, diet quality, diet supplementation (e.g.,

1 ionophores, edible oils), pasture management and proportion of weaned calves fed as finishers or
2 as stockers are highly variable from farm to farm and year to year.

3 **CONCLUSIONS**

4 Presently in Canada GHG emissions from enteric fermentation in beef cattle are
5 determined by IPCC Tier 1 guidelines. Our results show that IPCC Tier 1 GHG emissions from
6 enteric fermentation in beef cattle were 2.0-2.7%, 28.6-29.1% and 29.2-31.0% lower than values
7 determined from IPCC Tier 2, western Canadian research trial and Blaxter and Clapperton's
8 equation, respectively. Large variation existed among the three methods in methane emission
9 factors for beef cows, breeding bulls and young, growing cattle. These results reflect the
10 uncertainty associated with estimating methane emissions from enteric fermentation in cattle and
11 agrees with the degree of the uncertainty estimated in the IPCC guidelines ($\pm 20\%$; IPCC 2000).
12 Further research is required to improve the accuracy of methane emissions from beef cows and
13 young stocker and finisher beef cattle under Canadian conditions. A more robust methodology
14 for calculating methane emissions from enteric fermentation in beef cattle may be to combine
15 CowBytes[®] predicted DMI with regional specific methane emission factors, where methane loss
16 is expressed as a percentage of GEI.

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Table 1. Inventory of beef cattle on farms in Alberta for 1990, 1996, 2001 and 2008-2012

Animal Type	1990 ^z	1996 ^y	2001 ^y	2008-2012 ^x
1. Beef Cows	1,567,000	2,016,889	2,099,288	2,420,267
2. Calves, under 1 year	1,478,000	1,858,679	2,169,607	2,230,415
3. Breeding bulls, 1 year plus	94,000	118,600	111,379	142,320
4. Beef heifers, 1 year plus ^w	625,000	905,887	1,102,522	1,358,831
5. Beef steers, 1 year plus	568,000	892,696	991,554	1,339,044
Total Beef Cattle and Calves	4,332,000	5,792,751	6,474,350	7,490,877
Fed Cattle Production	1,385,156	2,160,178	2,507,923	3,240,267

1 ^z Numbers are based on July 1, 1990 data, Statistics Canada, Agriculture Division.

2 ^y Numbers are based on May 15 census data, Statistics Canada, Census of Agriculture.

3 ^x These are projected numbers based on a 20% increase in beef cows, calves under 1 year, and breeding bulls, and a
4 50% increase in beef heifers over 1 year, beef steers over 1 year and in fed cattle production from 1996 numbers.

5 ^w Heifers minus dairy cows and dairy replacement heifers or 95.1% of total census number.

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Table 2. Categories of beef cattle in Alberta including projected start, end and mid-point weight, average daily gain, diet quality and animal numbers for 1990, 1996 and 2001.

Categories of Beef Cattle	Age mo	Location	Time of year	d	Start weight, kg	End weight, kg	Mid weight, kg	ADG, kg d ⁻¹	Diet TDN %	Number of animal by year		
										1990	1996	2001
1. Cows, 3 rd trimester ^z	Unk	Confined	Jan-Apr	120	592	585	611	0.00	63	1,567,000	2,016,889	2,099,288
2. Cows, lactating	Unk	Pasture	May-Sep	153	585	606	596	0.14	65	1,567,000	2,016,889	2,099,288
3. Cows, 2 nd trimester	Unk	Confined	Oct-Dec	92	606	592	599	-0.15	58	1,567,000	2,016,889	2,099,288
4. Breeding bulls	Unk	Confined	Jan-Apr	120	877	937	907	0.50	63	94,000	118,600	111,379
5. Breeding bulls grazing	Unk	Pasture	May-Oct	184	937	1014	976	0.50	63	94,000	118,600	111,379
6. Breeding bulls	Unk	Confined	Nov-Dec	61	1014	1045	1030	0.50	63	94,000	118,600	111,379
7. Stocker calves, local	<6	Pasture	Apr-Sep	200	43	257	150	1.07	91	1,478,000	1,858,679	1,981,728
8. Beef calves, import/steer	8-9	Feedlot	Jan-Jul	182	323	612	467	1.59	80	0	0	93,940
9. Beef calves, import/heif.	8-9	Feedlot	Jan-Jul	182	319	590	454	1.49	80	0	0	93,940
10. Replacement heifers	6-7	Confined	Oct-Dec	92	250	312	281	0.68	65	251,260	315,975	336,894
11. Stocker heifers	6-7	Feedlot	Oct-Dec	92	250	312	281	0.68	65	243,870	306,682	326,985
12. Stocker steers	6-7	Feedlot	Oct-Dec	92	263	329	296	0.71	65	369,500	464,670	495,432
13. Finisher heifers	6-7	Feedlot	Oct-Dec	92	250	363	307	1.22	80	243,870	306,682	326,985
14. Finisher steers	6-7	Feedlot	Oct-Dec	92	263	388	326	1.36	80	369,500	464,670	495,432
15. Replacement heifers	9-10	Confined	Jan-May	151	312	414	363	0.68	65	241,570	302,600	304,300
16. Replacement heifers	14-15	Pasture	Jun-Sep	122	414	497	456	0.68	65	241,570	302,600	304,300
17. Replacement heifers	18-19	Confined	Oct-Dec	92	497	560	529	0.68	68	241,570	302,600	304,300
18. Finisher heifers	8-9	Feedlot	Jan-May	153	363	590	477	1.49	80	191,715	301,644	399,111
19. Stocker heifers	8-9	Feedlot	Jan-May	151	312	414	363	0.68	65	191,715	301,644	399,111
20. Stocker heifers	13-14	Pasture	Jun-Sep	122	414	497	456	0.68	65	191,715	301,644	399,111
21. Finisher heifers	17-18	Feedlot	Oct-Dec	62	497	590	544	1.49	80	191,715	301,644	399,111
22. Finisher steers	8-9	Feedlot	Jan-May	141	388	612	500	1.59	80	284,000	446,346	495,777
23. Stocker steers	8-9	Feedlot	Jan-May	151	329	436	382	0.71	65	284,000	446,346	495,777
24. Stocker steers	13-14	Pasture	Jun-Sep	122	436	519	477	0.68	65	284,000	446,346	495,777
25. Finisher steers	17-18	Feedlot	Oct-Dec	59	519	612	565	1.59	80	284,000	446,346	495,777
26. Stocker Import heifers	8-9	Pasture	Jun-Sep	122	312	395	353	0.68	65	108,432	166,049	132,567
27. Import heifers	12-13	Feedlot	Oct-Dec	92	395	532	463	1.49	80	108,432	166,049	132,567
28. Import heifers	8-9	Feedlot	Jun-Nov	187	312	590	451	1.49	80	108,432	166,050	132,567
29. Stocker Import steers	8-9	Pasture	Jun-Sep	122	329	415	372	0.71	65	108,432	166,050	132,567
30. Import steers	12-13	Feedlot	Oct-Dec	92	415	561	488	1.59	80	108,432	166,050	132,567
31. Import steers	8-9	Feedlot	Jun-Nov	178	329	612	470	1.59	80	108,432	166,050	132,567

^zMid-point weight (day 222 of pregnancy) was calculated assuming the cows were in day 162 of pregnancy on January 1, had an average gestation period of 282 days, an average calf birth weight of 43 kg and using the equation relating time of pregnancy to conceptus weight (NRC 1996). The difference between conceptus weights at day 222 and day 162 of pregnancy was then added to start weight to obtain mid-point weight (611 kg).

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Table 3. Methane emissions from enteric fermentation in Alberta's beef cattle, as determined by IPCC Tier 2 guidelines, for 1990, 1996 and 2001

Categories	Age, mo	Location	Time of year	Total DMI ^z kg d ⁻¹	Methane lost ^y , % of Gross Energy Intake	Methane ^z kg hd ⁻¹ yr ⁻¹	Methane, t yr ⁻¹		
							1990	1996	2001
1. Cows – 3 rd trimester	Unk	Confined	Jan-Apr	8.5	6.00	61.7	31,791	40,918	42,590
2. Cows - lactating	Unk	Pasture	May-Sep	14.2	6.00	103.0	67,676	87,106	90,665
3. Cows – 2 nd trimester	Unk	Confined	Oct-Dec	10.1	6.00	73.6	29,052	37,392	38,920
4. Breeding bulls	Unk	Confined	Jan-Apr	11.6	6.00	84.5	2,611	3,294	3,094
5. Breeding bulls grazing	Unk	Pasture	May-Oct	15.7	6.00	114.2	5,411	6,826	6,411
6. Breeding bulls	Unk	Confined	Nov-Dec	12.8	6.00	92.9	1,459	1,841	1,729
7. Stocker calves, grazing	<6	Pasture	Apr-Sep	3.2	6.00	23.4	18,981	23,869	25,449
8. Beef calves, import/steer	8-9	Feedlot	Jan-Jul	9.5	4.00	46.0	0	0	2,154
9. Beef calves, import/heif.	8-9	Feedlot	Jan-Jul	9.8	4.00	47.7	0	0	2,233
10. Replacement heifers	6-7	Confined	Oct-Dec	6.2	6.00	44.7	2,831	3,560	3,796
11. Stocker heifers	6-7	Feedlot	Oct-Dec	6.2	6.00	44.7	2,748	3,455	3,684
12. Stocker steers	6-7	Feedlot	Oct-Dec	6.1	6.00	44.3	4,123	5,185	5,529
13. Finisher heifers	6-7	Feedlot	Oct-Dec	6.5	4.00	31.3	1,921	2,416	2,576
14. Finisher steers	6-7	Feedlot	Oct-Dec	6.6	4.00	31.9	2,969	3,733	3,981
15. Replacement heifers	9-10	Confined	Jan-May	7.5	6.00	54.2	5,412	6,779	6,817
16. Replacement heifers	14-15	Pasture	Jun-Sep	10.7	6.00	77.7	6,276	7,861	7,905
17. Replacement heifers	18-19	Confined	Oct-Dec	9.7	6.00	70.3	4,281	5,362	5,392
18. Finisher heifers	8-9	Feedlot	Jan-May	10.2	4.00	49.4	3,970	6,246	8,265
19. Stocker heifers	8-9	Feedlot	Jan-May	7.5	6.00	54.2	4,295	6,758	8,941
20. Stocker heifers	13-14	Pasture	Jun-Sep	9.7	6.00	70.6	4,525	7,119	9,420
21. Finisher heifers	17-18	Feedlot	Oct-Dec	11.3	4.00	54.5	1,781	2,803	3,708
22. Finisher steers	8-9	Feedlot	Jan-May	10.0	4.00	48.4	5,299	8,328	9,251
23. Stocker steers	8-9	Feedlot	Jan-May	7.4	6.00	53.6	6,301	9,903	11,000
24. Stocker steers	13-14	Pasture	Jun-Sep	9.5	6.00	68.8	6,532	10,265	11,402
25. Finisher steers	17-18	Feedlot	Oct-Dec	11.0	4.00	53.0	2,423	3,808	4,230
26. Stocker Import heifers	8-9	Pasture	Jun-Sep	8.0	6.00	58.3	2,113	3,236	2,584
27. Import heifers	12-13	Feedlot	Oct-Dec	10.0	4.00	48.3	1,321	2,023	1,615
28. Import heifers	8-9	Feedlot	Jun-Nov	9.8	4.00	47.4	2,633	4,031	3,219
29. Stocker Import steers	8-9	Pasture	Jun-Sep	8.0	6.00	58.0	2,102	3,219	2,570
30. Import steers	12-13	Feedlot	Oct-Dec	9.8	4.00	47.5	1,299	1,989	1,588
31. Import steers	8-9	Feedlot	Jun-Nov	9.5	4.00	46.2	2,442	3,740	2,986
Total methane production, t yr ⁻¹							234,577	313,072	333,703
Total CO ₂ equivalents (total annual methane production x 21), t yr ⁻¹							4,926,117	6,574,512	7,007,763

^z Total daily dry matter as determined by IPCC Tier 2 (IPCC 2000).

^y Energy lost as methane, expressed as a percentage of gross energy intake (GEI) are 6% of GEI for all cattle except those fed diets containing 90% or more concentrates for which conversions are 4% of GEI (IPCC 2000).

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Table 4. Methane emissions from enteric fermentation in Alberta's beef cattle, as determined by emission factors taken from Western Canada literature, for 1990, 1996 and 2001.

Categories	Age, mo	Location	Time of year	Total DMI ^z kg d ⁻¹	Methane lost ^y , % of Gross Energy Intake	Methane ^x kg hd ⁻¹ yr ⁻¹	Methane, t yr ⁻¹		
							1990	1996	2001
1. Cows – 3 rd trimester	Unk	Confined	Jan-Apr	10.9	8.65	114.3	58,874	75,777	78,872
2. Cows - lactating	Unk	Pasture	May-Sep	12.9	8.65	135.2	88,837	114,343	119,014
3. Cows – 2 nd trimester	Unk	Confined	Oct-Dec	9.3	8.65	97.5	38,511	49,568	51,593
4. Breeding bulls	Unk	Confined	Jan-Apr	17.4	5.87	123.8	3,826	4,827	4,533
5. Breeding bulls grazing	Unk	Pasture	May-Oct	15.9	5.77	111.2	5,269	6,648	6,243
6. Breeding bulls	Unk	Confined	Nov-Dec	18.9	5.87	134.5	2,112	2,665	2,503
7. Stocker calves, grazing	<6	Pasture	Apr-Sep	2.9	5.77	20.3	16,425	20,656	22,023
8. Beef calves, import/steer	8-9	Feedlot	Jan-Jul	10.2	4.00	49.5	0	0	2,316
9. Beef calves, import/heif.	8-9	Feedlot	Jan-Jul	9.8	4.00	47.5	0	0	2,226
10. Replacement heifers	6-7	Confined	Oct-Dec	6.6	6.90	55.2	3,496	4,396	4,687
11. Stocker heifers	6-7	Feedlot	Oct-Dec	6.4	7.30	56.6	3,481	4,377	4,667
12. Stocker steers	6-7	Feedlot	Oct-Dec	6.7	7.30	59.3	5,521	6,943	7,403
13. Finisher heifers	6-7	Feedlot	Oct-Dec	6.4	4.00	31.0	1,907	2,399	2,557
14. Finisher steers	6-7	Feedlot	Oct-Dec	6.9	4.00	33.5	3,116	3,918	4,177
15. Replacement heifers	9-10	Confined	Jan-May	8.2	6.90	68.6	6,853	8,585	8,633
16. Replacement heifers	14-15	Pasture	Jun-Sep	8.8	5.77	61.5	4,969	6,225	6,260
17. Replacement heifers	18-19	Confined	Oct-Dec	10.1	6.90	84.5	5,143	6,443	6,479
18. Finisher heifers	8-9	Feedlot	Jan-May	10.1	4.00	49.0	3,935	6,192	8,192
19. Stocker heifers	8-9	Feedlot	Jan-May	7.8	7.30	69.0	5,474	8,612	11,395
20. Stocker heifers	13-14	Pasture	Jun-Sep	8.6	5.77	60.1	3,854	6,064	8,023
21. Finisher heifers	17-18	Feedlot	Oct-Dec	10.8	4.00	52.4	1,711	2,692	3,561
22. Finisher steers	8-9	Feedlot	Jan-May	10.8	4.00	52.4	5,732	9,009	10,007
23. Stocker steers	8-9	Feedlot	Jan-May	8.2	7.30	72.6	8,524	13,397	14,881
24. Stocker steers	13-14	Pasture	Jun-Sep	8.3	5.77	58.0	5,510	8,660	9,619
25. Finisher steers	17-18	Feedlot	Oct-Dec	11.4	4.00	55.3	2,524	3,967	4,407
26. Stocker Import heifers	8-9	Pasture	Jun-Sep	6.7	5.77	46.9	1,698	2,601	2,076
27. Import heifers	12-13	Feedlot	Oct-Dec	9.8	4.00	47.5	1,299	1,989	1,588
28. Import heifers	8-9	Feedlot	Jun-Nov	9.0	4.00	43.6	2,424	3,712	2,964
29. Stocker Import steers	8-9	Pasture	Jun-Sep	7.5	5.77	52.5	1,901	2,911	2,324
30. Import steers	12-13	Feedlot	Oct-Dec	10.2	4.00	49.5	1,352	2,070	1,652
31. Import steers	8-9	Feedlot	Jun-Nov	9.5	4.00	46.1	2,436	3,730	2,978
Total methane production, t yr ⁻¹							296,715	393,373	417,854
Total CO ₂ equivalents (total annual methane production x 21), t yr ⁻¹							6,231,015	8,260,833	8,774,934

1 ^z Total daily dry matter intake (DMI) was determined by CowBytes[®], Beef Ration Balancer (v 4.8, Alberta Agriculture, Food and Rural Development). Assumptions:
2 **Wintering cows/herd bulls**, British and British-continental crosses, body condition score=3.0, gestation length=282 d, calf birth weight=43 kg, wind speed=10 km hr⁻¹, night cooling, hair depth=0.51 cm,
3 hair condition dry and clean, average hide thickness, no mud in pen, no heat stress, no ionophores, peak milk=10 kg d⁻¹, lactation number =4; **Cows & calves on pasture**, growth implant, no ionophore, no
4 melengesterol acetate (MGA), pasture quality good (750-1150 kg DM ha⁻¹, terrain level, average stocking rate=5 ac cow-calf pair⁻¹ or 1 ac feeder⁻¹; **Feedlot cattle**, growth implant, ionophore, MGA for heifers,
5 body condition score=3.0, heifer slaughter weight=590 kg, steer slaughter weight=612, fed to 26.8% empty body fat or Canada AA marbling. Current ambient temperature (CT) = -10°C, previous ambient
6 temperature (PT) = -10°C for Jan-Apr.; CT = 15°C, PT = 15°C for May-Oct.; CT = -5°C, PT = 0°C for Oct-Dec; CT = -5°C, PT = -10°C for Jan-May; CT = 10°C, PT = -10°C for Jan-Jul.

1 ^y Methane lost, as a percentage of gross energy intake (GEI), were based on the following studies: Categories 1, 2 and 3 (McCaughey et al. 1999); Categories 4 and 6 (Okine et al. 1989); Categories 5, 7,
2 16, 20, 24, 26, and 29 (McCaughey et al. 1997; Boadi et al. 2002); Categories 8, 9, 13, 14, 18, 21, 22, 25, 27, 28, 30 and 31(Beauchemin and McGinn 2005); Categories 10, 15 and 17 (Boadi and
3 Wittenberg 2002); Categories 11, 12, 19 and 23 (Beauchemin and McGinn 2005).

4 ^x Methane, in kg hd⁻¹ yr⁻¹, was calculated as follows: (((DMI, kg d⁻¹ x 18.45 MJ kg⁻¹ DM x (methane lost as a % of GEI/100))/0.0555606 MJ g⁻¹) x 365)/1000), where 18.45 MJ kg⁻¹ DM is the gross
5 energy of the diet and 0.0555606 is the energy content (MJ) of one g of methane.

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Table 5. Methane emissions from enteric fermentation in Alberta's beef cattle, as determined by CowBytes[®] and Blaxter and Clapperton's (1965) equation, for 1990, 1996 and 2001.

Categories	Age, mo	Location	Time of year	Total DMI ^z kg d ⁻¹	Total maint. ^z kg d ⁻¹	Methane lost ^y , % of Gross Energy Intake	Methane ^x kg hd ⁻¹ yr ⁻¹	Methane, t yr ⁻¹		
								1990	1996	2001
1. Cows – 3 rd trimester	Unk	Confined	Jan-Apr	10.9	10.9	7.58	100.1	51,564	66,368	69,079
2. Cows - lactating	Unk	Pasture	May-Sep	12.9	12.1	7.31	114.3	75,104	96,667	100,616
3. Cows – 2 nd trimester	Unk	Confined	Oct-Dec	9.3	9.3	7.27	81.9	32,349	41,637	43,338
4. Breeding bulls	Unk	Confined	Jan-Apr	17.4	12.9	7.30	154.0	4,760	6,006	5,641
5. Breeding bulls grazing	Unk	Pasture	May-Oct	15.9	11.2	7.25	139.7	6,620	8,352	7,843
6. Breeding bulls	Unk	Confined	Nov-Dec	18.9	14.0	7.30	167.3	2,628	3,316	3,114
7. Stocker calves, grazing	<6	Pasture	Apr-Sep	2.9	1.5	7.28	25.6	20,725	26,063	27,788
8. Beef calves, import/steer	8-9	Feedlot	Jan-Jul	10.2	4.4	6.48	80.1	0	0	3,753
9. Beef calves, import/heif.	8-9	Feedlot	Jan-Jul	9.8	4.3	6.55	77.7	0	0	3,642
10. Replacement heifers	6-7	Confined	Oct-Dec	6.6	4.2	7.20	57.6	3,646	4,585	4,889
11. Stocker heifers	6-7	Feedlot	Oct-Dec	6.4	4.1	7.21	55.9	3,436	4,321	4,607
12. Stocker steers	6-7	Feedlot	Oct-Dec	6.7	4.2	7.18	58.3	5,428	6,825	7,277
13. Finisher heifers	6-7	Feedlot	Oct-Dec	6.4	3.1	6.89	53.5	3,288	4,134	4,408
14. Finisher steers	6-7	Feedlot	Oct-Dec	6.9	3.1	6.63	55.5	5,166	6,496	6,926
15. Replacement heifers	9-10	Confined	Jan-May	8.2	5.4	7.24	72.0	7,195	9,013	9,063
16. Replacement heifers	14-15	Pasture	Jun-Sep	8.8	5.3	7.12	75.9	6,131	7,680	7,723
17. Replacement heifers	18-19	Confined	Oct-Dec	10.1	6.6	7.34	89.9	5,471	6,853	6,892
18. Finisher heifers	8-9	Feedlot	Jan-May	10.1	4.5	6.60	80.8	6,494	10,218	13,520
19. Stocker heifers	8-9	Feedlot	Jan-May	7.8	4.9	7.18	67.9	5,383	8,470	11,206
20. Stocker heifers	13-14	Pasture	Jun-Sep	8.6	5.2	7.12	74.3	4,759	7,488	9,907
21. Finisher heifers	17-18	Feedlot	Oct-Dec	10.8	4.6	6.43	84.2	2,751	4,329	5,727
22. Finisher steers	8-9	Feedlot	Jan-May	10.8	4.6	6.43	84.2	9,219	14,489	16,093
23. Stocker steers	8-9	Feedlot	Jan-May	8.2	5.1	7.17	71.2	8,367	13,150	14,606
24. Stocker steers	13-14	Pasture	Jun-Sep	8.3	4.8	7.06	71.0	6,740	10,594	11,767
25. Finisher steers	17-18	Feedlot	Oct-Dec	11.4	4.7	6.31	87.1	3,980	6,255	6,948
26. Stocker Import heifers	8-9	Pasture	Jun-Sep	6.7	3.9	7.07	57.4	2,080	3,186	2,543
27. Import heifers	12-13	Feedlot	Oct-Dec	9.8	4.1	6.36	75.6	2,066	3,164	2,526
28. Import heifers	8-9	Feedlot	Jun-Nov	9.0	3.5	6.07	66.2	3,678	5,632	4,496
29. Stocker Import steers	8-9	Pasture	Jun-Sep	7.5	4.5	7.11	64.7	2,344	3,589	2,865
30. Import steers	12-13	Feedlot	Oct-Dec	10.2	4.2	6.30	77.9	2,129	3,261	2,603
31. Import steers	8-9	Feedlot	Jun-Nov	9.5	3.6	5.96	68.6	3,628	5,556	4,436
Total methane production, t yr ⁻¹								297,128	397,694	425,844
Total CO ₂ equivalents (total annual methane production x 21), t yr ⁻¹								6,239,688	8,351,574	8,942,724

^z Total daily dry matter intake (DMI) and daily DMI for maintenance were determined by CowBytes[®], Beef Ration Balancer (v 4.8, Alberta Agriculture, Food and Rural Development). Assumptions: **Wintering cows/herd bulls**, British and British-continental crosses, body condition score=3.0, gestation length=282 d, calf birth weight=43 kg, wind speed=10 km hr⁻¹, night cooling, hair depth=0.51 cm, hair condition dry and clean, average hide thickness, no mud in pen, no heat stress, no ionophores, peak milk=10 kg d⁻¹, lactation number =4; **Cows & calves on pasture**, growth implant, no ionophore, no melengesterol acetate (MGA), pasture quality good (750-1150 kg DM ha⁻¹, terrain level, average stocking rate=5 ac cow-calf pair⁻¹ or 1 ac feeder⁻¹); **Feedlot cattle**, growth implant, ionophore, MGA for heifers, body condition score=3.0, heifer slaughter weight=590 kg, steer slaughter weight=612, fed to 26.8% empty body fat or Canada AA marbling. Current ambient temperature (CT) = -10°C, previous ambient temperature (PT) = -10°C for Jan-Apr.; CT = 15°C, PT = 15°C for May-Oct.; CT = -5°C, PT = 0°C for Oct-Dec; CT = -5°C, PT = -10°C for Jan-May; CT = 10°C, PT = -10°C for Jan-Jul.

^y Methane emissions were based on the equation developed by Blaxter and Clapperton (1965) and later corrected by Wilkerson et al. (1995): %CH₄ loss (% of gross energy) = 1.30 + (0.112DE) +

1 LOI(2.37-0.05DE), where DE is percent digestible energy or percent total digestible nutrients (TDN) from Table 2 and LOI is the level of daily DMI above that required for maintenance or daily
2 DMI (kg) divided by DMI required for maintenance (kg).
3 ^x Methane, in kg hd⁻¹ yr⁻¹, was calculated as follows: (((DMI, kg d⁻¹ x 18.45 MJ kg⁻¹ DM x (methane lost as a % of GEI/100))/0.0555606 MJ g⁻¹) x 365)/1000), where 18.45 MJ kg⁻¹ DM is the
4 gross energy of the diet and 0.0555606 is the energy content (MJ) of one g of methane.
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Table 6. Methane emission factors for enteric fermentation from different categories of beef cattle as determined by three methods.^z

Categories	Age, mo	Location	Time of year	Method of determination for methane Emission Factor (EF), kg hd ⁻¹ yr ⁻¹			% Diff. Method 2 vs. Method 1	% Diff. Method 3 vs. Method 1
				Method 1:	Method 2:	Method 3:		
				IPCC Tier 2	Literature Values ^y	CowBytes [®] & Blaxter & Clapperton ^x		
1. Beef cows – pregnant	Unk	Confined	Jan-Apr	61.7	114.3	100.1	85.2	62.2
2. Beef cows – lactating	Unk	Pasture	May-Sep	103.0	135.2	114.3	31.3	11.0
3. Beef cows – pregnant	Unk	Confined	Oct-Dec	73.6	97.5	81.9	32.6	11.4
4. Breeding bulls	Unk	Confined	Jan-Apr	84.5	123.8	154.0	46.5	82.3
5. Breeding bulls grazing	Unk	Pasture	May-Oct	114.2	111.2	139.7	-2.6	22.3
6. Breeding bulls	Unk	Confined	Nov-Dec	92.9	134.5	167.3	44.8	80.1
7. Beef calves, grazing	<6	Pasture	Apr-Sep	23.4	20.3	25.6	-13.5	9.2
Mean (SD)							32.0 (32.8)	39.8 (33.7)

2 ^z Details of how the emission factors were determined are given in Tables 3-5 or in the text of paper.

3 ^y Actual values taken from literature shown in Table 4.

4 ^x Actual values taken from CowBytes[®] and Blaxter and Clapperton's (1965) equation shown in Table 5.

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Table 7. Methane emission factors for enteric fermentation from different categories of beef cattle as determined by three methods.^z

Categories	Age, mo	Location	Time of year	Method of determination for Methane Emission Factor, kg hd ⁻¹ yr ⁻¹			%Diff. Method 2 vs. Method 1	%Diff. Method 3 vs. Method 1
				Method 1: IPCC Tier 2	Method 2: Literature Values ^y	Method 3: CowBytes [®] & Blaxter & Clapperton ^x		
8. Beef calves, import/steer	8-9	Feedlot	Jan-Jul	46.0	49.5	80.1	7.5	74.3
9. Beef calves, import/heif.	8-9	Feedlot	Jan-Jul	47.7	47.5	77.7	-0.3	63.1
10. Replacement heifers	6-7	Confined	Oct-Dec	44.7	55.2	57.6	23.5	28.8
11. Stocker heifers	6-7	Feedlot	Oct-Dec	44.7	56.6	55.9	26.7	25.1
12. Stocker steers	6-7	Feedlot	Oct-Dec	44.3	59.3	58.3	33.9	31.6
13. Finisher heifers	6-7	Feedlot	Oct-Dec	31.3	31.0	53.5	-0.7	71.1
14. Finisher steers	6-7	Feedlot	Oct-Dec	31.9	33.5	55.5	4.9	74.0
15. Replacement heifers	9-10	Confined	Jan-May	54.2	68.6	72.0	26.6	32.9
16. Replacement heifers	14-15	Pasture	Jun-Sep	77.7	61.5	75.9	-20.8	-2.3
17. Replacement heifers	18-19	Confined	Oct-Dec	70.3	84.5	89.9	20.2	27.8
18. Finisher heifers	8-9	Feedlot	Jan-May	49.4	49.0	80.8	-0.9	63.6
19. Stocker heifers	8-9	Feedlot	Jan-May	54.2	69.0	67.9	27.4	25.3
20. Stocker heifers	13-14	Pasture	Jun-Sep	70.6	60.1	74.3	-14.8	5.2
21. Finisher heifers	17-18	Feedlot	Oct-Dec	54.5	52.4	84.2	-4.0	54.4
22. Finisher steers	8-9	Feedlot	Jan-May	48.4	52.4	84.2	8.2	74.0
23. Stocker steers	8-9	Feedlot	Jan-May	53.6	72.6	71.2	35.3	32.8
24. Stocker steers	13-14	Pasture	Jun-Sep	68.8	58.0	71.0	-15.6	3.2
25. Finisher steers	17-18	Feedlot	Oct-Dec	53.0	55.3	87.1	4.2	64.3
26. Stocker Import heifers	8-9	Pasture	Jun-Sep	58.3	46.9	57.4	-19.6	-1.6
27. Import heifers	12-13	Feedlot	Oct-Dec	48.3	47.5	75.6	-1.7	56.4
28. Import heifers	8-9	Feedlot	Jun-Nov	47.4	43.6	66.2	-7.9	39.7
29. Stocker Import steers	8-9	Pasture	Jun-Sep	58.0	52.5	64.7	-9.6	11.5
30. Import steers	12-13	Feedlot	Oct-Dec	47.5	49.5	77.9	4.1	63.9
31. Import steers	8-9	Feedlot	Jun-Nov	46.2	46.1	68.6	-0.3	48.6
Mean (SD)							5.3 (16.8)	40.3 (25.6)

1 ^z Details of how the emission factors were determined are given in Tables 3-5 or in the text of paper.

2 ^y Actual values taken from literature shown in Table 4.

3 ^x Actual values taken from CowBytes[®] and Blaxter and Clapperton's (1965) equation shown in Table 5.