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The impact of breeding to reduce residual feed intake on enteric methane emissions from the Australian beef industry

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Abstract. The expected reduction in methane emissions from the Australian beef herd resulting from using bulls identified as being more feed efficient as a result of having a lower residual feed intake (RFI) was modelled, both in a single herd in southern Australia and in the national herd. A gene flow model was developed to simulate the spread of improved RFI genes through a breeding herd over 25 years, from 2002 to 2026. Based on the estimated gene flow, the voluntary feed intakes were revised annually for all beef classes using livestock populations taken from the Australian National Greenhouse Gas Inventory (NGGI). Changes in emissions (kg methane/animal.year) associated with the reduction in feed intake were then calculated using NGGI procedures. Annual enteric methane emissions from both the individual and national herd were calculated by multiplying the livestock numbers in each beef class by the revised estimates of emissions per animal. For an individual adopting herd, the annual methane abatement in year 25 of selection was 15.9% lower than in year 1. For the national herd, differential lags and limits to adoption were assumed for northern and southern Australia. The cumulative reduction in national emissions was 568 100 t of methane over 25 years, with annual emissions in year 25 being 3.1% lower than in year 1. It is concluded that selection for reduced RFI will lead to substantial and lasting methane abatement, largely as a consequence of its implementation as a breeding objective for the grazing beef herd.

Additional keywords: beef industry, greenhouse gas, feed efficiency, residual feed intake.

Introduction

Enteric methane production in the digestive tract of ruminants is a central process in the disposal of rumen hydrogen (Hegarty and Gerdes 1999) but it constitutes both a loss of digested energy and a major source of agricultural greenhouse gas emissions. Chemical approaches to reducing livestock methane production rate (MPR) have sought to inhibit methane production directly (Czerkawski and Breckenridge 1975) or to otherwise repartition fermentation to alternative hydrogen sinks (Goodrich *et al*. 1984; Joblin 1999). While the role of feed intake was recognised in most algorithms predicting MPR (Blaxter and Clapperton 1965; Pelchen and Peters 1998), altering feed intake to reduce MPR had received little attention due to concern over correlated reduction in animal production. Genetic variation in feed intake exists, independent of liveweight (LW) and average daily gain (ADG), and this variation provides a basis for genetic selection for feed-use efficiency of cattle (Arthur *et al*. 2001*a*). Cattle that eat less than their peers of equivalent LW and ADG have a low residual feed intake (RFI) and are more feed efficient, as shown by lines of cattle divergently selected for RFI (Arthur *et al*. 1996). The genetic correlations of RFI with other traits (Arthur *et al*. 2001*a*; Robinson and Oddy 2004) and the anticipated difference in MPR between low and high RFI cattle have been calculated (Herd *et al*. 2002; Okine *et al*. 2001). These MPR differences have been confirmed experimentally (Hegarty *et al*. 2005) and in a major recent Canadian study (Nkrumah *et al*. 2006). Australian cattle can now be commercially tested for RFI and the estimated breeding values (EBVs) of bulls are used in sire selection (Arthur *et al*. 2004). This study uses the herd structure and methodologies of the Australian National Greenhouse Gas Inventory (NGGI) (AGO 2004*a*) to model the methane abatement resulting from the anticipated adoption of RFI in breeding programs within the Australian beef industry over the next 25 years. The industry context is that in 2002 the NGGI estimated total enteric methane production by the beef industry to be 1 964 800 t, of which 1 895 700 t or 96.5% was from beef cattle on pasture and 69 100 t or 3.5% was from beef cattle in feedlots.

Methodology

A 4-step procedure was used to model the effect of the reduced RFI on enteric methane emissions. These steps were initially used to model feed

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intake and MPR in a single beef herd in southern Australia selecting for RFI, and then in the Australian national herd where only some cattle will be selected for RFI. The steps were:

(i) Develop a RFI gene flow model for a representative commercial beef herd.
(ii) Derive from the gene flow model the expected percentage annual change in feed intake for each age and sex cohort of beef animals over a 25-year planning horizon, consistent with those beef animal categories used in the 2002 NGGI (AGO 2004*a*).
(iii) Use these predicted changes in annual feed intake to determine the dry matter (DM) intake requirement of different classes of beef cattle for maintenance and for LW gain in the subsequent year. These discounted values are then applied to the AGO (2004*a*) methodology for calculating enteric methane production. AGO (2004*a*) uses the equations of Minson and McDonald (1987) and Blaxter and Clapperton (1965) to predict DM intake and emissions of grazing cattle respectively, while the equation of Moe and Tyrrell (1979) is used to predict methane production from feedlot cattle.
(iv) Multiply the discounted methane production levels by beef cattle numbers, assuming lagged and differential adoption levels of selection for improved RFI by northern and southern Australian beef herds (including cattle in feedlots). The sum of emissions from each category provides the annual aggregate methane production for the beef industry over the 25-year planning horizon. These values are then compared with the base level of 2002 methane output.

All modelling, including replication of the 2002 NGGI (AGO 2004*b*) for enteric methane emissions from beef cattle on pasture and in feedlots, was implemented using Matlab Version 7.0 (Mathworks Inc. 2004) software.

A number of biological and management assumptions were necessary to model the impact of the RFI technology at the farm. Following Exton *et al*. (2000), it was assumed that beef producers could initially purchase bulls with EBVs for RFI that were 4% better than average bulls in the Australian herd. This is equivalent to a reduction in RFI of −0.4 kg DM/day, assuming an initial average intake of about 10.0 kg DM/day. Furthermore, an annual reduction in RFI of the seedstock herd of 0.16 kg DM/day was assumed to be feasible (Arthur *et al*. 2001*b*). However, given the likelihood that multitrait breeding objectives will be pursued by the industry, this annual potential rate of progress in RFI was assumed to be halved to 0.08 kg DM/day (Exton *et al*. 2000). In the study by Arthur *et al*. (2001*b*), daily feed intake averaged 10.5 kg DM/day for cattle that had not been selected for the RFI trait. Therefore, a reduction in RFI of 0.08 kg DM/day is equivalent to a 0.76% improvement in RFI per year that is used in the gene flow model.

Gene flow model

The accumulated improvement in RFI was determined by developing a gene flow model based on fixed proportions of the age cohorts within a representative commercial herd, with bulls purchased from the seedstock sector. Other biological and technical parameters concerning herd dynamics were generally consistent with the gene flow model for Australian beef cattle developed by Nitter *et al*. (1994). It was assumed that no additional selection pressure for RFI occurred in commercial herds, with replacement heifers selected on traits that were independent of RFI.

The commercial female herd consisted of ten age groups ($m = 0,1,\ldots,9$) representing heifer calves (less than 1 year old), yearling heifers (1–2 years old), 2-year-old heifers and cows up to 9 years old. Bulls were sourced from seedstock herds at 3 years of age and used in the commercial herd for 3 years at a joining rate of 3%. The cow herd in steady-state was composed of a given proportion of animals in each age group, denoted by a vector $\mathbf{p}$ with elements p_m, satisfying the constraints:

$$0 < p_m < 1, \quad \text{and} \quad \sum_{m=2}^{9} p_m = 1.$$

The values of $\mathbf{p}$ are 0.198, 0.171, 0.147, 0.127, 0.110, 0.095, 0.082 and 0.070 for ages 2 to 9 respectively, reflecting an adult mortality rate of 2% and an annual cow cull rate of 12% for non-pregnancy and other production criteria typical of southern Australian beef production systems.

The improvement in RFI ($C_{t,m}$) achieved by a given age cohort (m) in the commercial herd during year t was calculated based on the number of improved animals available the previous year:

$$C_{t,m} = C_{t-1,m-1}, \quad \text{for} \quad m = 1, \ldots, 9. \tag{1}$$

The improvement in RFI was introduced through the calves as

$$C_{t,0} = \sum_{m=2}^{9} p_m \frac{C_{t,m} + B_t}{2}. \tag{2}$$

B_t represents the average savings in feed intake of the existing seedstock herd:

$$B_t = \frac{\sum_{n=1}^{3} S_{t,n}}{3} \tag{3}$$

where $S_{t,n}$ represents the improvement in RFI by bull age n in year t in the seedstock herd, and each bull is used in the commercial herd for 3 years.

The RFI of older bulls depends upon the level of the trait in previous years:

$$S_{t,n} = S_{t-1,n-1}; \quad \text{for} \quad n = 2, 3 \quad \text{and} \quad t > 1. \tag{4}$$

The average RFI of new bulls ($n = 1$) entering the commercial herd was determined by:

$$S_{t,n} = S_{t-1,1} + \delta_g, \quad \text{for} \quad t > 1 \tag{5}$$

where δ_g is the percentage annual improvement in the average EBV for RFI.

It is acknowledged that differences in biological and technical parameters exist between the northern and southern Australian systems which influence potential rates of genetic gain. However, several differing population parameters have contrary effects on the potential rate of genetic gain in the northern and southern Australian herds respectively. For example, the average age at first calving is higher in the northern herd than that applied in this model, which would slow genetic progress. However, a shorter average productive lifetime in the northern herd compared with the southern herd would have the opposite effect by increasing the possible rate of genetic gain. Further, given the limited knowledge of RFI with respect to its correlation with other beef production traits, a single representative gene flow model was assumed to be adequate across all of the Australian herd. This gene flow model represented by setting $S_{1,1} = 4.0\%$ and $S_{1,2} = S_{1,3} = 0$ and then solving equations 1 to 5 iteratively through time for 25 years, from 2002 to 2026. Sensitivity analysis on the likely improvement in RFI EBV for the commercial herd was undertaken by changing the values of the initial improvement.

Solution of the model results in a matrix of predicted reductions in DM-intake for the commercial herd, measured relative to the base situation (2002 NGGI year). Table 1 shows the matrix $\mathbf{C}$, for which the elements are $C_{t,m}$. Matrix $\mathbf{C}$ has 25 rows and 10 columns, which represent the simulation years and age groups of females in the herd respectively. Male offspring were assumed to have the same phenotype for RFI, as females of the same age. That is, male calves have a predicted reduction in DM intake of $C_{t,0}$. Male (steer) offspring older than 1 year (AGO 2004*b*) were assumed to have a reduction in RFI equivalent to

Table 1. Percentage residual feed intake reduction (% of base year) for different age cohorts in a representative commercial herd over 25 years

Year	Age cohorts for cows (years)									Bulls
	<1	1–2	2	3	4	5	6	7	8	9	
1	0.67	0	0	0	0	0	0	0	0	0	1.33
2	1.46	0.67	0	0	0	0	0	0	0	0	2.92
3	2.45	1.46	0.67	0	0	0	0	0	0	0	4.76
4	2.96	2.45	1.46	0.67	0	0	0	0	0	0	5.52
5	3.56	2.96	2.45	1.46	0.67	0	0	0	0	0	6.28
6	4.17	3.56	2.96	2.45	1.46	0.67	0	0	0	0	7.04
7	4.82	4.17	3.56	2.96	2.45	1.46	0.67	0	0	0	7.80
8	5.48	4.82	4.17	3.56	2.96	2.45	1.46	0.67	0	0	8.56
9	6.17	5.48	4.82	4.17	3.56	2.96	2.45	1.46	0.67	0	9.32
10	6.89	6.17	5.48	4.82	4.17	3.56	2.96	2.45	1.46	0.67	10.08
11	7.61	6.89	6.17	5.48	4.82	4.17	3.56	2.96	2.45	1.46	10.84
12	8.33	7.61	6.89	6.17	5.48	4.82	4.17	3.56	2.96	2.45	11.60
13	9.04	8.33	7.61	6.89	6.17	5.48	4.82	4.17	3.56	2.96	12.36
14	9.76	9.04	8.33	7.61	6.89	6.17	5.48	4.82	4.17	3.56	13.12
15	10.49	9.76	9.04	8.33	7.61	6.89	6.17	5.48	4.82	4.17	13.88
16	11.22	10.49	9.76	9.04	8.33	7.61	6.89	6.17	5.48	4.82	14.64
17	11.96	11.22	10.49	9.76	9.04	8.33	7.61	6.89	6.17	5.48	15.40
18	12.70	11.96	11.22	10.49	9.76	9.04	8.33	7.61	6.89	6.17	16.16
19	13.44	12.70	11.96	11.22	10.49	9.76	9.04	8.33	7.61	6.89	16.92
20	14.18	13.44	12.70	11.96	11.22	10.49	9.76	9.04	8.33	7.61	17.68
21	14.93	14.18	13.44	12.70	11.96	11.22	10.49	9.76	9.04	8.33	18.44
22	15.68	14.93	14.18	13.44	12.70	11.96	11.22	10.49	9.76	9.04	19.20
23	16.43	15.68	14.93	14.18	13.44	12.70	11.96	11.22	10.49	9.76	19.96
24	17.18	16.43	15.68	14.93	14.18	13.44	12.70	11.96	11.22	10.49	20.72
25	17.93	17.18	16.43	15.68	14.93	14.18	13.44	12.70	11.96	11.22	21.48

the average of $C_{t,1}$ and $C_{t,2}$, to account for steers kept for longer than 2 years.

The predicted changes in RFI of different classes of beef animals were applied to the NGGI using the methodology developed by the AGO (2004*a*) to derive the adjusted total enteric methane production from beef cattle. That is, the DM intake (I_{ijkl} kg DM/animal.day) of cattle is determined from liveweight (*W*) and liveweight gain (*LWG*) for each state (*i*), region (*j*), season (*k*) and age and class of beef animal (*l*) and adjusted for changes in RFI for each class of animal for each year ($C_{t,m}$):

$$I_{ijklt} = [(1.185 + 0.00454W_{ijkl} - 0.0000026W_{ijkl}^2 + 0.315LWG_{ijkl})^2 \times MA_{ijkl=5}] \times (1 - C_{t,m}) \quad (6)$$

where $MA_{ijkl=5}$ is the additional intake for milk production (Minson and McDonald 1987), given by:

$$MA_{ijkl=5} = (LC_{ijkl=5} \cdot FA_{ijkl=5}) + [(1 - LC_{ijkl=5}) \cdot 1]. \quad (7)$$

$LC_{ijkl=5}$ is the proportion of cows over 2 years of age lactating ($l = 5$) and $FA_{ijkl=5}$ is a feed intake adjustment for calving cows (AGO 2004*a*). This DM intake is converted to gross energy intake (*GEI*), assuming that feed dry matter has, on average, a gross energy intake of 18.4 MJ/kg (AGO 2004*a*; SCA 1990):

$$GEI_{ijklt} = 18.4I_{ijklt}. \quad (8)$$

The DM intake relative to that needed for maintenance (L_{ijklt}) was estimated as actual intake divided by DM intake for maintenance of a non-lactating animal with no weight gain (AGO 2004*a*):

$$L_{ijklt} = I_{ijklt}/(1.185 + 0.00454W_{ijkl} - 0.0000026W_{ijkl}^2)^2. \quad (9)$$

From this, the percentage of the gross energy intake that is yielded as methane was derived to finally determine total enteric methane production using the equation from Blaxter and Clapperton (1965):

$$Y_{ijklt} = 1.3 + 0.112DMD_{ijkl} + L_{ijklt}(2.37 - 0.05DMD_{ijkl}) \quad (10)$$

where, DMD_{ijkl} is the digestibility of feed (%) as detailed by AGO (2004*a*). Then total daily production of methane (M_{ijklt}, kg CH_4/animal.day) was calculated as:

$$M_{ijklt} = (Y_{ijklt}/100)GEI_{ijklt}/F \quad (11)$$

for temperate regions of Australia, where *F* represents the energy per kg of methane (55.22 MJ/kg CH_4). While the equation of Blaxter and Clapperton (1965) used to predict methane emission from grazing cattle has been shown to be biased predictions in some situations (Benchaar *et al*. 1998), it was used in this study because (i) it is currently used in calculating Australia's national inventory and (ii) it is appropriate for the mid-range digestibility pastures that predominate in the Australian inventory.

For cattle on tropical pastures, total daily methane production is given by (AGO 2004*a*; Kurihara *et al*. 1999):

$$M_{ijklt} = (41.5I_{ijklt} - 36.2)/1000. \quad (12)$$

Total annual enteric methane production was then derived for each region, state, season and beef animal class as identified by NGGI, by multiplying by the number of cattle and summing to estimate the national annual enteric methane production (AGO 2004*a*).

For feedlot cattle, the NGGI uses methane emission equations developed by Moe and Tyrrell (1979), which predicts daily enteric methane yield (Y_{ij}, MJ CH_4/animal.day) from 3 components of dietary carbohydrate intake. These are soluble residue (SR_{ij}), hemicellulose (H_{ij}) and cellulose (Ce_{ij}), for feedlot cattle in each state (i) and for an average length of stay in the feedlot (j), which was taken to be 75, 140 or 250 days providing 3 classes of feedlot cattle (AGO 2004*a*). Data on carbohydrate content of feedlot rations used in the NGGI had been obtained from a professional scientific panel, and daily intake of feedlot cattle was estimated as 2.4, 2.2 and 2.0% of LW for domestic, export and Japanese ox classes in the NGGI.

$$Y_{ij} = 3.406 + 0.51SR_{ij} + 1.736H_{ij} + 2.648Ce_{ij} \quad (13)$$

Each of these carbohydrate components is determined from the total intake of the animal (adjusted by the estimated improvement in NFI, $C_{t,m}$), the estimated proportions of the diet of each class of animal that is grass, legume, grain and other concentrates and the SR_{ij}, H_{ij} and Ce_{ij} fractions of each of these components. Detailed equations, dietary assumptions and feedlot cattle numbers are provided in the NGGI methodology (AGO 2004*a*) and related appendices (AGO 2004*b*).

Total daily methane production (M_{ij}, kg CH_4/animal.day) is given by (AGO 2004*a*):

$$M_{ij} = Y_{ij}/F \quad (14)$$

where F has a value of 55.22 MJ/kg CH_4 (Brouwer 1965). Enteric methane production was then summed for all classes of feedlot cattle, across all states to derive an annual estimate of their methane production. This was then added to the estimate for beef cattle on pasture.

Individual herd

In the first instance, the gene flow model was applied to an individual 100-cow commercial beef herd. This herd was assumed to be a self-replacing cow-calf enterprise producing heavy feeder steers. Cows were joined to calve in August and September, and heifers were joined to calve at 2 years of age. Heifers were sold as weaners at around 9 months of age, while steers were sold at approximately 18 months of age at 440–450 kg LW. Herd parameters, including mortality, and cull rates are provided in Alford *et al.* (2004) and are consistent with the herd model described in the gene flow model. Assumptions regarding average seasonal LW, ADG and seasonal DM digestibility of feed intake were the values applied in the NGGI (AGO 2004*a*) for New South Wales.

A 25-year planning period was used in this study, similar to previous investigators examining RFI (e.g. Archer and Barwick 1999; Exton *et al.* 2000). This is also consistent with the timeframe commonly used by geneticists to evaluate beef-cattle breeding programs, for example Nitter *et al.* (1994). To implement the effect of improved RFI, the DM intake estimates of the 100-cow beef herd were adjusted for each class of animal and the total annual production of methane determined for each year of the planning horizon.

National herd

The same methodology was applied to the national herd numbers detailed in the NGGI (AGO 2004*b*). However, various adoption rates and adoption time lags were applied as detailed below. Also, the extensive nature and generally lower fertility rates of the northern Australian beef herd (O'Rourke *et al.* 1990) reduces the potential rate of genetic gain possible. Factors such as extended mating and calving periods (Davis 1993), lead to lower annual rates of genetic improvement. Consequently, it was assumed that the rate of genetic improvement in the northern beef herd (0.38% per annum) for RFI was half the annual gain achieved by the southern herd (0.76% per annum).

As the 2002 NGGI (AGO 2004*b*) aggregates cows greater than 2 years old into 1 category, the discount to DM intake applied to this category was a weighted average improvement of RFI of the cow age cohorts obtained from the gene flow model. That is, in any year t, the discount applied to the DM intake to the annual number of cows greater than 2 years old is:

$$\text{RFI Cows } (>2 \text{ years old})_t = \sum_{m=2}^{9} p_m C_{t,m}. \quad (15)$$

Adoption rates

Figure 1 illustrates the assumed trend in adoption of genetic improvement in RFI for the southern and northern beef herds. The base adoption rate assumed for the trait by the Australian beef industry was zero in 2002, and the maximum adoption level was 30% for all cattle, consistent with that used by Griffith *et al.* (2004). This maximum is attained by year 11. The start year, 2002, is the first year that an EBV for RFI was published for Angus and Hereford-Poll Hereford breeds in Australia (Arthur *et al.* 2004).

For the northern herd in Australia, it was assumed that adoption would lag the southern herd adoption rate by 5 years (Farquharson *et al.* 2003) and that the maximum adoption level would be only half that achieved in the southern herd. In 2002, an estimated 80.1% of the northern herd contained some level of Brahman or other tropical breed genetics (Riley *et al.* 2001), and while RFI has been examined in tropically adapted breeds (Arthur *et al.* 2004), commercial application has occurred mostly in the southern beef herd (Exton *et al.* 2000). Furthermore, the overall benefit of the trait in the northern beef herd may be of less potential significance because of lower overall feed costs per unit of turnoff (Barwick *et al.* 2003).

Results and discussion

As seen in Table 1, by year 25 following adoption of the RFI trait, the reduction in RFI in a commercial herd in southern Australia ranges from 11.22 to 21.48% for the various classes of beef cattle. These realised benefits are sensitive to the level of annual genetic gain and the pattern of adoption among Australian beef producers.

Response in an adopting herd

For the representative 100-cow commercial herd in southern Australia, which purchased bulls of superior RFI in year 1, the cumulative total of enteric methane abatement over the 25-year simulation period was 24.5 t (Fig. 2). This represents a 7.4% cumulative decrease in enteric methane production over the simulation period, compared with an unimproved herd. Figure 2 shows that the annual saving in methane production over an unimproved herd by year 25 was 15.9%. This farm analysis represents the potential enteric methane

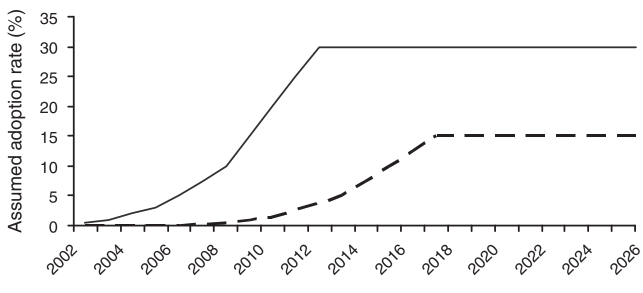

Fig. 1. Assumed adoption rate (%) of genetic improvement of residual feed intake in southern (solid line) and northern (dashed line) Australian beef herds.

abatement for a commercial herd that uses the RFI superior bulls from year 1.

The continuous reduction in RFI and enteric methane production modelled here, is supported by findings from research into feed efficiency carried out in other species, indicating that there is substantial genetic variation for RFI in animal populations. For example, Hughes and Pitchford (2004) found a significant and symmetrical response to selection for RFI in mice over 11 generations. These findings were consistent with other researchers (Bünger *et al*. 1998; Nielsen *et al*. 1997), where selection for feed efficiency traits (corrected for body weight) resulted in linear responses for up to 38 generations examined. This indicates that there is substantial genetic variation for the trait, which is unlikely to be exhausted within the period considered in this simulation.

Response in the national herd

The simulation of the effect of RFI reduction on enteric methane production of the entire Australian beef herd incorporated the various patterns of adoption shown in Figure 1. Over the 25-year simulation period, a cumulative total of 568 100 t of methane was abated. In the final year of the simulation period, the annual saving in enteric methane production from the Australian beef industry was 60 900 t or 3.1% of the 2002 inventory total of 1 964 800 t of methane. In terms of CO_2 equivalents (CO_2–e), this annual saving represents 1 278 900 t CO_2–e (given that methane has 21 times the global warming potential of CO_2). This is about 1.9% of the 67 600 000 t CO_2–e of total net greenhouse gas emissions (including methane and other gases) produced by the Australian livestock sector in 2002, which in turn was responsible for 12.3% of net national emissions (AGO 2004*b*).

A potential additional economic benefit as a consequence of a reduction in methane emissions from the Australian beef herd may also be derived from the application of carbon trading markets. Currently, the NSW Greenhouse Abatement Scheme has a penalty for NSW power generators exceeding their CO_2 targets of AU$10.50/t of CO_2 (NSW Independent Pricing and Regulatory Tribunal 2005). The estimated 568 100 t of methane abated over 25 years is equivalent to an average annual saving of 477 204 t CO_2–e which on current values would imply an annual value of AU$5 million across the beef industry.

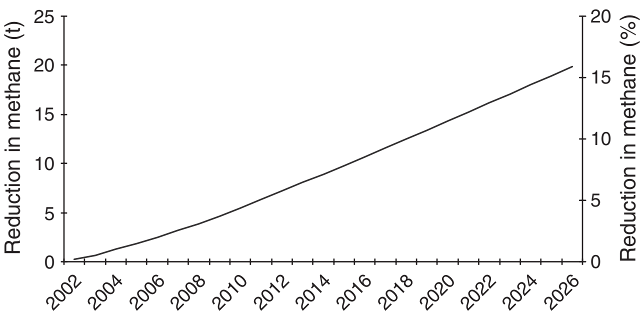

Fig. 2. Estimated annual reduction in enteric methane produced by a representative 100-head commercial herd in southern Australia as a result of selection of bulls using an index providing lower residual feed intake over the period 2002 to 2026. Data are percentage reduction in emissions relative to the base year (2002).

Benefits relating to methane abatement from reduced RFI might be enhanced by increasing the annual rate of genetic gain and/or by increasing the level of adoption of the RFI technology by Australian beef producers. In relation to increasing the annual rate of genetic gain, the identification of superior animals for RFI is currently undertaken by conducting relatively expensive feed-intake trials on individual animals (Graser 2004). Alternate methods of identifying animals that are genetically superior for RFI, such as the use of indirect markers such as insulin-like growth factor-I (IGF-I), may decrease this cost (Moore *et al*. 2005). Using IGF-I to indirectly select for RFI is quicker, cheaper and can be applied to younger animals. This allows breeders to make selection decisions earlier and may increase the number of animals measured for feed intake, thus increasing the potential for identifying genetically superior animals (Moore *et al*. 2005).

Sensitivity to model assumptions

In relation to increasing the rate of adoption and/or raising the maximum adoption level of RFI improvement, especially in the northern herd, the new Cooperative Research Centre for Beef Genetic Technologies (Beef CRC) has an objective to increase adoption rates for RFI technologies (Beef CRC 2004).

Table 2 shows the impact on the base results of an increase in the assumed level of adoption or in the annual rate of genetic gain. A 50% increase in the annual rate of genetic improvement in RFI for bulls used in the commercial herd, from 0.76 to 1.14% per year, would result in a decrease in annual enteric methane production of 84 400 t, or 4.3% by year 2026 (year 25 of the simulation). Similarly, a 50% increase in the maximum level of adoption of the RFI technology to 45 and 22.5% for the southern and northern beef industries respectively, would result in an increase in annual abatement of enteric methane to 91 300 t or 4.7% by year 25. This analysis provides a measure of the potential benefits of the Beef CRC's goal of enhancing adoption of RFI technologies.

While breeding for lower RFI will result in decreases in enteric methane produced by the Australian beef industry, the long generation intervals associated with cattle breeding programs mean that the technology should be considered as a longer-term strategy for methane abatement. It is evident from Figure 3 that there will be limited abatement from the implementation of the RFI technology in the first carbon-accounting period of the Kyoto Protocol, from 2008 to 2012.

Table 2. Sensitivity of final year enteric methane savings to assumed adoption rates of genetic gain in the Australian herd

	Methane abated (t)	(% of base scenario)
Base scenario (0.76% annual rate of genetic improvement and 30% maximum adoption)	60 900	n.a.
50% increase in maximum adoption rates	91 300	50.0
50% increase in annual rate of genetic gain	84 400	38.6

In 2008, only 1800 t, or 0.1% of enteric methane would be saved over the 2002 inventory year. By 2012, 10 700 t of enteric methane would be saved, or 0.5%, relative to the 2002 inventory.

The simulation assumes that the cattle population remains constant and equal to the 2002 beef cattle population. The Australian beef-cattle herd has decreased slightly from 24 739 million in 2002 to 24 110 million animals in 2004 (ABS 2004). Australian beef cattle numbers are typically cyclical, and are influenced by the US cattle cycle (Griffith and Alford 2002). However, since 1984 the Australian herd has increased at an average annual rate of 1.15%, although prior to this period it reached a record 29.833 million animals in 1976. Another important factor is the increase in the size of the northern herd relative to the southern herd. This is partly a consequence of increased productivity amongst northern beef producers (Gleeson *et al*. 2003). Given the assumed difference in adoption and the potential impact of reduced RFI on northern and southern herds, any continuing regional shift in beef cattle numbers will impact on predicted emissions from the industry.

Although the current assessment has only considered abatement of methane, reduced RFI would also reduce the intake of dietary nitrogen and, hence, potential nitrous oxide (N_2O) release from manure. Australia's dry environment and extensive grazing practices mean that overall N_2O emissions from manure are relatively modest. But in moister environments and locations where pastures are nitrogen fertilised, abatement of N_2O emission could also be a substantial benefit from improved RFI.

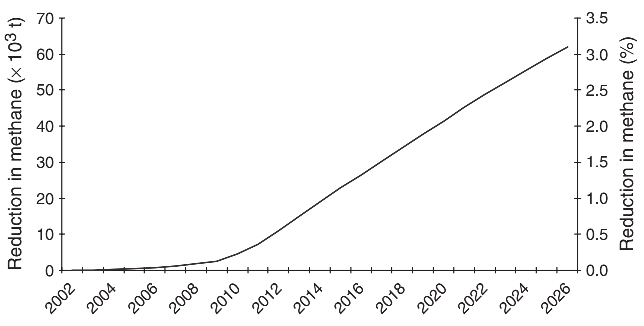

Fig. 3. Estimated annual reduction in enteric methane produced by the Australian beef herd relative to the base year (2002) as a result of reduced residual feed intake over the period 2002 to 2026.

Alternative methane abatement strategies

As an existing technology, livestock selection for reduced RFI is one of the few readily implementable strategies for reducing methane emissions from the beef industry that does not require a concomitant reduction in livestock numbers or level of individual animal production. Improvement of pasture digestibility will generally reduce the methane cost of beef production (methane/kg of beef), but increase the daily (or annual) methane emission by the individual, due to the rise in feed intake associated with improved digestibility of pasture (Freer and Jones 1984; Hegarty 2001). There are few rumen modification strategies available to the beef industry to reduce methane production. The ionophore monensin is one available technology that reduces methane production, partly by reducing feed intake and partly by altering rumen hydrogen partitioning. Although early studies suggested that monensin's abatement effect was short lived, recent studies have shown a longer-term impact (Johnson *et al*. 1994; Mbanzamihigo *et al*. 1996). Feed additives that inhibit methane production are being considered (McCrabb *et al*. 1997), but since these are likely to require ongoing inclusion on a daily basis, they may only be suited to feedlot cattle, which contribute only 3.5% of methane emissions from the Australian beef herd. It can be expected that reductions in enteric methane production due to reduced RFI will be achieved in addition to abatement delivered by technologies modifying rumen fermentation.

An additional benefit of the selection for reduced RFI is that it has been shown to be a profitable technology for southern Australian beef producers (Griffith *et al*. 2004), as a result of the herd's improved feed efficiency. Specifically, farm level benefits include the potential to increase stocking rates and/or to reduce supplementary feed costs in poor pasture growth seasons (Alford *et al.* 2006). Furthermore, the estimated 24.5 t of methane saved over 25 years by the representative southern Australian herd is equivalent to an annual average saving of 20.6 t CO_2–e which could be valued given access to a carbon trading scheme. Using the current value per tonne of CO_2 of AU$10.50 (NSW Independent Pricing and Regulatory Tribunal 2005), a minimum value for the saved methane output due to adoption of RFI genetics for a 100-cow southern herd is on average AU$216 per annum. Therefore, enteric methane abatement resulting from selection for lower RFI is not at the expense of farm profit, as may be the case for some alternative abatement strategies.

Conclusions

Selection for reduced RFI is expected to reduce greenhouse gas emissions from beef cattle, although the time lag for abatement is substantial. RFI offers a commercially attractive and practical abatement technology because it does not demand reductions in livestock numbers or level of production. The 2 particular aspects of selection for improved RFI that ensure its role in livestock greenhouse gas abatement are (i) the impact of the genetic improvement on the grazing herd, not just finishing animals, and (ii) the cumulative nature of the response over time.

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