SCIENCE DISCUSSION PAPER

Reduction in greenhouse gas emissions associated with selection for residual feed intake in beef cattle in Alberta

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Submitted to:
Alberta Environment
and
Alberta Agriculture and Rural Development

CONTENTS

ABBREVIATIONS

ADG	Average daily gain
AGBU	Animal Genetics and Breeding Unit
AUD	Australian dollar
BIO	Beef Improvement Ontario
BLUP	Best linear unbiased prediction
BW	Bodyweight
CAD	Canadian dollar
CCIA	Canadian Cattle Identification Agency
CH_4	Methane
CO_2	Carbon dioxide
CO_2 E	Carbon dioxide equivalent
DM	Dry matter
DMI	Dry matter intake
EBV	Estimated breeding values
EPD	Estimated progeny difference
FCR	Feed conversion ratio
GHG	Greenhouse gas
GEI	Gross energy intake
IGF-I	Insulin-like growth factor – I
MBV	Molecular breeding value
ME	Metabolizable energy
MJ	Megajoules
MMWT	Metabolic mid-weight
N_2O	Nitrous oxide
NBCEC	National Beef Cattle Evaluation Consortium
NFI	Net (or residual) feed intake
NGGI	National greenhouse gas inventory (Australia)
NPV	Net present value
NSW	New South Wales
QTL	Quantitative trait loci
RFI	Residual feed intake
RFI-F	Postweaning residual feed intake
RFI-P	Feedlot (finishing) residual feed intake
SF_6	Sulphur hexafluoride
SNP	Single nucleotide polymorphism

EXECUTIVE SUMMARY

Providing feed to animals is a major input cost in most animal production systems, hence improvement in feed utilization will improve profitability. The utilization of the feed consumed by an animal involves a complex of biological processes and interactions with the environment. In addition, it is complicated by the fact that feed intake is highly correlated with body size and level of production. To overcome these complexities and to relate feed intake to production system efficiency, several measures of feed efficiency have been developed and used. Residual feed intake is a measure of feed efficiency, and it represents the amount of feed consumed, net of the animal’s requirements for maintenance of body weight and production. In beef cattle, residual feed intake (RFI) is defined as the difference between an animal's actual feed intake and its expected feed intake based on its size and growth, hence efficient animals having lower (negative) RFI values. Relative to high RFI cattle, Low RFI cattle have been shown to emit less methane, a potent greenhouse gas (GHG).

The objective of this paper is to compile and review the state of the science relating to selection for residual feed intake (RFI) and its association with reduction in GHG emission in beef cattle. The scope for the work includes the assessment of the scientific feasibility of selection for RFI in beef cattle, and its link to quantified GHG reductions using a combination of the above information and scientific expert opinion. The intention is to use the information from this discussion paper as a basis for developing science-based standardized protocols to identify net GHG emission reductions for agricultural carbon offset projects as a result of improvements in agricultural management.

Residual feed intake is the amount of feed consumed, net of the animal’s expected requirements for maintenance of body weight and production. There is conclusive scientific evidence that cattle with low RFI consume less feed at the same level of production as high RFI cattle. There is genetic variation in RFI in most cattle breeds, and it is a heritable trait. This means that genetic improvement in RFI can be made through selection, and that progeny of low RFI cattle will consume less feed without compromising growth and other economically important traits. Cattle with low RFI produce less methane from enteric fermentation and also less manure, relative to high RFI cattle, due to that fact that they consume less feed. Selection for low RFI can therefore be used as a GHG mitigation strategy in beef cattle.

Selection for RFI is a profitable genetic improvement strategy to reduce the cost of beef production, and has the additional benefit of reducing the carbon footprint of the beef industry. The adoption of the RFI technology has already started in the beef industry in Alberta, with world-class facilities and quality assurance standards in place for testing cattle for RFI. Over 4,300 cattle have been tested for RFI in Alberta from 2000 to November 2008. The majority of these were research steers, heifers and cows, with only 1220 being commercial breeding bulls. The beef industry in Alberta is therefore in a good position to develop a project for GHG reduction credits based on selection for low RFI.

Recommendations for residual feed intake based carbon offset credit project

- The scientific evidence for the reduction in methane and manure production through selection for low RFI indicates that this is through the reduction in feed intake. This reduction in feed intake is captured by RFI, since it is the reduction in feed intake relative to the expected feed intake for the size and growth of the animal. Expressed as kg of feed [on dry matter (DM) basis and at a specified metabolizable energy (ME) content] per day, this should form the basis of any carbon credit project for GHG emission reduction from selection for low RFI.

- Currently in Alberta, RFI values for industry cattle are standardized to 10 MJ ME on as fed basis. There is therefore the need to express these values on DM basis.

- Fitting a regression to the data anytime there is an RFI test means that each test will have a mean of zero. This will make it difficult to track the progress of genetic improvement over time in a herd or across the province. It is therefore important that at some point when enough data have been collected, an RFI regression model is run with all the fixed effects fitted in the model. The equation obtained will then be used for all future tests, thus making it unnecessary to fit a regression model to each test.

- Australian data indicates that postweaning RFI (RFI-P) and feedlot finish RFI (RFI-F) are two different traits. It is recommended that RFI-P and RFI-F be considered as two traits in Alberta until such time that enough data has been generated under Alberta conditions to enable a re-evaluation.

- A centralized database needs to be developed in Alberta for collating, processing, and storage of all RFI test data. From this database, standardized data and results can then be sent out to owners of the animals tested or to other appropriate agencies, such as breed associations. This will ensure that all RFI data in Alberta are standardized in a consistent manner. It will also simplify any auditing requirements.

- To make it easier to verify that a breeding animal with the low RFI EBV was used to produce the progeny for which the GHG emission credits are being claimed it is important that the identification of animals tested for RFI be linked into the national livestock identification system administered by Canadian Cattle Identification Agency.

QUESTIONS TO BE EXPLORED AT WORKSHOP

(refer to pages 42-44 for further context)

1. Is the scientific evidence strong enough for the reduction in GHG emissions (methane and manure) from selection for low RFI in beef cattle through the reduction in feed intake?

2. Is the scientific evidence strong enough for the reduction in GHG emissions from selection for low RFI in beef cattle through improved digestibility and/or less methane being lost as a percentage of gross energy intake (e.g., 4% vs. 3% of GEI for a high grain diet)?

3. Can auditing of this protocol occur: a) by registering the RFID of bulls with certified RFI EBVs with a third party, and b) by registering the RFID of progeny produced from certified RFI EBV bulls with a third party?

4. What level of accuracy of RFI EBVs is acceptable?

5. Can carbon credits be claimed for second generation progeny whose parents do not have certified EBVs for RFI?

6. What sector of the beef industry claims the carbon credits?

7. Can carbon credits be claimed on overseas/out-of-country semen/bulls with certified RFI EBV?

OBJECTIVE AND SCOPE OF DISCUSSION PAPER

Introduction

In 1998 Canada signed the Kyoto Protocol committing to reduce greenhouse gas (GHG) emissions to 6% below the 1990 levels by 2008 to 2012 (Environment Canada 2006). The agreement was ratified by the Canadian government in 2004. With that came the need by all industries to examine and develop strategies to reduce their contribution to GHG emissions. The contribution of the agricultural sector to greenhouse gas (GHG) emissions in Canada is estimated at 62,000 kt [CO_2 equivalent (CO_2 E)] for 2006, which translates to 8.6% of the national emissions (Environment Canada 2008). The contribution of beef cattle (33.7%) to GHG emissions from the agricultural sector, is second only to the 48% from N_2O emissions from agricultural soils (Environment Canada 2008). Greenhouse gas emission by beef cattle is through methane production from enteric fermentation, and a small amount through manure management. It is therefore appropriate to examine strategies to reduce GHG from beef cattle. Recent research indicates that selection for low residual feed intake can reduce methane emissions by beef cattle.

Alberta is the first province in Canada to legislate GHG reductions. Starting on July 1, 2007 all companies that emit more than 100,000 tonnes of GHG a year must reduce their emission intensity by 12% per year starting in 2007 (Alberta Environment, news release, March 8, 2007; Bill 3, Climate Change and Emissions Management Amendment Act, Specified Gas Emitters Regulation). Companies can reduce their emissions intensity by making operational improvements, by buying an Alberta-based offset to apply against their emissions total or by contributing to a government fund that will invest in technology to reduce GHG emissions in the province. Buyers and sellers of GHG credits can register on-line with Climate Change Central, Emissions Offset and Trading (http://environment.alberta.ca/1238.html). Sellers must follow one of 12 quantification protocols which are filed on-line at the above mentioned website. There are three registered protocols relating to beef cattle: 1) Quantification protocol for including edible oils in cattle feeding regimes, 2) Reducing days on feed in the feedlot, and 3) Reducing age at slaughter in beef cattle. The first two protocols are marginal in their reduction of GHG and only result in $1.50-$2:00 in carbon credits/animal registered in the protocol (Basarab et al. 2007b), while the third could be more substantial (Basarab et al. 2007a).

Objective

The objective of this paper is to compile and review the state of the science relating to selection for residual feed intake (RFI) and its association with reduction in GHG emission in beef cattle. The review includes:

- Greenhouse gas emissions by cattle and relationships with residual feed intake
- Genetics of residual feed intake
- Beef industry adoption of residual feed intake
- Genetic markers for residual feed intake
- Economic benefit from selection for residual feed intake
- Procedures for quantification and auditing of GHG emissions

Scope

The scope for the work includes the assessment of the scientific feasibility of selection for RFI in beef cattle, and its link to quantified GHG reductions using a combination of the above information and scientific expert opinion. It therefore involves the gathering of the available scientific information on quantified GHG reductions (primarily methane from enteric fermentation) due to feeding cattle that use their feed more efficiently.

The information from this discussion paper will be used, in the next phase, as a basis for developing science-based standardized protocols to identify net GHG emission reductions for agricultural carbon offset projects as a result of improvements in agricultural management.

WHAT IS RESIDUAL FEED INTAKE

Background

Profitability of production is dependent on both inputs and outputs. Providing feed to animals is a major input cost in most animal production systems. This has long been recognized in the pig and poultry industries, in which cost of feed is easily quantified. In beef production, the cost of providing feed to cattle in feedlots are relatively easy to quantify, while feed cost of grazing cattle is more difficult to quantify. In most livestock species, genetic improvement strategies have concentrated on improving output traits with very little attention paid to input traits. The reason has been that measuring individual animals for the major input trait, feed intake, has been difficult, under both intensive and extensive production systems. Recent advances in computing and electronics have paved the way for development of reliable automatic feed intake recorders, making it easier to measure feed intake. This has allowed the pig and poultry industries to make significant improvements in efficiency of feed utilization through both genetic and non-genetic means. In beef cattle, there has been interest in the improvement of the efficiency of feed utilization since the 1960s (Koch et al. 1963), but the numbers of cattle tested were not large enough to provide reliable genetic parameters for use in developing breeding strategies. Since the early 1990s there has been renewed interest in improving feed efficiency of beef cattle, and there has been a resurgence of research and development work in North America (Basarab et al. 2003, Schenkel et al. 2004) and Australia (Arthur et al. 2004), with significant numbers of animals tested, to allow for the estimation of genetic parameters.

Definition and computation of residual feed intake

The utilization of the feed consumed by an animal involves a complex of biological processes and interactions with the environment. In addition, it is complicated by the fact that feed intake is highly correlated with body size and level of production. To overcome these complexities and to relate feed intake to production system efficiency, several measures of feed efficiency have been developed and used, as described in detail by Archer et al. (1999). In young beef cattle, feed efficiency is usually evaluated in relation to growth, and some of the most common measures used, such as partial efficiency of growth, feed conversion ratio (FCR) and residual feed intake, have been described by Arthur et al. (2001b). Residual feed intake is a measure of feed efficiency, and it represents the amount of feed consumed, net of the animal’s requirements for maintenance of body weight and production.

In beef cattle, residual feed intake (RFI) is defined as the difference between an animal's actual feed intake and its expected feed intake based on its size and growth over a specified period. Therefore, efficient animals have lower RFI values relative to inefficient animals. For beef cattle, the concept of residual feed intake was first used by Koch et al. (1963), who examined a number of indices for calculating efficiency which recognised that differences in both weight maintained and weight gain affect feed requirements in growing cattle. Koch et al. (1963) suggested that feed intake could be adjusted for body weight and weight gain (or any other production trait or energy sink identified), effectively partitioning feed intake into 2 components: (1) the feed intake expected for the given level of production; and (2) a residual portion. The residual portion of feed intake can be used to identify animals that deviate from their expected feed intake, with efficient animals having lower (negative) RFI values.

In addition to the measurement of actual size, growth and feed intake of the animal, the computation of RFI requires the estimation of expected feed intake. This can be predicted from production data by using feeding standards formulae (e.g. NRC 1996), or by regression using actual feed test data (Kennedy et al. 1993, Arthur et al. 2001b). Although the genetic correlations among the different forms of RFI may be high, their relationships with other traits may be different (Arthur et al. 2001b). In this paper, only the RFI computed by the regression approach is used, as this method has become the accepted form of RFI for genetic improvement purposes. It is calculated by fitting the model:

$$DFI_i = ßo + ß_1 ADG_i + ß_2 MMWT_i + e_i$$

where: DFI_i = daily feed intake of animal i, $ßo$ = intercept, $ß_1$ = partial regression coefficient of daily feed intake on average daily gain (ADG), $ß_2$ = partial regression coefficient of daily feed intake on metabolic mid-weight (MMWT; mean test period weight raised to the power of 0.75 or 0.73), and e_i = residual error term.

Residual feed intake is equated to the residual error term in the model. Occasionally a measure of body composition (e.g. backfat thickness) is included in the model. Residual feed intake computed by regression is phenotypically independent of the production traits (except feed intake) used to calculate expected feed intake, and so allows comparison between individuals differing in level of production during the measurement period. The independence of RFI from production has led some authors to suggest that RFI may represent inherent variation in basic metabolic processes which determine efficiency (Brelin and Brannang 1982, Korver 1988).

Measurement of residual feed intake

Testing cattle for RFI requires the measurement of feed intake and growth over a defined period of time. Typically, bulls and heifers are evaluated in a performance test facility where feed intake is recorded in addition to the measurement of body weight at regular frequency during the test. The measurement of feed intake can either be done manually, or with automatic electronic feeders, which dispense and record feed intake, such as the GrowSafe automatic feeding system (GrowSafe systems Ltd., Airdrie, Alberta, Canada). The optimum duration of test is around 70 days after an adjustment period of about 21 days. The cattle on the test are required to be weighed at least every fortnight (Archer et al. 1997, Wang et al. 2006). Additional measurements, such as, ultrasound scanning for subcutaneous fat thickness and area of the muscle, *M. longissimus*, can be taken during the test. The results from the test can then used to compute RFI. The performance of two bulls in a group tested for RFI is presented in Table 1, to highlight individual animal differences in feed use.

Table 1. Residual feed intake test results for two bulls of similar size and growth (*Data provided by Arthur*)

Trait	Bull A	Bull B
Start of test weight (kg)	398	386
End of test weight (kg)	581	569
Growth rate (kg/day)	1.54	1.54
Gain in backfat thickness (mm)[1]	10.0	9.0
Actual feed intake (kg as fed/day)	13.2	15.7
Expected feed intake (kg as fed /day)	13.9	13.7
Residual feed intake (kg as fed /day)	-0.68	2.00

[1]The difference between start of test and end of test backfat thickness at the 12/13 rib.

GREENHOUSE GAS EMISSIONS BY CATTLE AND RELATIONSHIP WITH RESIDUAL FEED INTAKE

Greenhouse gas emissions from beef cattle

Cattle produce methane (CH_4) and nitrous oxide (N_2O), both of which are greenhouse gases. The standard reference gas for GHG is carbon dioxide (CO_2). Methane and N_2O have global warming potential 21 times and 310 times the global warming potential of CO_2, making them very potent GHG. In cattle GHG are produced through enteric fermentation and in the manure they produce (Fig 1). Enteric fermentation results in the production of CH_4, which is a bi-product of microbial fermentation of hydrolysed dietary carbohydrates. Under both pastoral and feedlot management conditions CH_4 and N_2O are produced by cattle manure.

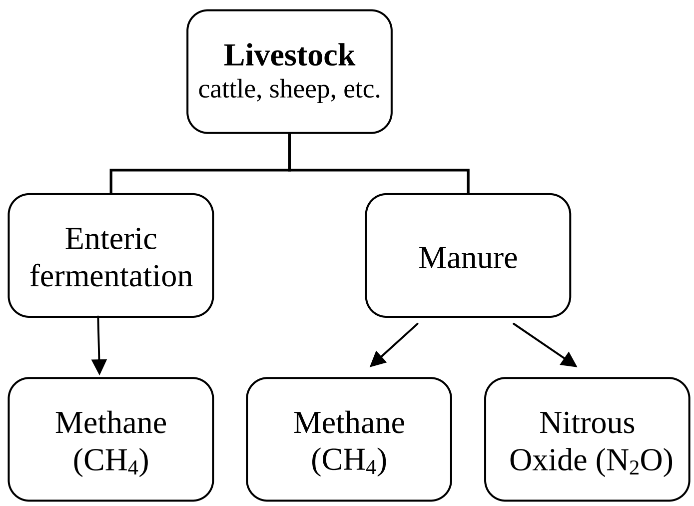

Figure 1. Greenhouse gas emissions from livestock

The agricultural sector is a source of greenhouse emissions worldwide, with the magnitude of its contribution differing from country to country. A recent FAO report estimates that globally livestock are responsible for 18 percent of greenhouse gas emissions (Steinfeld et al. 2006). In Canada, the agricultural sector produced 62,000 kt (CO_2 E) of GHG emissions in 2006, and this constitutes 8.6% of the national GHG emissions (Environment Canada 2008). Of this amount from the agricultural sector, the contribution of GHG from enteric fermentation is 39%, and is the largest source of GHG emissions from livestock, with beef cattle as the major source (Fig 2).

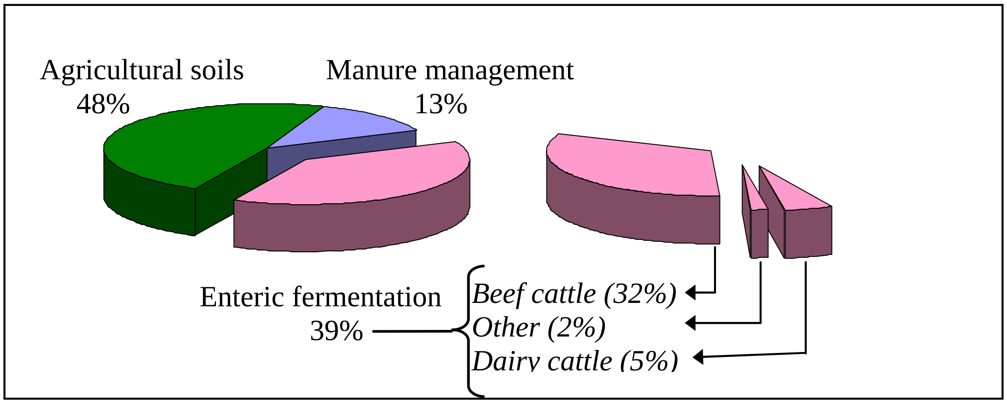

Figure 2. Sources of GHG emissions from the Canadian Agricultural sector in 2006.
(*Data Source: Environment Canada 2008*)

Relationship between residual feed intake and greenhouse gas emissions

The relationship between feed intake and methane production in ruminants has been known for years, and is recognized in most algorithms predicting methane production rate (Blaxter and Clapperton 1965, Pelchen and Peters 1998). In general, the higher the feed intake the higher the methane production rate by the ruminant, on the same feedstuff. However a strategy of reducing feed intake to achieve lower levels of methane production has received little attention because of concerns over reduction in productivity of the ruminant. In beef production such a strategy would mean that slaughter cattle will take longer to reach market weight, young replacement heifers will take longer to reach puberty and weaning rates in cows will reduce. Therefore to achieve the same level of productivity, this will mean that all classes of cattle (steers, heifers, cows etc) have to be kept longer resulting in potentially higher total feed intake.

Theoretical calculations

Low RFI cattle have the same level of production as high RFI cattle, but they do so at a reduced level of feed intake (Arthur et al. 2001a, Nkrumah et al. 2007a). This finding therefore offers the potential to reduce methane emission from cattle without compromising productivity. To explore this potential the research group based in Alberta used actual data from RFI projects to calculate methane production using standard algorithms (Blaxter and Clapperton 1965).

The results indicated that yearly methane emissions and manure production from high efficiency (Low RFI) steers was 21% and 15% lower, respectively, than for low efficiency (High RFI) steers, with no significant difference in size and growth traits between the 2 groups (Okine et al. 2001). The research group in Australia also used similar algorithms on the RFI selection line data and estimated that cattle selected for low RFI produced 15% less enteric methane per day than those selected for high RFI (Herd et al. 2002a). Methane and nitrous oxide production from fermentation of faeces was 15% and 17% lower, respectively, in low RFI compared to high RFI cattle. It was concluded that the total greenhouse gas emission per unit liveweight gain was 16% lower in the low RFI cattle relative to the high RFI cattle. In both studies the GHG emissions were estimated, and not measured.

Empirical data

Although the strategy of reducing methane emissions for cattle without loss of production has been proven in two studies, using a combination of actual production data and theoretical methane calculations, it was necessary to obtain empirical data where actual methane measurements were taken, to validate these findings. To obtain empirical data the Alberta research group used steers tested at the University of Alberta, Kinsella Ranch Station. Out of 306 steers tested for RFI, 11 extreme high and 8 extreme low and 8 medium RFI steers were selected for calorimetry studies. The mean body weight (BW) as well as mean average daily gain (ADG) on the RFI test were similar between the low RFI (496 kg BW and 1.46 kg/day ADG) and high (501 kg BW and 1.48 kg/day ADG) RFI groups. However the low RFI steers consumed 17% less dry matter than the high RFI group, resulting in mean RFI of -1.18 for the low RFI and +1.26 for the high RFI groups. Oxygen and methane production of the steers were measured in a 4-chamber, open circuit, indirect calorimetry system. Methane production in the low RFI steers was 28% less than that in the high RFI steers (Nkrumah et al. 2006).

The Australian research group used the progeny of cattle from the RFI selection lines (Arthur et al. 2001c). To evaluate differences in methane production, 10 steers from the low RFI and 10 from the high RFI selection lines were selected out of 76 steers which had just completed RFI tests. Methane was measure by a marker-based method with the marker gas (SF_6) released from an intraruminal permeation device. All steers were fitted with a halter and gas collection apparatus (Fig 3), and gas sample collection made over 10 days, after a five day adaptation period. The gas analysis procedure is described in Hegarty et al. (2007). Methane production in the low RFI steers was 25% less than that in the high RFI steers (Hegarty et al. 2007).

Figure 3. Steer fitted with methane collection apparatus.
(*From: Hegarty et al. 2007*)

In the study by Nkrumah et al. (2006), the low RFI steers had significantly lower energy loss as methane as a percentage of gross energy intake (GEI) relative to the high RFI steers (3.19%

versus 4.28%). Fecal dry matter (DM) production per kg DMI was not significant between the low RFI and high RFI steers. Given that low RFI cattle have low DMI relative to high RFI cattle, the result implies that the low RFI steers had lower total fecal DM production. In the study by Hegarty et al. (2007), energy loss as methane was not explicitly expressed as a percentage of GEI. However, the study reported non significant differences between the RFI lines in methane production per kg DMI. Since all the steers were on the same diet, the non significant difference in methane production per kg DMI implies that there were no differences in energy loss as methane as a percentage of GEI. Fecal DM production was not measured in the study by Hegarty et al. (2007).

Although from the two studies it is not clear if there are differences between low RFI and high RFI steers in methane energy loss as a percentage of GEI, the studies clearly show that low RFI cattle emit less methane, mainly through the fact that they have low feed intake relative to high RFI cattle. The fact that they are still able to maintain the same level of production is due to the fact that they are biological efficient in the use of the feed consumed. Herd et al. (2004b) reviewed published information across livestock species to come up with some potential physiological mechanisms by which variation in RFI may occur. Five major processes were identified, being those associated with intake of feed, digestion of feed, metabolism (anabolism and catabolism associated with and including variation in body composition), activity, and thermoregulation. Richardson and Herd (2004) provided a synthesis of results of a series of experiments in cattle divergently selected for RFI, and estimated that heat production from metabolic processes, body composition and activity explained 73% of the variation in RFI. The proportion of variation in RFI that these processes explain, are: protein turnover, tissue metabolism and stress (37%), digestibility (10%), heat increment and fermentation (9%), physical activity (9%), body composition (5%) and feeding patterns (2%). The mechanisms responsible for over a quarter of the variation in RFI are still not known. Recent reports by Carstens et al. (2002), Basarab et al. (2003) and Nkrumah et al. (2006) confirm some of these results.

Implications on various diets

The available information on the relationship between RFI and methane emission indicates that it is through the association between feed intake and methane emission. Basically, animals which consume less feed emit less methane and this is recognized in most algorithms predicting methane production rate (Blaxter and Clapperton 1965, Pelchen and Peters 1998). It therefore implies that where animals are fed diets of similar nutritive value (including similar digestibility), the type of ingredients used (e.g. corn *versus* barley) is of little consequence. Standard RFI testing protocol have been developed in Australia and in Canada, and they specify some standard nutritional quality of the test diet. A copy of the Australian Standards Manual can be obtained from: www.dpi.nsw.gov.au/agriculture/livestock/beef/breeding/general/feed-efficiency. In Australia, for example, the diet for postweaning RFI test should provide approximately 10 MJ metabolizable energy (ME)/kg DM. Different tests will not have diets exactly 10 MJ ME/kg DM, hence for genetic improvement purposes, all feed intake data for postweaning RFI are mathematically corrected to 10 MJ/kg DM before the calculation of RFI is done. For feedlot RFI tests the diet should provide approximately 12 MJ ME/kg DM. With such standardization, the magnitude of reduction in methane emission by low RFI cattle is dependent mainly on feed intake and not the source or type of ingredients in the diet.

Summary of greenhouse gas emissions by cattle and relationship with residual feed intake

- Of the 62,000 kt (CO_2 E) of GHG emissions by the Canadian agricultural sector, 32% of this is by beef cattle through methane production from enteric fermentation.
- Low RFI cattle emit less methane than high RFI cattle in experiments where production data were used in the estimation of methane production (15% - 21%), and also where actual methane emission was measured (25-30%).
- Low RFI cattle produce less fecal DM than high RFI cattle.
- The reduction in methane production by Low RFI cattle is achieved with no major impact on the growth of the cattle.
- The reduction in methane emissions by Low RFI cattle is through reduction of feed intake. With standardization of nutritive value of diets used in RFI tests, the source or type of ingredients in these diets should have little effect on this relationship.
- It is currently not clear if there are differences between low RFI and high RFI steers in methane energy loss as a percentage of GEI,
- There is the potential to continually and permanently reduce methane emission by cattle through selection for low RFI. In addition, unlike land based carbon credits which are stored in the soil and are re-emitted due to practice changes (e.g., zero tillage to summer fallow), those generated from cattle are permanent.

GENETICS OF RESIDUAL FEED INTAKE

Genetic variation in residual feed intake

Genetic variation and heritability of residual feed intake

The genetic control of residual feed intake was one of the components of the review of feed efficiency in beef cattle by Archer et al. (1999), using pre-1999 information. A summary of the results from Archer et al. (1999) has been combined with the results of a review by Arthur and Herd (2008) and presented in Table 2. Although RFI data are limited relative to data on other traits, the surge in interest in RFI since 1990 has resulted in large numbers of cattle being tested for RFI. Hence, the available estimates of genetic variation covers studies from several countries, different breed types of cattle, using different types of diets, and with different sources of ingredients (barley, oats, wheat, silage etc). These results indicate that there is genetic variation in RFI in most beef cattle breeds, and that the heritability is moderate; similar to that for growth. This indicates that, as with growth, there is the potential to genetically improve the efficiency of feed utilization by beef cattle through selection for low RFI.

Table 2. Heritability estimates (± standard error) for residual feed intake in beef cattle

Breed type	Country	No. of animals	Heritability	Source
Pre 2000 reports	Various		0.14 to 0.28	Archer et al. (1999)
Hereford	Britain	540	0.16 ± 0.08	Herd and Bishop (2000)
Angus	Australia	1180	0.39 ± 0.03	Arthur et al. (2001a)
Charolais	France	792	0.39 ± 0.04	Arthur et al. (2001b)
Mixed	Australia	1481	0.18 ± 0.06	Robinson and Oddy (2004)
Mixed	Canada	2284	0.38 ± 0.07	Schenkel et al. (2004)
Wagyu	Japan	740	0.24 ± 0.11	Hoque et al. (2006a)
Composite	Canada	464	0.21 ± 0.12	Nkrumah et al. (2007a)

Repeatability of residual feed intake

Most of the data used to generate the genetic parameters were from cattle tested for RFI during the postweaning period. Using the same groups of Charolais bulls, which were tested for RFI (postweaning) as weaners (start of test age of 274days) and again as yearlings (start of test age of 430 days), Arthur et al. (2001d) reported a genetic correlation of 0.75 between weaner RFI and yearling RFI. Archer et al. (2002) also reported a high genetic correlation between postweaning RFI and mature cow RFI. These results indicate that a relatively high proportion of the same genes control the expression of RFI throughout the animal's life. Hence an animal assessed early in life to be efficient (low RFI) will be efficient throughout its life.

Measuring individual animal feed intake of cattle on pasture is difficult hence there are very few studies on RFI in cattle at pasture. In a study by Meyer et al. (2008), young heifers were tested for RFI by the standard procedures on prepared diets and then classified into Low and high RFI groups. As pregnant heifers in mid to late gestation, they were assessed for pasture dry matter intake (DMI), using grazing enclosures. They were assessed for pasture DMI again after calving, as cows with their calves. The results indicated that, although the Low RFI females had lower DMI as pregnant heifers and as cows with calves, the differences were not significant relative to the High RFI females. Growth of the heifers, cows and calves were not reported in that study.

A series of studies have been conducted with steers from the Trangie RFI selection lines (Arthur et al. 2001c) on pasture. In these studies pasture intake was estimated using alkane markers (Hegarty et al. 2000). In a study with steers (n=91) on medium quality pasture (ADG of 0.84 kg/day), Herd et al. (2004a) reported that initial and final liveweight of the steers, and feed intake, were not associated with variation in RFI estimated breeding values (EBV) of their sires. However, ADG tended ($P<0.1$) toward a favourable negative association with sire RFI EBV. The results show that 1 kg/day lower RFI EBV of a sire produced steer progeny that grew 19% faster, with no increase in feed intake, had a 26% lower RFI, and a 41% better FCR. In another study (Herd et al. 2002b), steer progeny (n=51) of Low and High RFI parents were evaluated during a dry summer period of low pasture availability which restricted ADG to 0.46 kg/day. Under those pasture conditions, Low RFI steers grew at 0.50 kg/day compared with 0.42 kg/day by high RFI steers (20% faster), consumed 3.04 kg/day of pasture compared with 3.23 kg/day (6% less) and had a FCR of 6.4:1 compared with 8.5:1 (25% better). These results indicate that the independence between RFI and growth is valid only under *ad libitum* energy intake. Where feed energy intake is restricted, such as on low quality pastures, steer progeny of low RFI parents grow faster relative to high RFI parents. There is some evidence (Herd et al. 2004b) which points to the fact that Low RFI steers have more efficient metabolic processes, hence they are able to meet their maintenance energy requirements with less energy intake than high RFI steers.

Sustaining genetic improvement in residual feed intake

Although the genetic parameters indicate that selection for RFI will be effective in improving feed efficiency, it is worth knowing how long this continuous reduction in RFI can continue. In beef cattle there is only one population in the world in which RFI selection lines have been developed and maintained. This is the Angus RFI divergent selection lines at Trangie in New South Wales, Australia (Arthur et al. 2001c). Currently only 3.5 generations of selection have been achieved in the selection lines, so it is too early to know how long selection can continue before the responses to selection plateau. However, feed efficiency research in other animal species provides useful clues. Hughes and Pitchford (2004) reported a significant and symmetrical response to divergent selection for RFI in mice over 11 generations. In a mice experiment at the University of Nebraska, where selection was based on feed efficiency, corrected for body weight, linear responses up to 38 generations were reported (Nielsen et al. 1997, Bünger et al. 1998). In commercial beef cattle herds, the average generation interval is 4 to 5 years. Hence these results indicate that there is substantial variation for RFI, and that this variation is unlikely to be exhausted for a long time.

Genetic correlation with other economically important traits

A summary of the genetic correlation between RFI and other economically important traits in beef cattle is presented in Table 3. The information indicates that RFI is genetically correlated with feed conversion ratio (FCR; another feed efficiency trait), with reported genetic correlation coefficients ranging from 0.45 to 0.85. This implies that genetic improvement in RFI will result in a correlated improvement in FCR (Arthur et al. 2001a,b, Schenkel et al. 2004, Robinson and Oddy 2004, Hoque et al. 2006a, Nkrumah et al. 2007a). As expected, there is a positive correlation between RFI and feed intake indicating that more efficient (with low RFI) cattle consume less feed. Residual feed intake, by definition, is phenotypically independent of the production traits (ADG and metabolic weight) used in its calculation. It has been asserted that this relationship might not apply at the genetic level (Kennedy et al. 1993). The close to zero genetic correlations (when the standard errors are taken into consideration) between RFI and ADG and metabolic weight indicates that this relationship holds at the genetic level as well. This implies that selection for low RFI (high efficiency) will result in progeny that consume less feed for the same level of performance as the progeny selected for high RFI (low efficiency). Genetic correlations between RFI and other growth traits (except yearling fat depth) are also close to zero. In the report by Arthur et al. (2001a), the genetic effects for weaning and yearling weights were partitioned into direct and maternal additive effects. However, the net (not partitioned) effects of the correlations were close to zero, after taking into account the magnitude of the standard errors and the opposing signs for the direct and maternal effects in that study. Although the number of reports available is limited, it appears that postweaning RFI is also genetically independent of mature cow weight (Herd and Bishop 2000, Archer et al. 2002, Arthur et al. 2005).

Available information tends to indicate that RFI is either not associated (Arthur et al. 2001a, Robinson and Oddy 2004) or very weakly associated (Hoque et al. 2006b) with rib eye area. However, the recent report by Nkrumah et al. (2007a) showed a low to moderate correlation between RFI and rib eye area, even after accounting for the high standard errors in their estimates. When measured ultrasonically in the live animal or directly on the carcass, rib fat depth tends to be weak to moderately associated with RFI. In the studies by Arthur et al. (2001a,b), weaner bulls and heifers were used, whereas in the study by Robinson and Oddy (2004), 1 to 2 year-old feedlot steers were used. The results of these two studies suggest that the magnitude of the association is influenced by age, sex and diet of the test animals.

Table 3. Genetic correlations (± standard error) between postweaning residual feed intake (RFI) and other economically important traits in beef cattle (*Adapted from Arthur and Herd 2008*)

	Breed and source[A] of information						
Traits	Hereford *(Source-1)*	Angus *(Source-2)*	Charolais *(Source-3)*	Mixed *(Source-4)*	Mixed *(Source-5)*	Wagyu *(Source-6)*	Composites *(Source-7)*
No. of animals	540	1180	792	1481	2284	740	464
Feed intake	0.64±0.16	0.66±0.05	0.79±0.04	0.43±0.15	0.81	0.78±0.06	0.73±0.18
Average daily gain	0.09±0.29	-0.04±0.08	-0.10±0.13	0.09±0.20	0.01	0.25±0.16	0.46±0.45
Metabolic weight	0.22±0.29	-0.06±0.08		-0.20±0.16	-0.17	0.16±0.13	0.27±0.33
Feed conversion ratio	0.70±0.22	0.66±0.05	0.85±0.05	0.41±0.32	0.69	0.64±0.10	0.62±0.09
Weaning weight	0.34±0.34	-0.45 (0.22)[B]					
Yearling weight	0.15±0.28	-0.26 (0.14)[B]	0.32±0.10			0.19±0.15	
Scrotal circumference		-0.03±0.11			0.15		
Yearling rib fat depth		0.17±0.05			0.16		0.35±0.30
Yearling rib eye area		0.09±0.09			-0.17		-0.52±0.32
Yearling marbling score					-0.02		0.32±0.29
Carcass rib fat depth				0.48±0.12		0.27±0.20	0.33±0.29
Carcass rib eye area				-0.24±0.26		-0.45±0.29	-0.64±0.26
Intra-muscular fat				0.22±0.17			
Carcass marbling score						-0.50±0.31	0.28±0.38

[A]Sources: 1. Herd and Bishop (2000), 2. Arthur et al. (2001a), 3. Arthur et al. (2001b), 4. Robinson and Oddy (2004), 5. Schenkel et al. (2004), 6. Hoque et al. (2006a,b), 7. Nkrumah et al. (2007a).
[B]Values in parentheses are maternal heritability estimates.

Information available on the genetic relationships between RFI and carcass and meat quality attributes is limited, and the results are conflicting. In the study with mixed breeds of temperate and tropically adapted cattle, Robinson and Oddy (2004) reported a positive but weak genetic correlation between RFI and chemically extracted intramuscular fat, whereas in the study with Black Waygu steers, Hoque et al. (2006b) reported a negative but medium genetic correlation between RFI and marbling score. Using Angus cattle which have been divergently selected for RFI (Arthur et al. 2001c), Richardson et al. (2001) used total tissue dissections of carcasses of first generation steers (n=33) to study body composition. The study showed significant selection line differences in percent carcass fat but not in percent retail beef (Table 4). This confirms the presence of a weak genetic relationship between RFI and rib fat, as indicated by the genetic parameter estimates reported in Table 3.

Table 4. Least squares means (± standard errors) for body composition and meat attributes of beef cattle divergently selected for residual feed intake (RFI)

Traits[a]	Generations of selection	Selection line Low RFI	Selection line High RFI	Significance
Body composition[A,B]	1.0			
Internal organs (%)		3.2±0.07	3.1±0.04	n.s.
External organs (%)		13.3±0.15	12.8±0.15	*
Non-carcass fat (%)		7.8±0.35	8.4±0.31	n.s.
Carcass fat (%)		9.9±0.39	11.3±0.39	*
Bone (%)		10.7±0.15	10.3±0.12	*
Retail beef (%)		35.4±0.36	35.2±0.49	n.s.
Meat attributes[C]	1.0			
12/13th rib fat depth (mm)		9.2±0.3	10.1±0.2	*
Shear force (kg)				
Meat aged for 1 day		4.6±0.2	4.6±0.2	n.s.
Meat aged for 14 days		3.8±0.2	3.5±0.2	n.s.
m-Calpain (units/g tissue)		1.9±0.1	1.8±0.1	n.s.
µ-Calpain (units/g tissue)		2.3±0.1	2.1±0.1	n.s.
Calpastatin (units/g tissue)		5.2±0.3	4.6±0.3	*

[A]Source: Richardson et al. 2001.
[B]As percentage of final liveweight.
[C]Source: McDonaugh et al. 2001.
* $P<0.05$; n.s. $P>0.05$.

As far as the author is aware, there are no published estimates of the genetic correlation between RFI and meat quality traits. The only published information is by McDonaugh et al. (2001, Table 4) who used cattle from the same RFI selection lines as Richardson et al. (2001) to study meat attributes of the steers. It was reported that after one generation of divergent selection for RFI, there were no significant differences between the selection lines in the quality of meat from steers (n=189), as assessed by shear force (a measure of meat tenderness). Using a subset of the meat samples (n=71) it was observed that the selection line differences in calpain levels in meat tissues were not significant, however, meat tissue from Low RFI steers had higher calpastatin levels than that from High RFI steers, without any impact on tenderness.

As far as the author is aware, there is no published estimate of the genetic correlation between RFI and maternal productivity traits. Information from the Trangie RFI selection lines (Arthur et al. 2001c) indicates that genetic correlations may be close to zero or low. Arthur et al. (2005) reported non-significant differences in calving rate, weaning rate and cow productivity between low RFI and high RFI females. Another study which provides useful genetic information was by Basarab et al. (2007) which examine the relationship between progeny RFI and the productivity of their dams. It was concluded that cows that produced low RFI progeny had calving rates, weaning rates and cow productivity values similar to cows that produced high RFI progeny. Arthur et al. (2005) reported that low RFI females calved 5 days later ($P = 0.07$) than high RFI cows. Similar results were obtained by Basarab et al. (2007), who reported that cows that produced low RFI progeny calved 5-6 days later ($P = 0.01$) than cows that produced high RFI progeny. This result points to the possible existence of some level of genetic correlation between RFI and calving date.

Preliminary results from Basarab et al. (2008) indicate that efficient heifers may have delayed puberty and become pregnant later in the breeding season than inefficient heifers. The delayed puberty associated with [-] RFI_{fat} heifers may be partially due to the increased energy demands associated with sexual development and/or activity, and the confounding effect this has on calculating RFI_{fat}. When RFI_{fat} was re-calculated using only feed intake data from pre-pubertal heifers (n-31), no differences were observed between - and + RFI_{fat} heifers in cumulative age at puberty or in cumulative pregnancy rate. These results have implications for when to test heifers for RFI, and the need to emphasize fertility, particularly in negative (-) RFI heifers.

Proof of concept demonstration herds

At the NSW Department of Primary Industries, Agricultural Research Centre at Trangie, Australia, Angus cattle have been divergently selected for Low RFI and High RFI since 1994 (Arthur et al. 2001c). It is a single trait selection population, with the sole criterion for replacement bulls and heifers being RFI. Selection continued in the selection lines up to the 1999 born progeny, after which RFI selection was suspended, and the females used in other projects. The selection for RFI was resumed in 2002 by artificially inseminating females with stored semen from the 1998- and 1999-born bulls. The original selection lines were maintained in the 2002 matings and selection has continued to date.

Two generations of selection had been achieved by 1999, and there was evidence of a clear divergence between the two lines (Fig 4). The evaluation of the responses to selection by the RFI selection lines, up to the 1999-born progeny, clearly indicates that after two generations of selection the growth of young cattle and the maternal productivity of cows from the Low RFI line were similar to those of the High RFI lines. However, the Low RFI cattle consumed less feed to achieve this, and produced less methane (Table 5). The quality of the meat of cattle from the two selection lines was also found to be similar (Table 4). The only differences found were that Low RFI cattle are slightly leaner and that Low RFI cows tended to calve a few days later in the calving season.

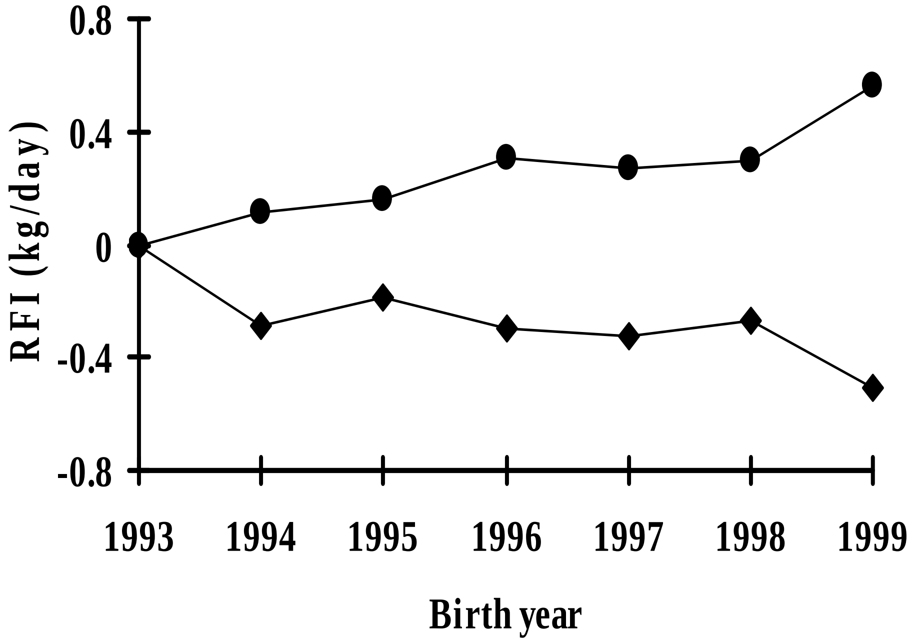

Figure 4. Trends in estimated breeding values for postweaning residual feed intake (RFI) for the Low (♦) and High (●) RFI selection lines. (*From: Arthur et al. 2001c*)

There are no other RFI selection lines in beef cattle in the world, however results from other major single generation studies where cattle have been phenotypically classified into Low and High RFI groups have confirmed the results of the selection lines. For example, results from Nkrumah et al. (2007a) confirms the fact that Low RFI slaughter cattle have slightly less fat relative to High RFI cattle, but also indicate that the level of fatness in Low RFI cattle was well above the minimum requirement for the Canadian carcass specification for slaughter cattle. Results from Basarab et al. (2007) confirm the maternal productivity results, but in addition it showed that the increase in calving date by Low RFI cows was indeed significant (P = 0.01), whereas in the selection lines (Arthur et al. 2005) it only approached statistical significance (P = 0.07).

Summary of genetics of residual feed intake

- There is genetic variation in RFI, and the trait is moderately heritable,
- Progeny of cattle selected for low RFI (high efficiency) consume less feed for the same level of growth as progeny of cattle selected for high RFI, irrespective of the source of the ingredients (e.g. wheat, oats or barley) of the diet.
- On low quality nutrition, such as poor quality pastures, where daily feed energy intake is low, cattle selected for low RFI may exhibit higher growth rates than progeny of cattle selected for high RFI, at the same level of feed intake.
- Cattle tested as efficient (Low RFI) during the postweaning period, remain efficient throughout their lives.

- With the exception of a strong positive genetic correlation with feed intake, other feed efficiency traits (e.g. FCR), and a weak to moderate correlation with fatness, the available information suggests that RFI is not genetically correlated with most traits of economic importance in beef cattle.
- Genetic improvement in feed efficiency in beef cattle can be achieved by selection for low RFI, with minimal level of correlated responses in growth and other economically important traits.

Table 5. Least squares means (± standard errors) for growth, feed efficiency, reproduction and maternal productivity in beef cattle divergently selected for residual feed intake (RFI)

Traits	Generations of selection	Selection line: Low RFI	Selection line: High RFI	Significance
Growth and feed efficiency	2.0			
Weaning weight (kg)		232.5±3.1	228.3±2.9	n.s.
Yearling weight (kg)		384.3±6.9	380.7±6.7	n.s.
Average daily gain (kg)		1.44±0.03	1.40±0.03	n.s.
12/13th rib fat depth (mm)		5.3±0.2	7.2±0.2	*
Rib eye area, (cm^2)		72.1±0.8	74.2±0.7	n.s.
Daily feed intake (kg)		9.4±0.3	10.6±0.3	*
Feed conversion ratio		6.6±0.2	7.8±0.2	*
Residual feed intake (kg/day)		-0.54±0.12	0.71±0.17	*
Maternal productivity[A,B]	1.5			
Calving rate (%)		89.2	88.3	n.s.
Weaning rate (%)		81.5	80.2	n.s.
Milk yield (kg/day)		7.5±0.3	7.8±0.3	n.s.
Wt of calf weaned (kg)		191.3±8.4	198.4±7.7	n.s.
Methane production in steers[C]	2.4			
Dry mater intake (DMI, kg/day)		8.38	14.13	*
Average daily gain (kg)		1.13	1.23	n.s.
Methane (g/day)		142.3	190.2	*
Methane (g/kg of ADG)		131.8	173.0	*P* = 0.09

[A]Source: Arthur et al. 2005.
[B]Per cow exposed to bull.
[C]Source: Hegarty et al. 2007.
* P<0.05; n.s. P>0.05.

ECONOMIC BENEFITS FROM SELECTION FOR RESIDUAL FEED INTAKE

Reports on economic analysis for most research and development projects are kept as internal documents. They are usually not externally peer-reviewed and are not published in mainstream journals hence they are not readily accessible. Public access peer-reviewed economic analysis reports on RFI are therefore limited.

Economics of production benefits from selection for residual feed intake

Internal and other general publications

Most of the general economic analyses on RFI presented as a minor section in a journal paper, in internal reports, field day handouts, agricultural notes etc. indicate that selection for RFI is economically beneficial at the farm as well as the national or provincial level. Excerpts from some of these reports are as follows:

1. From: "Cost-benefit analysis of feed efficiency testing in bull evaluation programs in Ontario." In: 1996 Ontario Beef Research Update, University of Guelph Publication.

   "A cost-benefit study was done to determine the direct costs of measuring feed intake at the three Bull Evaluation Centres operated by Beef Improvement Ontario (BIO) and to calculate the potential returns from this information for the Ontario beef industry. The measurement of feed intake of bulls on test provides information for the calculation of Expected Progeny Differences (EPD's) which allows the selection of breeding stock for this trait. The potential future returns to all sectors of the provincial beef industry outweigh the present cost of measuring feed intake at the Arkell, New Liskeard and Kemptville bull stations."

2. From: "Genetics of efficient feed utilization and national cattle evaluation: a review." In: Genetics and Molecular Research. 2005 Volume 12.

   "Assuming a feed cost of $0.101 per kg ……., a daily intake difference of 2.50 kg translates to feed cost savings of $0.25 per animal per day, or $37.87 per animal over a typical 150-day finishing period. In the southern Alberta cattle feeding region, for example, where approximately 2.4 million head of market cattle are fed, small genetic improvements in RFI could easily translate into annual savings of more than $100 million in finishing feed costs alone with no loss in animal performance."

3. From: "Residual feed intake (Net feed efficiency) in beef cattle." In: AGRI-FACTS, July 2006; Agdex 420/11-1. (Alberta Agriculture, Food and Rural Development).

   "On average, it costs $50 less over 112 days to feed an efficient bull compared to an inefficient one. ……….

   The economic potential, accrued after 15 – 25 years of selection for RFI, is estimated at $109 million annually for Alberta's feeder cattle industry and at least as much for the cow-calf producers. ………."

Australian peer-reviewed publications

The only comprehensive peer-reviewed publications on the economic analysis on production benefits from selection for RFI are based on Australian research data, but the findings are applicable to the Canadian beef cattle industry. Three integrated long-term research projects on the genetics of feed efficiency in beef cattle have been in progress in Australia since 1992, as reported by Arthur et al. (2004). Data from these projects have been used to form the basis of a number of comprehensive economic analyses on production benefits from selection for RFI.

Using RFI as the model under a scenario where all young bulls are measured for feed intake, Archer and Barwick (1999) concluded that for southern Australian beef production that targets the long-fed, premium Japanese market, incorporation of feed intake data in breeding schemes was profitable even at the highest cost of 450 Australian dollars (AUD) per animal, for the measurement of feed intake. For the domestic, grass-fed market incorporation of feed intake data in breeding schemes was marginally profitable when measurement cost was AUD150 per animal, and not profitable at higher measurement cost. The high cost of measurement raises two issues. First, that in practice seedstock breeders will not measure feed intake of all their young male progeny, and that only those with superior genetic merit for the other economically important traits are likely to be measured. Secondly, that cheaper direct or indirect measures of feed intake and efficiency need to be developed. These issues highlight the need for the development of efficient breeding system design that includes two-stage selection using less expensive tests, such as gene markers, to choose a strategic sub-set of individuals in the herd to be measured for feed intake.

The second analysis (Exton et al. 2000) modelled a 100-cow herd run on native pasture, with progeny being grown on improved pastures. The cash-flow for the commercial cow/calf operation was slightly reduced for the first 5 years as a consequence of the initial purchase cost of the more efficient bulls. Benefits from improvements in efficiency in calves and in the cow herd accrue slowly but are cumulative so that over the 25-year life of the investment the internal rate of return was a healthy 42% and the net present value (NPV) of surplus income over expenses was AUD17,363. This equates to an annual benefit per cow of AUD6.95. If 80% of steers were sold for feedlot finishing and a premium paid for them equal to half the cost of feed saved by the feedlot operator, this premium to the commercial cattle producer had an additional NPV of AUD4,771, or AUD1.91 per cow annually. This premium for more feed-efficient steers is almost equivalent to a third of the benefit from improvements in efficiency in the entire cow/calf operation, comes at no additional cost, and reduces the initial period of slight reduction in cash-flow. For the combined cow/calf and feeder steer operation the NPV of surplus income over expenses was AUD21,907, the internal rate of return of investing in RFI was 61%, and the net present benefit per cow was $8.76.

In a third analysis, an evaluation of the benefit of recording RFI in industry breeding schemes using a model of investment and gene flow resulting from selection activities was conducted. The analysis considered breeding schemes targeting either the high quality Japanese export market (with steers fed for 210 days in the feedlot) or the grass fed domestic market. A base scenario was modelled where a range of criteria (without feed intake data) were used. A second scenario incorporated selection of sires for the breeding unit using a two-stage selection process, with a proportion of bulls selected after weaning for measurement of feed intake. After accounting for the cost of measuring feed intake (ranging from AUD150 to AUD450), additional profit was generated from inclusion of feed intake measurement on a proportion of bulls, for all the breeding schemes considered. Profit was generally maximised where 10% to 20% of bulls were selected at weaning for measurement of feed intake. Details of this analysis have been reported by Archer et al. (2004).

It should be noted that in all the economic analyses presented, the genetic selection applied was not for the single trait, RFI. It was evaluated in a multi-trait selection index in representative genetic improvement schemes. The benefits presented are the marginal increase due to the inclusion of RFI and, therefore, it represents the additional benefits from genetic improvement in RFI.

Applicability of Australian economics of production benefits to the Canadian situation

In terms of similarity with Canadian cattle types and climate, the data used in all the Australian economic analyses were predominantly from the temperate southern Australia and on *Bos taurus* cattle, hence similar outcomes will be expected under the Canadian beef production system.

However temperatures in Canada are markedly lower than in Australia. Australian beef cattle production is mainly pasture-based. Breeding and cow-calf units are on grass all year round, with supplementary feed provided only when there is a drought, or for very short periods when breeding bulls are being prepared for sale. Backgrounding of steers is done on pasture. Over half of the slaughter cattle for the domestic market are finished on pasture, while the remainder are finished in the feedlot for approximately 75 days on feed. Cattle earmarked for export are either finished on pasture or in the feedlot for between 100 to 250 days on feed, depending on the export destination. This is in contrast to the Canadian system where the breeding herd and cow-calf unit are supplementary fed in the colder months, backgrounding is either grain and/or silage, and most slaughter cattle are feedlot finished on grain. Given the differences in climate and production system, it is likely that the Australian beef industry utilizes a higher proportion of low cost feed (i.e. pasture) than the Canadian beef industry. The economic analysis (Personal communication: L. Davies, the economist on paper by Exton et al. 2000) indicates that the more expensive the source of feed, the higher the monetary value of the benefit from selection for low RFI. Therefore the magnitude of the monetary benefits from selection for low RFI is likely to be higher under the Canadian production system relative to the Australian.

Economics of environmental benefits from selection for residual feed intake

Using data from all the Australian research projects on RFI, a study was undertaken to model the methane abatement resulting from the anticipated adoption of RFI in breeding programs within the Australian beef industry over a 25-year period. 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 low 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. 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 a 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. This represents a 7.4% cumulative decrease in enteric methane production over the simulation period, compared with an unimproved herd. The annual saving in methane production over an unimproved herd by year 25 was 15.9%. 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.

For the national herd, various adoption rates and adoption time lags were applied. At the base scenario of 0.76% rate of genetic improvement and 30% maximum adoption, 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. Any increase in the rate of genetic improvement and/or the maximum adoption level increases the cumulative reduction in methane emission. For example, 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 25. Similarly, a 50% increase in the maximum level of adoption of the RFI technology would result in an increase in annual abatement of enteric methane to 91 300 t or 4.7% by year 25.

It was concluded that, despite the substantial time lag for most genetic improvement program, such as that for RFI, selection for reduced RFI is expected to reduce greenhouse gas emissions from beef cattle. Residual feed intake offers a commercially attractive and practical abatement technology because it does not demand reductions in livestock numbers or level of production. The two 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 beef herd, not just finishing animals, and (ii) the cumulative nature of the response over time. The methodologies, assumptions and results obtained were reported in detail by Alford et al. (2006).

Applicability of Australian economics of environmental benefits to the Canadian situation

As with the production economics analyses, the data used in the Australian economic analysis for the environmental benefit were predominantly from the temperate southern Australia and on *Bos taurus* cattle, hence similar outcomes will be expected under the Canadian beef production system.

It is generally accepted that supplementation of forages with grain provides the rumen microbes with readily fermentable energy source which leads to increases in ruminal propionate concentration and reduction in methane production (Reis et al. 2001, Boadi et al. 2002). Given that a higher level of supplementation is provided in Canada relative to Australia, it is likely that the annual per cow reduction in GHG emissions under the Canadian beef production system may be slightly less than in Australia.

The value of carbon under the carbon trading scheme differ from country to country. In the Australian study by Alford et al. (2006) the value of carbon was set at AUD10.50/t of CO_2. Any differences in this unit price between Australia and Canada will affect the monetary value of the benefit in Canada.

Summary of economic benefits from selection for residual feed intake

- In spite of the high initial capital outlay to invest in RFI technology, selection for low RFI is profitable at the individual farm level as well as at the national industry level.
- For a representative 100-cow herd in southern Australia there is an annual benefit in the order of AUD 8.17 per cow, 61% return on investment and a surplus income over expenses of AUD21907 over the 25-year investment period.
- In industry breeding schemes for all production systems and all target markets, profit was maximized where 10% - 20% of all potential breeding bulls were tested for RFI.
- For the representative 100-cow Australian herd, the reduction in GHG emission was in the order of 20.6 t (CO_2 E) per annum over the 25-year investment period.
- At the industry-wide level the reduction in GHG will depend on rate of genetic improvement in RFI and the maximum level of adoption that can be achieved.

BEEF INDUSTRY APPLICATION OF RESIDUAL FEED INTAKE TECHNOLOGY

For genetic improvement of RFI to occur animals superior for RFI need to be used for breeding. The first step is to measure potential breeding animals or their relatives for RFI, to determine the genetic merit of those animals. Seedstock breeders can then offer such animals for sale as breeding animals with reliable genetic merit data. The majority of potential breeding animals will be measured for economically important traits. This is because the traits are relatively easy to measure and the cost of measurement is low. Residual feed intake, however, is an expensive trait to measure, therefore it should be expected that seedstock breeders will not measure all their potential breeding stock for RFI. The results of the breeding systems design analysis done by Archer et al. (2004) indicate that with RFI, there is no need to measure the whole cohort of potential breeding animals. Profitability is maximized when 10% – 20% of the potential breeding bulls are measured. After weaning, information on the calves themselves, and their relatives should be used to select those to be tested for RFI. In order words, if the genetic merit of a bull for other important traits is not good, then there is no need to test this bull for RFI. This is because bull buyers will not only look at the genetic merit for RFI, they will also look at the genetic merit for the other traits before making purchasing decisions.

Quality standards and capacity for residual feed intake testing

Quality standards for residual feed intake testing

Feed intake and its utilization by cattle involve a complex of biological processes and interactions with the environment. In order to be able to compare RFI test results across time and across location, as required for genetic analyses it is important to control as much as possible, those factors that affect feed intake and its utilization. There is therefore a need to standardize the methodologies and procedures associated with RFI testing.

Testing standards and protocols for the measurement of RFI have already been established. These standards were based on the scientific data published by Archer et al. (1997) and Wang et al.

(2006). In Australia, a Standards Manual for testing cattle for RFI, was developed in 1999 for all RFI tests. This ensures that data from tests conducted at different times in the year and at different locations can be accepted for genetic improvement. The manual, which was revised in 2001, outlines protocols and procedures to use. These cover eligibility of cattle (age, sex etc), conduct of test, data processing, and accreditation of test stations. A copy of the Standards Manual can be obtained from the following URL:
"http://www.dpi.nsw.gov.au/agriculture/livestock/beef/breeding/general/feed-efficiency"
Standardized testing procedures used in Alberta, Canada and other test stations world-wide are similar to the Australian standards. It is important that these testing protocols are adhered to, as they ensure that from year to year, test station to test station, country to country, RFI test results are comparable.

Facilities and capacity in Alberta, Canada for residual feed intake testing

There are currently seven facilities in Alberta that offer or could offer RFI testing, with a total annual capacity of 2,716 head of cattle (Table 6). This capacity is expected to increase to 3,716 head in 2009, when planned expansion of the facility at the University of Alberta Kinsella Ranch is implemented. Three of these facilities are used for research while the others are used for testing of industry cattle on a commercial basis. These facilities have automatic feeders manufactured by GrowSafe Systems LTD.

Table 6. Residual feed intake testing facilities in Alberta, Canada

Location	Owner	Brand of feeder	Primary purpose of use	No. of nodes	Annual capacity[1] *(head. of cattle)*
Lacombe	Alberta Agriculture & Rural Development	GrowSafe	Research	16	224
Kinsella[2]	University of Alberta	GrowSafe	Research	20	280
Lethbridge	Agriculture and Agri-Food Canada	GrowSafe	Research	36	504
Strathmore	Cattleland Feedyards	GrowSafe	Commercial	40	560
Strathmore	Namaka Farms	GrowSafe	Commercial	28	392
Olds	Olds College	GrowSafe	Commercial	10	140
Airdrie	Morrison's Feedlot[3]	GrowSafe	Commercial	29	406

[1]Annual capacity is based on feeding 1-2 times per day, a high grain diet, seven youthful animals per node and two tests per year. The GrowSafe System can be operated at 10 youthful cattle per node and three tests per year given careful management, feeding 2-3 times per day and feeding a high grain diet.
[2]There are plans to expand the Kinsella facilities to 140 nodes with an annual capacity of 1,000 head of cattle.
[3]Feeders owned by GrowSafe Systems Ltd.

The GrowSafe automatic feeders are state-of-the-art equipment, with modern electronics and computing software that includes world wide remote monitoring of the performance of the equipment. The GrowSafe automatic feeders have now become the system of choice, world-wide, when the purchase of new automatic feeders for RFI measurement in beef cattle is being considered. GrowSafe Systems Ltd, is an Alberta company located near Airdrie. Proximity to the manufacturer for service and advice is thus an advantage for the Alberta based RFI testing facilities.

With the large annual capacity for RFI testing in modern state-of-the-art facilities and the proximity to the manufacturer of the automatic feeders, Alberta has one of the best RFI testing facilities for beef cattle in the world.

Estimation of genetic merit for residual feed intake

Standardization of data

The quality standards for RFI testing give the range (rather than the absolute value) of metabolizable energy (ME) and crude protein of test diets, in recognition of the fact that ingredient source and quality changes with season, and from one test station to the other. In the standards manual for RFI testing in Australia it specifies that testing stations must have feed samples for each RFI test analysed, and the feed test result submitted with the data to the organization doing the genetic evaluation. It is therefore essential that prior to the computation of RFI, the feed intake data is corrected to dry matter basis and the feed energy content corrected to a specified ME. In Australia, the feed intake of all postweaning RFI tests is standardized to 10 MJ ME, and to 12 MJ ME for feedlot finishing test. Currently in Alberta, RFI values for industry cattle are standardized to 10 MJ ME on as fed basis. There is the need to express these values on DM basis.

Standardization of computational methods

There are different ways to calculate RFI (Arthur et al. 2004a, Nkrumah et al. 2007a). Currently, the most common form used is the phenotypic regression model of feed intake with average daily gain and metabolic bodyweight as explanatory variables. This is explained in detail in the section on "Definition and computation of residual feed intake". This is currently the standard computational form for RFI in beef cattle and almost all the published genetic parameters for RFI are based on this form of RFI. It is acknowledged that the other forms of RFI (e.g. including a measure of fatness) have their advantages and disadvantages. If in the future a different form of RFI achieves widespread use and there are reliable genetic parameter estimates (especially genetic correlations with other traits), it will need to be differentiated from the standard form (e.g. RFI_{std} versus RFI_{fat}). For this paper however, the standard RFI is being used.

Secondly, in the computation of RFI the three genders (females, entire males and steers) of beef cattle are treated differently. That is, the calculations are done within gender, hence they have different formulas. This is in recognition of the fact that feed utilization and nutrient partitioning is different among gender, as recognized in various national feeding standards (e.g. NRC 1996).

Related to the gender differences is the fact that usually young bulls and heifers (and occasionally steers) are tested for RFI after weaning and before one year of age. Results from such tests are referred to as postweaning RFI (RFI-P). Usually steers (and occasionally bulls and heifers) are tested for RFI after backgrounding, by which time the steers are older (typically over one year of age) and weighing over 400 kg. Results from such tests are referred to as feedlot or finishing RFI (RFI-F). It was only recently that enough data have been collected in Australia on animals tested for RFI-P and their relatives tested for RFI-F. Treating them as two different traits, analysis of the data showed that the genetic correlation between RFI-P and RFI-F is 0.65. If two traits have a genetic correlation greater than 0.8, and are biologically related, they are usually considered as the same trait. Although the two RFI traits are biologically related and have a relatively high genetic correlation, it was not high enough. Therefore, from June 2007 RFI-P and RFI-F were considered two different traits under the Australian genetic evaluation system (Personal Communication: David Johnston, AGBU Technical Director). Generating the data required to assess whether RFI-P and RFI-F are different traits, is not easy and takes several years to accumulate. Therefore it is recommended that RFI-P and RFI-F be considered as two traits until such time that enough data has been generated under Alberta conditions to enable such assessment to be made.

Thirdly, fitting a regression to the data anytime there is an RFI test means that each test will have a mean of zero. This will make it difficult to track the progress of genetic improvement over time in a herd or across the province. It is therefore important that at some point when enough data have been collected, an RFI regression model is run with all the fixed effects fitted in the model. The equation obtained will then be used for all future tests, thus making it unnecessary to fit a regression model to each test. Currently in Australia, standard equations have been developed for the calculation of RFI-P and RFI-F.

To facilitate standardization of data and computational methods, data from RFI testes in Australia are all sent to a centralized database for processing prior to the estimation of genetic merit. Currently majority of RFI data in Alberta is either kept by the University of Alberta or Alberta Agriculture and Rural Development. In addition, RFI data on purebreds are incorporated into their respective North American breed database under the guidance of the Beef Information Federation. A centralized database needs to be developed in Alberta for collating, processing, and storage of all RFI test data. From the database standardized data and results can then be sent out to owners of the animals tested or to other appropriate agencies.

Best Linear Unbiased Prediction (BLUP)
The testing of breeding cattle for RFI is important, as it provides the phenotypic measure of RFI. This information is useful for selection if the animal with the phenotypic measure of RFI is used within the same herd and within the same year of birth cohort. The ideal, however, is to use this phenotypic information and combine it with the pedigree and information on the animals relatives to obtain an estimate of the animal’s genetic merit for RFI. This is because the phenotypic measure is made up of genetic and environmental components. The environmental component is not passed on from parent to offspring; only the genetic component, known as the genetic merit, is transmitted to the offspring, hence the most important component when practising genetic selection.

The BLUP methodology is now the most common statistical procedure used to estimate the genetic merit of an animal for a particular trait. It utilizes pedigree information and records on the animal and its relatives. The estimated genetic merit is usually expressed as an estimated breeding value (EBV) or expected progeny difference (EPD). An EPD is half the value of the EBV. In Australia, the genetic merit of an animal is expressed as EBV whereas in North America it is usually expressed as EPD. For simplicity EBV will be used for the rest of this discussion paper. The principles of BLUP are standard however there need to be some standardization in the reporting of results.

There need to be indications in the reporting as to whether results are "within herd" or "across herd" EBVs. For a "within herd" analysis, there should be link sires across years. Comparisons of genetic merit can only be made among the animals within the herd. Across herd EBVs are usually referred to simply as EBVs. For this to be effective there should be link sires across years and across herds. Comparisons can be made with animals from all the herds participating in the genetic evaluation. The EBVs reported by most breed societies around the world are across herd. Effort should be made to generate across herd EBVs for RFI in all juridictions. Australian RFI EBVs are across herd EBVs.

Like any estimate an EBV is a prediction, with a level of accuracy attached to it. The value of the EBV should be reported together with its accuracy, as accuracy gives an indication of how much confidence should be place on the reported EBV value. An RFI-P EBV based on an animal's own record will have an accuracy of around 65%. As the RFI records on relatives of the animal are included in the analysis, the accuracy of the animal's EBV increases. Angus Breed Society in Australia, for example, has decided to publish the EBV for an animal only when the accuracy of either RFI-P or RFI-F of the animal is 60% or more.

The genetic evaluation system in Australia is called BREEDPLAN and it handles all traits in beef cattle for all breeds. The standardization of BLUP procedures and results reporting happens naturally because of the centralization of the system in Australia. In a feed efficiency project in Alberta, across herd RFI EPDs and accuracies were calculated for 220 bulls tested at the Olds College facility (Basarab et al. 2005). However, EPDs were not been calculated for some breeding cattle already tested for RFI in Alberta. As an interim measure, the RFI EBVs of such cattle can be approximated by multiplying the phenotypic RFI value by the heritability. The accuracy of such EBVs can be approximated as the square root of the heritability. There values can then be divided by 2 to obtain EPDs. In the long term effort should be made to compute EPDs for all potential breeding animals tested for RFI.

Summary of beef industry application of residual feed intake technology

- Quality standards for testing cattle for RFI have been developed and are being followed at all RFI testing stations in Alberta.
- Facilities in Alberta for testing cattle for RFI and the capacity of the facilities are among the best in the world.
- Province-wide database for RFI tests to facilitate proper standardization of data and computation methods may need to be set up in Alberta.
- Standardization of BLUP protocols and reporting of EPDs need to be developed and implemented in Alberta.

BEEF INDUSTRY ADOPTION OF RESIDUAL FEED INTAKE TECHNOLOGY

Adoption and adoption rates for residual feed intake technology

On a national, beef industry-wide basis, the economic benefit from selection for low RFI increases as the level of adoption increases. The level of adoption of new agricultural technologies is usually pegged at a maximum of 30% (L. Davies, personal comm.). The rate of adoption then determines how quickly the maximum level of adoption is reached. To date there are no reliable publicly available survey data on the use of RFI technology in the beef industry, that the author is aware of to work out actual levels of adoption and adoption rate.

In the beef industry, the availability of well characterized low RFI breeding animals for sale to the cow-calf sector is one of the ultimate measures of adoption by the seedstock sector. One of the measurable indicators is the number of cattle tested for RFI and/or the number within that sector with RFI EBVs, with a reasonable degree of accuracy. In Alberta over 4,300 cattle have been tested for RFI to date with another 3,600 projected to be tested within the next four years (Fig. 6). Unfortunately, only 1220 potential breeding bulls were tested for RFI over a nine year period from 2000 to November of 2008. The number of bulls, steers and heifers tested at the various RFI testing facilities in Alberta is presented in Table 7.

In Australia, about 10,000 cattle have been tested for RFI, with Angus breed having the most cattle tested. Since 2002, Australia's beef genetic improvement program, BREEDPLAN, has been providing Trial EBVs for net (also called residual) feed intake (NFI). Figure 7 shows the number of Angus cattle tested to date and the number of cattle with NFI EBVs. The January 2008 BREEDPLAN release of Angus Trial NFI EBVs is presented in Appendix 1.

For an individual cow-calf operator the simplest way to improve the efficiency of feed utilization is to purchase well characterized low RFI replacement bulls, heifers, semen or embyos. The progeny out of these low RFI replacement animals are expected to be feed efficient. The cow-calf operator will therefore begin to reap some benefit of his investment through low feed intake of the progeny in about 18 months (9 months gestation + 6 to 9 months preweaning period) from when he made his purchase. There are currently no reliable publicly available data on adoption levels and rate for this sector. The cow-calf operator may also receive premium price for any feeder cattle that are sold.

The feedlot sector only needs to go out and buy feeder steers and heifers that are progeny of low RFI parents. The benefit to the feedlot owner for paying a premium for such cattle is almost instant. As with the cow-calf sector, there are currently no reliable publicly available data on adoption levels and rate for this sector.

Table 7. Cattle tested for residual feed intake in Alberta using the GrowSafe System (Basarab, pers. comm. 2008)

	Residual feed intake testing facility[1]															
Year	Lacombe Res. Centre[2]			Olds College[3]	Cattleland Feedyards[4]			Lethbridge Res. Centre[4]			University Ranch Kinsella[5]			Namaka Farms[3]		Total
	S	H	C	B	B	S	H	S	H	C	B	S	H	S	H	
2000/01	90	0	0	0	0	0	0	0	0	100	0	0	0	0	0	190
2001/02	90	0	0	0	0	0	0	170	0	99	0	0	0	0	0	359
2002/03	0	0	0	0	0	0	0	159	0	0	0	90	0	0	0	249
2003/04	42	29	37	76	0	0	0	178	0	97	90	90	0	0	0	639
2004/05	44	19	39	114	146	0	0	198	99	50	90	90	0	0	0	889
2005/06	44	0	40	69	0	72	0	194	100	50	90	0	0	0	0	659
2006/07	44	0	0	121	162	18	14	175	0	0	0	170	0	0	0	704
2007/08	0	61	0	117	68	71	0	155	0	0	0	170	0	0	0	642
2008/09*	112	68	0	109	77	0	0	155	0	0	0	170	0	105	65	861
2009/10*	112	65	0	110	unk	unk	unk	0	0	0	0	180	0	320	180	967
2010/11*	112	65	0	110	unk	unk	unk	0	0	0	0	180	0	320	180	967
2011/12*	112	65	0	110	unk	unk	unk	0	0	0	0	180	0	215	115	797
Total	802	372	116	936	453	161	14	1384	199	396	270	1320	0	960	540	7923

[1]Letters under each testing facility refer to steers (S), heifers (H), cows (C) and bulls (B).

[2] Animal number for 2000/01-2006/07 were taken from the following sources: Basarab et al. 2003 Can. J. Anim. Sci. 83: 189-204; Basarab et al. 2007 Can. J. Anim. Sci. 87: 489-502.

[3] Animal numbers are from Basarab, November 2008, personnel communication (Senior Research Scientist, Alberta Agriculture and Rural Development, Lacombe Research Centre, 6000 C & E Trail, Lacombe, AB, Canada; john.basarab@gov.ab.ca).

[4] Animal numbers are from D. H. Crews, November 2008, personnel communication (Professor, Beef Cattle Breeding and Genetics Department of Animal Sciences, Colorado State University, Fort Collins, Colorado 80523-1171 USA, Denny.Crews@ColoState.edu).

[5] Animal numbers are from S.S. Moore, November 2008, personnel communication (Professor, Bovine Genomics, Department of Agricultural, Food and Nutritional Sciences, University of Alberta, Stephen.moore@ualberta.ca) .

* These values are projected based on studies already underway.

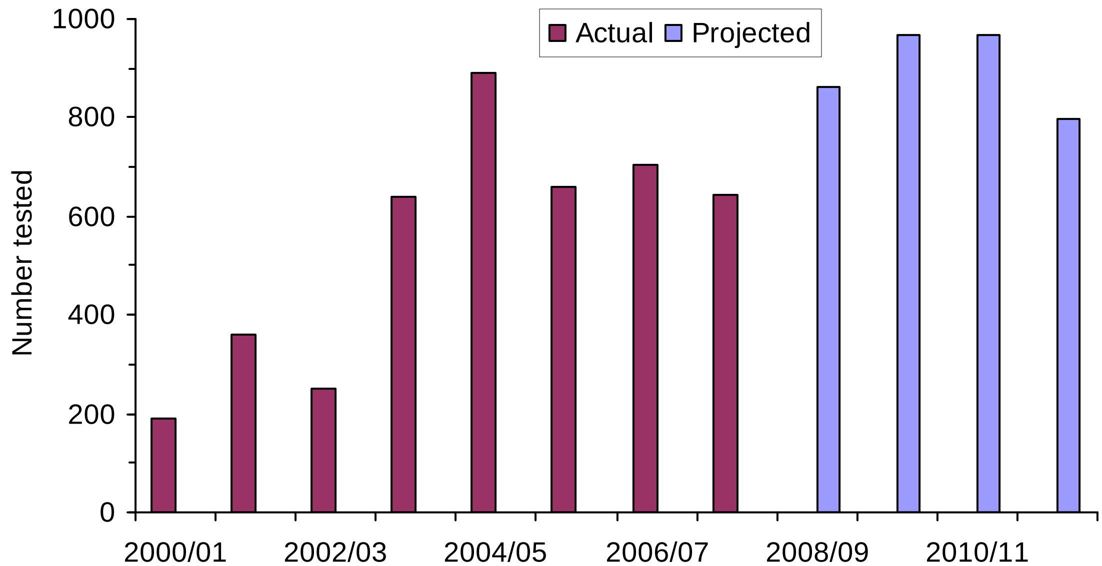

Figure 6. Actual (2001- 2007) and projected number of cattle tested for residual feed intake in Alberta (*Data provided by Basarab, Nov 2008 – Personal communication*)

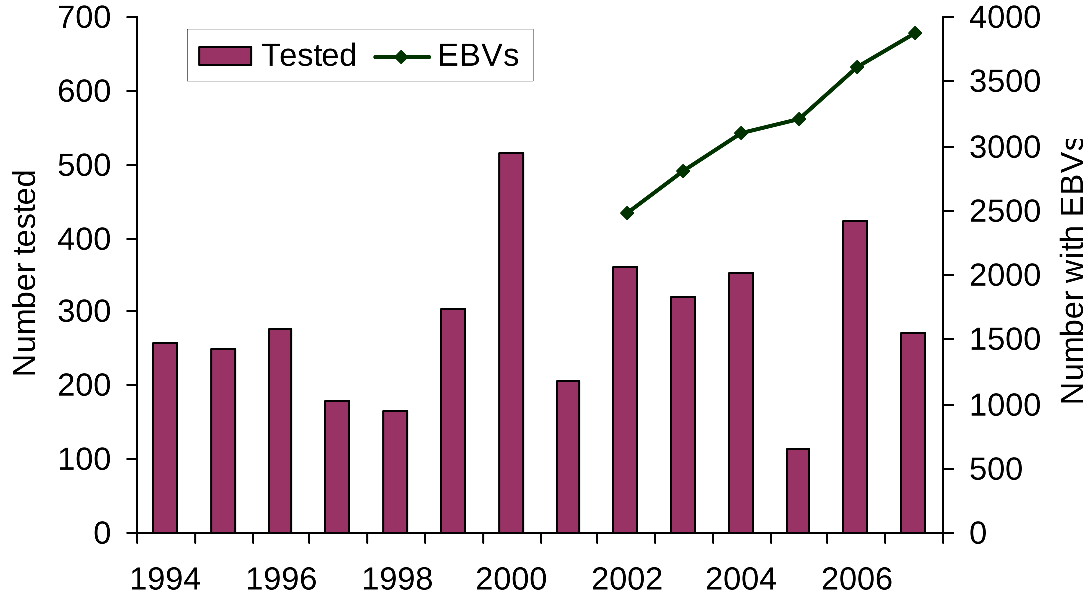

Figure 7. Number of Angus cattle tested and number with estimated breeding values (EBVs) for residual feed intake in Australia (*Data provided by Arthur from RFI industry database*)

Barriers to adoption of residual feed intake technology

Most economic analyses show a positive return on investment in selection for low RFI in beef cattle. However the level of adoption remains low. Arthur et al. (2004) outlined some real as well as perceived barriers to adoption, and these include:

i. The complexity of the operation of automatic feed intake recorders limits the use of such equipment on-farm, to be operated by the seedstock breeder.
ii. The general lack of appreciation in the beef industry of the importance of feed costs to enterprise profitability.
iii. The lack of accurate individual animal pasture intake measurement.
iv. The practical limitations, animal health concerns and cost associated with centralised RFI testing.
v. The reluctance of many seedstock breeders to hand over the management of their high value seedstock cattle to central test operators.
vi. The minimal use of artificial breeding technologies in the beef industry results in the lack of opportunity to recoup costs through high volume dissemination of superior genetics.
vii. The high cost of identifying animals with superior RFI. In Australia the most expensive trait to measure used to be ultrasound scanning in the live animal. The cost is between AUD25 to AUD45, for information on rib fat, rump fat, eye muscle area and intramuscular fat. Currently the actual cost of measurement of RFI is around AUD150. The measurement cost for RFI in Alberta is currently around 70 – 85 Canadian dollars (CAD) per head or CAD1 per head per day on test.
viii. Related to the high cost of identifying animals with superior RFI is the long period required for the investment in feed efficiency technology to return economic benefit. In the data presented by Exton et al. (2000) one of the assumptions was that a bull genetically superior for feed efficiency commands a AUD153 premium over a standard bull. The premium is equivalent to the amount required by the seedstock breeder to recoup the cost of testing elite candidate bulls in a two-stage selection program and paying AUD300 for the cost of measuring feed intake on each bull tested for feed efficiency (Exton et al. 2000). The results indicate that there is a negative cash flow in the first 10 years of investing in superior feed efficiency genetics (Arthur and Herd 2005).

Managing the barriers to adoption of residual feed intake technology

Since the review by Arthur et al. (2004), there has been a better understanding of RFI and its benefits by seedstock and commercial beef producers, and some of the barriers to adoption are gradually breaking down, or are being managed.

While automatic feeder intake recorders are still complex to operate by the average producer, they are now more robust, reliable and need minimal maintenance. Remote monitoring of GrowSafe feeders is now possible from anywhere in the world and most customers choose this option. It allows the equipment manufacturer to remotely interrogate and check the systems' mechanical functions, software and data integrity. This ensures early detection of problems, and assistance is provided in fixing problems where necessary.

Feedlot managers have a good appreciation of the importance of the cost of feed to their enterprises. The recent trend in diverting their traditional feed grain sources to biofuel production has heightened the awareness of feedlot and cow-calf managers of feed costs, and increased their desire for more efficient cattle to feed.

Accurate measurement of individual animal pasture feed intake is still not available. Although it is still desirable to be able to accurately measure individual animal feed intake at pasture, recent research reports (e.g. Herd et al. 2004a) that low RFI cattle (which are usually tested on prepared diets) are also efficient on pasture, has made this need not as critical or urgent.

In Australia young potential breeding bulls are raised on pasture, and the industry does not have a history of sending young bulls for performance testing at central test stations. In contrast the North American beef industry has a long history of central test stations, hence the concerns about centralised RFI testing, may not be a major barrier, although an increase in the participation rate will be desirable.

When any new technology is adopted, there is a period of negative cash flow. In beef breeding this period can by substantial because the average generation interval in cattle is 4-5 years. Analysis of the data used by Exton et al. (2000) indicates that the period of negative cash flow is sensitive to the value of the premium; with a reduction in the premium corresponding to a reduction in the length of the negative cash flow period. The value of the premium is also dependent on the cost of measurement therefore any reduction in the cost of measurement of RFI will reduce the duration of the period of negative cash flow. In the analysis by Exton et al. (2000) a premium of AUD300 was used. The reduction in RFI measurement cost to the current cost of AUD150 in Australia (and CAD70 - 85 in Alberta) will greatly reduce the duration of the negative cash flow period.

The simplest solution to the high cost of identifying breeding cattle that are superior for RFI is to bring down RFI measurement cost. For most economically important traits each potential breeding bull is measured for the trait. For RFI however, the high cost of measurement means that, in practice, all potential breeding bulls will not be measured. The finding by Archer et al. (2004) that profit was maximized where 10% - 20% of all potential breeding bulls were tested for RFI translates to a great cost saving to the individual seedstock breeder as well as to the industry as a whole.

Major improvements in the automatic feeder systems coupled with increases in sales (economies of scale), with its attendant decrease in cost price of the equipment has contributed to gradual reduction in RFI measurement cost. While it is still profitable to select for low RFI animals using the current direct RFI testing method, there is a need to further reduce the cost of identifying superior RFI breeding animals, if the technology is to achieve widespread adoption. Simpler and inexpensive methods of identifying breeding animals that are superior for RFI need to be developed. Work on physiological markers for RFI started with a lot of promise after a study in Australia by Moore et al. (2005) indicated that plasma insulin-like growth factor-I (IGF-I) concentration was genetically correlated with RFI, and hence could be used as an indicator trait for RFI. After additional data were collected from industry herds, a re-analysis was done in 2006, which indicated that the genetic correlation was weaker, and that IGF-I was not an accurate predictor of genetic merit for RFI as previously thought (Technical Update NFI & IGF-I, March 2007, published by the Animal Breeding and Genetics Unit, University of New England, Australia). A recent report by Lancaster et al. (2008) also confirms this finding.

Gene markers for residual feed intake

Molecular genetics research and its application to livestock improvement is relatively new. Although its impact (e.g. DNA fingerprinting, marker assisted selection) in the livestock industries have already started, the realization of its full potential is a few decades away. To date, the most common applied livestock molecular genetics research has involved the identification of quantitative trait loci (QTL) and single nucleotide polymorphisms (SNPs) that are associated with certain production characteristics. Such QTL or SNPs are usually referred to as gene markers. Research to date has yielded some RFI gene markers, some of which have been developed into commercial tests. Commercially available gene markers for RFI are as follows:

> *GeneSTAR Feed Efficiency* – marketed by Pfizer Animal Health (previously marketed by Catapult Genetics and Bovigen). Pfizer currently offers four feed efficiency markers based on RFI, under an additive system which represents the number of favorable alleles of the four markers that an animal has.
>
> *IGENITY Profile Feed Efficiency* – marketed by Igenity (parent company is Merial). Igenity currently offers feed efficiency markers for *Bos indicus*-influenced cattle. Igenity has developed molecular breeding values (MBVs) for these markers.

For genetic improvement, gene markers can be used to provide additional information in the generation of standard EBVs for the trait. Alternatively, the marker information can be used to generate molecular breeding values (MBVs) for the trait. To be able to effectively use the marker information, the frequency of the favorable alleles of the markers in the population and the percentage of genetic variation in the trait that they explain need to be known. The National Beef Cattle Evaluation Consortium (NBCEC), has its head office at Cornell University and it offers a service in the United States whereby companies can voluntarily offer their gene markers to be validated in their validation herd. To date no RFI gene markers have been validated through NBCEC.

A study has recently been completed by the Animal Genetics and Breeding Unit (AGBU) at University of New England, Australia on all the GeneSTAR gene markers for all traits in a project called SMARTGENE project. The aim of the project was to further the development of BREEDPLAN (the Australian genetic evaluation system) towards marker enhanced EBVs and to establish the effects of the GeneSTAR markers in a number of well recorded Australia cattle populations. It was in essence a major validation project with a population of over 12,000 animals. The population size for the validation of the RFI markers was 4925 animals. The results indicate that the effect of the feed efficiency markers were significant only in the same population in which the discovery animals came from. And secondly the percentage of variation explained by the four feed efficiency markers was low; about 1.8% of the phenotypic variance. A full report on the SMARTGENE project can be obtained using the following URL:

http://agbu.une.edu.au/smartgene.php

A similar validation study of the Igenity gene markers utilizing the same validation population as used in the SMARTGENE project has been conducted by AGBU. The full report has not been publicly released yet, but excerpts of the results pertaining to the Igenity feed efficiency markers for *Bos indicus* influenced cattle can be viewed using the following URL: http://www.ansci.cornell.edu/nbcec/ucdavis/IGENITY_Profile.htm.
The feed efficiency MBVs were found to be significantly and positively associated with RFI in the 1270 tropically adapted *Bos indicus* influenced cattle. However, as with the SMARTGENE markers, the report indicates that the variance explained by the MBV was very small. No association was found in the 720 pure Brahman cattle.

On a smaller scale, a validation study on a RFI panel of 6 SNPs discovered in the University of Alberta, Kinsella ranch beef cattle population was tested on 262 crossbred cattle at the Lacombe Research Centre as reported by Nkrumah and Basarab (2007). The results indicate that the panel of markers explained about 10% of the variation in RFI.

These validation results indicate that good progress has been made in the detection of effective gene markers for RFI, but there is still a long way to go to come up with a suite of markers which explain a good proportion of the genetic variation.

Research into finding gene markers for RFI in beef cattle has intensified in the last five years. At the forefront of the gene marker search is the research by a consortium of organizations (including the University of Alberta) in Alberta, Canada and the Beef Cooperative Research Centre in Australia (a consortium of several research organizations). Both groups have identified several QTL and SNPs that are associated with RFI, and are at various stages of validation and commercial release (Pitchford et al. 2002, Hayes et al. 2006, Barendse et al. 2007, Nkrumah et al. 2007b, Sherman et al. 2008). Other research groups world-wide, such as University of Guelph, are also working on identifying RFI gene markers. To speed up the process for detection of gene markers for a range of economically important traits in beef cattle, including RFI, a collaborative arrangement has recently been forged between the Alberta consortium (which includes the University of Alberta), the University of Guelph, the United States Department of Agriculture Meat Animal Research Centre and Beef Cooperative Research Centre in Australia. When a gene marker for a particular trait is detected in a research project, it needs to be validated in a large population, to determine the frequency of the favourable marker allele in other populations and to work out the percentage of the genetic variation in the trait that the new gene marker explains. Unfortunately there are very few well characterized populations, especially for new traits like RFI, with large enough number of animals in which new markers can be validated. The pulling together of well characterized animal genetics resources of these four major institutions provides a large population for validation of any new gene markers,

The physiological mechanisms underlying the variation in RFI (Herd et al. 2004b, Richardson and Herd 2004) is very complex, hence it is expected that a suite of gene markers will be required to explain a sizeable amount of the genetic variation in RFI. The rate of detection of gene markers for RFI is very promising, and with the renewed international collaborative effort among several institutions, there is great potential for the discovery of a suite of markers which explain a sizeable proportion of the genetic variation in RFI. Testing of animals for known gene markers is relatively easy and it is hoped that the cost will be significantly cheaper than the current CAN70 - 85 for an RFI test.

Dr. John Basarab, in cooperation with the Alberta Bovine Genomics Program, University of Alberta, Alberta Agriculture and Rural Development, Agriculture and Agri-Food Canada and industry partners, is leading a $4 million, 4.5 year project on “Application of next generation genomic tools in Beef: Addressing the Phenomic Gap”. The purpose of the project is to accelerate the adoption of RFI and meat quality traits through the use and application of genomic genetic technology in the beef cattle industry. This will be accomplished by: 1) phenotyping large numbers of cattle for feed intake, RFI, live animal carcass merit, carcass characteristics, meat quality and palatability, 2) genotyping large numbers of cattle for 50,000 SNPs, 3) quantifying the relationships between traits of economic importance and genetic markers; and 4) validating commercial genetic marker panels for RFI, growth, carcass and meat quality.

Summary of beef industry adoption of residual feed intake technology

- Residual feed intake technology is already being adopted by the Alberta beef industry, with over 4300 cattle tested for RFI between 2000 and November 2008.
- There are barriers to adoption of the RFI technology, but these barriers are being managed to reduce their impact on the rate and level of adoption.
- The proportion of genetic variation in RFI explained by current commercially available gene markers for RFI is low, hence they are not effective as the sole tool for selection for RFI. However, the newly formed international collaborative arrangements recently put together for the detection and validation of gene markers will accelerate the rate of progress in finding a suite of useful and effective RFI markers.

GENERAL CONCLUSIONS

Residual feed intake is the amount of feed consumed, net of the animal’s expected requirements for maintenance of body weight and production. There is conclusive scientific evidence that cattle with low RFI consume less feed at the same level of production as high RFI cattle. There is genetic variation in RFI in most cattle breeds, and it is a heritable trait. This means that genetic improvement in RFI can be made through selection, and that progeny of low RFI cattle will consume less feed without compromising growth and other economically important traits. Cattle with low RFI also produce less methane from enteric fermentation, relative to high RFI cattle, due to that fact that they consume less feed. Selection for low RFI can therefore be used as a GHG mitigation strategy in beef cattle.

Selection for RFI is a profitable genetic improvement strategy to reduce the cost of beef production, and has the additional benefit of reducing the carbon footprint of the beef industry. The adoption of the RFI technology has already started in the beef industry in Alberta, with world-class facilities and quality assurance standards in place for testing cattle for RFI. Over 4,300 cattle have been tested for RFI in Alberta from 2000 to November 2008. The majority of these were research steers, heifers and cows, with only 1220 being commercial breeding bulls. The beef industry in Alberta is therefore in a good position to develop a project for GHG reduction credits based on selection for low RFI.

PROCEDURES FOR QUANTIFICATION AND AUDITING OF GHG EMISSIONS

Quantification of GHG reduction in cattle with low residual feed intake

The production of methane from enteric fermentation in cattle can be measured directly in metabolic chambers or indirectly using tracers such as sulphur hexafluoride. These are short duration techniques, and are expensive, cumbersome and not practical under normal farming conditions. Hence they are useful research tools but not practical quantification method for methane production. The scientific evidence for the relationship between selection for low RFI and reduction in methane production indicates that this is through the reduction in feed intake. This reduction in feed intake is captured by RFI, since it is the reduction in feed intake relative to the expected feed intake for the size and growth of the animal. Measured as kg of feed (DM basis) per day, this should form the basis of any project for GHG emission reduction from selection for low RFI.

Use of genetic merit information

The protocol is based on genetic selection for low RFI, hence the genetic merit (expressed as EBV) of an animal for RFI (rather than the phenotypic measure) should be used for quantification of reductions in GHG emissions. For this section of the paper EBVs generated using BLUP procedures by a recognized agency or specialist will be referred to as “certified” EBVs. Since RFI is a relatively new trait in the beef industry it is recognized that sometimes unrelated animals are tested for RFI, and also pedigree information is not always available for a BLUP analysis to be conducted. In such instances, certified EBVs can be approximated as the heritability of RFI multiplied by the phenotypic RFI value of the animal. The accuracy of the EBV can be calculated as the square root of the heritability. As RFI information builds up over time efforts should be made to generate EBVs by BLUP for all animals.

The beef industry is made up of a number of sectors. In broad terms the participants of each sector may contribute in the following manner:

- The seedstock breeder will be breeding low RFI breeding animals for sale. It is expected that breeding stock for sale will have certified RFI EBVs and accuracies as part of the sale information.

- The cow-calf manager will purchase breeding stock with certified RFI EBVs from a seedtock breeder and use them in matings to produce progeny. The expectation is that the genetic merit of an offspring from such a mating by the cow-calf manager will be equivalent to half the genetic merit of its sire plus half that of its dam. Hence each progeny can be “assigned” a RFI EBV equal to the mean EBV of the parents, if the progeny does not have its own certified RFI EBV. If one of the parents does not have a certified RFI EBV, its EBV can be assumed to be zero. Selection for RFI is relative new in the industry hence it has not been practised in most beef herds. As such, the assumption of zero RFI EBV for untested animals is valid on an industry-wide basis.

  Apart from those retained by the manager for replacement, it is expected that majority of the progeny will be sold at the appropriate age/weight. At the time of sale the assigned RFI EBV should be provided as part of the sale information.

- The feedlot manager will purchase these cattle from the cow-calf manager and feed them for slaughter. These cattle will maintain their assigned RFI EBVs.

- The packing plant and itself associated wholesale/retail outlet will slaughter the cattle, process and sell the beef to the consumer. If any of the practitioners in this sector is eligible for carbon credits, the assigned EBVs of the slaughter animals can be used.

Estimating reduction in feed intake

Estimated breeding values are computed using a specified year as the base. The mean EBV of a particular trait is set to zero for all the animals born in that year or earlier. This ensures that genetic improvement relative to the base year can be tracked over several years. This base year can also be used in the protocol to illustrate that practice change since that year has resulted in reductions in GHG emissions. For RFI, it is also essential that the average feed intake (DMI) of animals during the RFI test period for the base year is calculated or estimated. For example, if for a participating herd, 2004 is chosen as the base year, the average DMI of all cattle which were tested for RFI-P can be calculated or estimated at a standard ME content per kg DM. With this information the reduction in feed intake due to selection for RFI can be estimated using procedures similar to the reports by Exton et al. (2000) and Alford et al. (2006).

The first step is to estimate the expected percentage reduction in DMI of the animal of interest relative to that of the base year animals. The second step is to estimate actual reduction in DMI in the current year. Two examples are used to illustrate how these can be calculated:

STEP 1

Example 1, Seedstock bull NDAX150

<u>*Available information*</u>

Certified RFI-P EBV:	-0.48 kg DM/day
Base Year (2004) Mean DMI:	10 kg DM/day (*has been adjusted to 10 MJ ME/kg DM*)

<u>*Percentage change in DMI (due to genetic selection) of the bull relative to DMI of base year:*</u>

Percentage change	= [(RFI-P EBV) / (Base Year mean DMI)] x 100
	= [(-0.48 kg DM/day) / (10 kg DM/day)] x 100
	= -4.8%

Example 2, Steer calf NDAY062

<u>*Available information*</u>

Certified RFI-P EBV of sire:	-0.48 kg DM/day
Certified RFI-P EBV of dam:	Not known
Base Year (2004) Mean DMI:	10 kg DM/day (*has been adjusted to 10 MJ ME/kg DM*)

<u>*Percentage change in DMI (due to genetic selection) of the bull relative to DMI of base year:*</u>

Assigned RFI-P EBV of steer	= [(Sire RFI-P EBV) + (Dam RFI-P EBV)] / 2
	= [(-0.48) + (0)] / 2
	= -0.24 kg DM/day

Percentage change = [(RFI-P EBV) / (Base Year mean DMI)] x 100
= [(-0.24 kg DM/day) / (10 kg DM/day)] x 100
= -2.4%

STEP 2

For a specified period in the current year (e.g. 2009), estimate the mean DMI of animals of the same age and type, taking into consideration the seasonal and other environmental (non-genetic) conditions. This can be done using procedures acceptable to Environment Canada. The actual reduction in DMI due to selection for RFI-P will be calculated as:

(Estimated mean DMI for 2009) x (percentage change) / 100

For example,

If the estimated mean DMI for 2009 is 12 kg DM/day, the reduction in DMI due to RFI selection (reduction in DMI) will be:

For Bull NDAX150

Reduction in DMI = (12kg DM/day) x (4.8) / 100
= 0.576 kg DM/day

Hence DMI intake for the specified period in 2009 = 12 – 0.576 = 11.424 kg DM/day

For Steer NDAY062

Reduction in DMI = (12kg DM/day) x (2.4) / 100
= 0.288 kg DM/day

Hence DMI intake for the specified period in 2009 = 12 – 0.576 = 11.712 kg DM/day

Estimating reductions in GHG emissions

These estimates of DMI of the animals can then be used in standard equations (e.g. IPCC 2006) to estimate the greenhouse gas production from enteric fermentation and manure production. The greenhouse gas production of these animals can then be compared with those obtained from using the estimated mean DMI for 2009.

Additive nature of GHG reduction in cattle with low residual feed intake

Residual feed intake is independent of liveweight and growth, the reduction in GHG emission in low RFI cattle is additional to other GHG reduction strategies relating to liveweight or growth. For example, if cattle finished in feedlots get GHG credit relative to pasture finished cattle, this credit should be additional to the low RFI credit. There are currently several research projects worldwide for the development of bio-actives (e.g. drugs, vaccines) for cattle to reduce methane emissions. If some of these R&D become commercialized, there would be the need to examine whether GHG reduction through selection for RFI is additive or negated by these bio-actives.

Verification strategies

The phenotypic measure of RFI and EBVs for RFI will be used as the basis for the project. As detailed under "Beef industry application of residual feed intake technology" section, there are quality assurance standard protocols for RFI as they relate to measurement, data, computational method, and estimation of genetic merit of an animal. These QA standards lend themselves to auditing, hence systems should be put in place to facilitate such audits. The only other step which requires an audit trail is a system to verify that the breeding animal with the low RFI EBV was used to produce the progeny, for which the GHG emission credits are being claimed. It is therefore important that the identification of animals tested for RFI be linked into the national livestock identification system administered by the Canadian Cattle Identification Agency (CCIA). This will mean that all cattle on RFI tests must have a registered RFID.

Recommendations for residual feed intake based carbon offset credit project

- The scientific evidence for the reduction in methane and manure production through selection for low RFI indicates that this is through the reduction in feed intake. This reduction in feed intake is captured by RFI, since it is the reduction in feed intake relative to the expected feed intake for the size and growth of the animal. Expressed as kg of feed (on DM basis and at a specified ME content) per day, this should form the basis of any carbon credit project for GHG emission reduction from selection for low RFI.

- Currently in Alberta, RFI values for industry cattle are standardized to 10 MJ ME on as fed basis. There is therefore the need to express these values on DM basis.

- Fitting a regression to the data anytime there is an RFI test means that each test will have a mean of zero. This will make it difficult to track the progress of genetic improvement over time in a herd or across the province. It is therefore important that at some point when enough data have been collected, an RFI regression model is run with all the fixed effects fitted in the model. The equation obtained will then be used for all future tests, thus making it unnecessary to fit a regression model to each test.

- Australian data indicates that RFI-P and RFI-F are two different traits. It is recommended that RFI-P and RFI-F be considered as two traits in Alberta until such time that enough data has been generated under local conditions to enable such assessment to be made.

- A centralized database needs to be developed in Alberta for collating, processing, and storage of all RFI test data. From this database, standardized data and results can then be sent out to owners of the animals tested or to other appropriate agencies, such as breed associations. This will ensure that all RFI data in Alberta are standardized in a consistent manner. It will also simplify any auditing requirements.

- To make it easier to verify that a breeding animal with the low RFI EBV was used to produce the progeny for which the GHG emission credits are being claimed it is important that the identification of animals tested for RFI be linked into the national livestock identification system administered by CCIA.

Additional issues for consideration during protocol development

1. ***What level of accuracy of RFI EBVs will be accepted for consideration under the RFI protocol?***
   Estimated breeding values are reported with a specified level of accuracy, which can range from zero to 100. If no additional RFI records on an animal's relatives are available, the accuracy of an RFI EBV for an animal who has been tested for RFI-P is 65%. If an animal

was not tested for RFI, an RFI EBV can still be estimated as long as some of its relatives have RFI information. The accuracy of such an EBV will depend on the number of relatives with RFI information and how closely related these relatives are to the animal. For example, a bull who was not tested for RFI-P but had 10 of itself progeny tested will have an accuracy of 60% or higher for its RFI-P EBV. As a guide for the protocol development phase, it is worth noting that the Angus Breed Society in Australia, for example, has decided to publish the EBV for an animal only when the accuracy of either RFI-P or RFI-F of the animal is 60% or more.

2. ***How would any protocol-specific standards for the computation of EBVs be enforced and maintained?***

   Unlike Australia where one agency (BREEDPLAN) is responsible for the computation of EBVs for all beef cattle breeds and traits, In North America, including Alberta there are several agencies and specialists involved in the provision of EBVs. This makes standardisation of methodologies challenging. Should funding for a specialist position (e.g. on 40% full-time equivalent basis) be sought to assist in the coordination and liaison of such activities?

3. ***What happens if a cow-calf manager uses semen from a bull with RFI EBV from overseas (e.g. Australia)?***

   With the global trade in genetic material on the rise in the beef industry, this is an issue for consideration. The questions that will arise are:

   - Are the RFI testing protocols and EBV calculations procedures similar to those used in Alberta?
   - Is there any reason to think that genotype by environment (country) interaction is significant? If so, how will this be dealt with?

4. ***Can carbon credits be claimed for second generation progeny whose parents do not have certified EBVs for RFI?***

   Progeny who do not have certified RFI EBVs of their own can be assigned RFI EBVs if one or both of their parents have certified RFI EBVs. Such progeny are referred to as "first generation" cattle, and each animal's assigned EBV will be the mean EBV of its parents. If these first generation animals latter get progeny of their own, will these "second generation" cattle be eligible for carbon credits, if the only certified RFI EBVs available are those of their grandparents and a BLUP analysis has not been run to generate RFI EBVs and their associated accuracies for these animals? The question is:

   - Can we continue to assign EBVs from generation to generation without the use of certified EBVs from any of the parents of the animal of interest?

5. ***What sector of the beef industry claims the carbon credit?***

   In a fully vertically integrated enterprise, there will be no issue with which sector claims the carbon credits. However, majority of beef enterprises in Alberta are not vertically integrated. Each of the industry sectors (seedstock, cow-calf, feedlot, packing plant/processor and wholesaler/retailer) may lay claim to the carbon credit, with some justification. Some of the questions which need to be answered are:

   - In which sector(s) will the carbon credits be applied?
   - Does the sale of a bull by a seedstock breeder extinguish his rights to the carbon credits of its subsequent progeny?

6. How can the rate and level of adoption of residual feed intake technology be increased?

The science of selection for low RFI and its association with reductions in GHG emissions is solid. Most economic analyses show substantial return on investment in this technology over a long term (25 years) outlook, as a result of reduction in cost of beef production. This improvement in production efficiency has been and will continue to be the driver for adoption of this technology. Any financial gain through carbon trading will be an additional benefit. Selection for low RFI is a relatively new technology hence the current level and rate of adoption are low. For the province to capture substantial environmental benefit through this technology the adoption rate and level needs to be increased. Serious consideration should be given to the use of policy measures and funding for industry development activities to address the barriers to adoption in order to increase the adoption rate and level.

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Appendix 1. Trial estimated breeding values for net (residual) feed intake, from the January 2008 Angus GROUP BREEDPLAN Sire Summary files *(Downloaded on 7th Nov 2008: http://www.angusaustralia.com.au/BP_Download_Files.htm)*

Trial NFI EBVs for BLACK and RED Angus sires*

Name	Ident	Trial NFI EBVs NFI-P	Acc	NFI-F	Acc
ALLOURA WARRIOR W06	DGJW06			+0.28	71%
ALUMY CREEK KM FUTURE DIRECTION W0	NKEW03			+0.50	68%
ARDROSSAN DIRECTION W109	NAQW109	+0.47	68%		
B C C BUSHWACKER 41-93	USA41-93	+0.01	63%		
B/R NEW DESIGN 036	USA036	+0.21	91%	-0.04	84%
B/R NEW DESIGN 323	USA323	+0.16	76%	+0.13	65%
BALD BLAIR DIRECTION W118	NBBW118	+0.05	82%	+0.24	72%
BALD BLAIR FUTURE DIRECTION X73	NBBX73	-0.06	62%	-0.06	71%
BASIN MAX 602C	USA602C	-0.07	62%		
BLACKMORE QUANTUM Q21	VBPQ21	-0.02	64%		
BON VIEW BALANCE 834	USA834	+0.16	62%		
BOOROOMOOKA TIM T204	NGMT204	-0.02	60%		
BOOROOMOOKA WESTALL W391	NGMW391	+0.10	60%	+0.75	71%
BRUMAR VANQUISH V9	WMCV9			+0.13	69%
BUTCHS MAXIMUM 3130	USA3130	+0.14	84%	+0.44	71%
C A FUTURE DIRECTION 5321	USA5321	+0.05	81%	+0.28	75%
CAMPBELL FARMS EMULATION V536	VVXV536	-0.48	65%	-1.04	71%
COMFORT HILL STOCKMAN U26	BBAU26			-0.13	64%
COMFORT HILL YELLOWSTONE W86	BBAW86			-0.42	67%
DUNOON REAGAN R093	BHRR093	+0.01	61%		
EASTERN PLAINS NEW DESIGN W102	NEPW102	+0.09	77%	+0.14	76%
EDI ANGUS A. RITO S8	CMFS8			-0.22	70%
FIVE STAR WHISKEY W6	BGXW006			-0.01	65%
G A R BINGO 4192	USA4192	+0.28	68%	+0.52	74%
G A R EVAS CONSISTENCE 3803	USA3803			-0.31	63%
G A R EVAS CONVERGENCE 3403	USA3403			-0.30	60%
G A R PRECISION 1680	USA1680	-0.01	73%	+0.26	69%
G T MAXIMUM	USA88	-0.34	89%	-0.04	77%
GARDENS EXT 4137 S2	USA4137	-0.33	61%		
GLENOCH MEGAFORCE	QBGM16	-0.22	72%	+0.07	60%
HAZELDEAN PERFECT STORM V113	NHZV113	+0.07	65%	+0.23	74%
HAZELDEAN YELLOWSTONE X155	NHZX155	-0.17	62%		
HIDDEN VALLEY EXISTENCE X18	SEWX18			-0.02	71%
HIGH SPA BULLION 6801 (IMP USA)	USA6801	-0.30	79%		
HIGH SPA USHER U81	CJMU81	+0.11	60%		

Name	Ident	Trial NFI EBVs NFI-P	Acc	NFI-F	Acc
HYLINE RIGHT TIME 338	USA13058662	-0.91	62%		
J L B EXACTO 416	USA12223258	-0.01	76%	-0.03	67%
KENNY'S CREEK TONKIN T25	NDIT25	+0.12	62%	+0.76	71%
KENNY'S CREEK WHITWORTH W134	NDIW134	+0.17	66%		
KOOJAN HILLS SOMETHIN SPECIAL	WKHW26	-0.12	60%	+0.16	72%
M A COMMANDER (IMP USA)	USA356	-0.16	75%		
MERRIC RIVERS NEW DESIGN T149	NXJT149	+0.11	62%		
MILLAH MURRAH WOODY W100	NMMW100	+0.01	69%		
MORDALLUP KING B72.	WGMB72+82	-0.14	78%		
N BAR EMULATION EXT	USAU23	-0.41	71%	-0.68	62%
NOONEE WOOLAHRA W90	NNHW90	-0.02	75%		
P A R B DESIGN PLUS 97	USA97	-0.03	73%		
PARAMONT AMBUSH 2172	USA2172	+0.22	85%	+0.41	70%
PONO OF KAWATIRI AB	NZE536	-0.59	66%	-1.06	64%
Q A S TRAVELER 23-4	USA23-4	-0.05	86%	-0.16	75%
R R SCOTCHCAP 9440	USA9440	-0.08	69%		
RAFF ULTIMATE U27	QRFU27			+0.07	68%
RITO 6I6 OF 4B20 6807	USA6I6	+0.36	70%		
ROCKN D AMBUSH 1531	USA1531	-0.14	72%	+0.15	62%
SCOTCH CAP	USA14	-0.26	86%	+0.03	75%
ST PAULS TRAV-ALBERT T67	NSTT67			+0.64	70%
ST PAULS VAMPIRE V51	NSTV51			+0.10	74%
SUMMITCREST POWER PLAY M032 (IMP US	USAM032	+0.33	81%	+0.12	63%
TC STOCKMAN 365	USA365	-0.21	68%		
TE MANIA KELP K207	VTMK207	+0.35	76%	+0.37	68%
TE MANIA KNIGHT K206	VTMK206	+0.36	86%	+0.48	76%
TE MANIA ULTRA U367	VTMU367	+0.28	68%		
TE MANIA UNLIMITED U3271	VTMU3271	+0.65	67%		
TRANGIE A069 (APR)	NDAA069	-0.69	73%	-0.86	60%
TRANGIE A086 (APR)	NDAA086	+0.91	72%		
TRANGIE A158 (APR)	NDAA158	-0.72	60%		
TRANGIE A160 (APR)	NDAA160	+0.96	71%		
TRANGIE A183 (APR)	NDAA183	-1.23	72%		
TRANGIE A201 (APR)	NDAA201	-0.90	73%		
TRANGIE A210 (APR)	NDAA210	-0.69	73%		

*Includes black and red Angus sires with at least 80% accuracy for one or more EBVs, calves recorded in the last 2 years, a total of 25 or more progeny analysed and at least 60% accuracy for the Trial Net Feed Intake EBV.

Appendix 1 *continued*.

Trial NFI EBVs for BLACK and RED Angus sires*

Name	Ident	Trial NFI EBVs NFI-P	Acc	NFI-F	Acc
TRANGIE A311 (APR)	NDAA311	+0.71	72%		
TRANGIE A312 (APR)	NDAA312	-0.38	71%		
TRANGIE A332 (APR)	NDAA332	-0.43	70%		
TRANGIE CTS472 (APR)	NDAS472	-0.87	87%	-0.63	80%
TRANGIE CTS537 (APR)	NDAS537	+0.99	86%	+0.97	75%
TRANGIE CTT119	NDAT119	-0.78	90%	-1.09	84%
TRANGIE CTT24 (APR)	NDAT24	+1.12	90%	+1.30	83%
TRANGIE CTT34 (APR)	NDAT34	+0.90	87%	+1.07	79%
TRANGIE CTT95	NDAT95	-0.74	81%	-0.84	79%
TRANGIE U124 (APR)	NDAU124	-0.56	85%	-0.63	73%
TRANGIE U5 (APR)	NDAU5	+0.91	86%	+0.92	67%
TRANGIE U51 (APR)	NDAU51	+1.20	83%	+1.55	74%
TRANGIE U77 (APR)	NDAU77	+1.04	86%	+1.18	79%
V D A R LUCYS BOY	USA101	+0.34	69%		
V D A R NEW TREND 315	USA315	+0.00	87%	-0.11	76%

Name	Ident	Trial NFI EBVs NFI-P	Acc	NFI-F	Acc
WAITAPU GOVERNOR (AI)(NZ)	NZE386	-0.16	82%	-0.44	65%
WATTLETOP ULTRASONIC U138	NWPU138			-0.46	61%
WATTLETOP VIBE V86	NWPV86	-0.13	64%	-0.38	72%
WATTLETOP X392 (APR)	NWPX392			+0.14	65%
WITHERSWOOD WATERLOO W93	CWJW93			-0.33	70%
YTHANBRAE GAR EXT T4	VLYT4			-0.67	73%
YTHANBRAE HENRY VIII U8	VLYU8	-0.01	60%	+0.00	66%
YTHANBRAE NEW DESIGN 036 U242	VLYU242			+0.04	64%
YTHANBRAE NEW DESIGN 036 U6	VLYU6			+0.04	65%
YTHANBRAE NEW DESIGN 036 U84	VLYU84			+0.07	69%
YTHANBRAE NEW DESIGN 036 V404	VLYV404	+0.03	71%	-0.01	67%
YTHANBRAE PRECISION U28	VLYU28	-0.02	62%	-0.05	70%
YTHANBRAE PRECISION V329	VLYV329	-0.20	69%	+0.00	62%
YTHANBRAE PRECISION V527	VLYV527			+0.05	63%
YTHANBRAE TRUE BLUE N33	VLYN33	-0.34	83%	-0.19	79%

*Includes black and red Angus sires with at least 80% accuracy for one or more EBVs, calves recorded in the last 2 years, a total of 25 or more progeny analysed and at least 60% accuracy for the Trial Net Feed Intake EBV.