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The role of cattle genetically efficient in feed utilisation in an Australian carbon trading environment

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Abstract: Residual feed intake (RFI) is a measure of feed efficiency in beef cattle. It is a moderately heritable trait, and cattle with low RFI consume less feed than expected at the same level of growth relative to their high RFI contemporaries. Selection for RFI is a relatively new genetic improvement tool in beef cattle to reduce the cost of production, and currently has a low level of adoption in the industry. Selection for low RFI is associated with reduction in greenhouse gas (GHG) emissions, hence could play a role in any carbon trading scheme implemented in Australia. For any GHG reduction protocol to be acceptable in a carbon trading/offset environment, it needs to follow United Nations IPCC guidelines, be based on science, be quantifiable and be auditable. The beef industry already has quality assurance systems in place for RFI that can be fine-tuned to meet these criteria. Scientific information currently available is adequate for the development of GHG emission reduction protocols for cattle raised for slaughter. Selection for RFI also has an impact on GHG emissions from the breeding herd. However, information currently available lacks the degree of accuracy needed for protocol development. It is therefore recommended that funding be provided to continue the research on the relationships among RFI, cow feed intake and maternal productivity traits.

Keywords: feed efficiency, residual feed intake, methane, greenhouse gas, emission, beef cattle.

Introduction

The agricultural sector is a source of greenhouse gas (GHG) emissions worldwide, with the magnitude of its contribution differing from country to country. A recent Food and Agriculture Organization (FAO) report estimates that globally livestock are responsible for 18 percent of greenhouse gas emissions (Steinfeld et al. 2006), though this report attributes all clearing of rain forests to livestock and does not account for carbon sequestration or for the substitution of biological nitrogen for fertiliser nitrogen. In Australia, emissions from the livestock industries are estimated at 62.8 Mt CO₂e, which represented 10.7% of the net national GHG emissions in 2008 (DCCEE 2010). More than 90% of the livestock emissions are from ruminants, predominantly sheep and cattle.

Greenhouse gases generated by cattle production include methane (CH₄) and nitrous oxide (N₂O), which have global warming potentials 21 and 310 times that of CO₂ respectively, making them potent GHGs. Methane primarily arises from enteric fermentation, but also small amounts derive from manure stores.

Some countries already have a carbon trading scheme, and Australia is currently in the process of putting a price on carbon. With this comes the need for all industries to examine and develop strategies to reduce their contribution to GHG emissions. The objectives of this paper were to provide the scientific information underpinning the use of selection for feed efficiency in beef cattle to reduce GHG emissions, to review the beef industries preparedness for selection for feed

efficiency, and to outline a process that can be used to develop quantification protocols for any Australian carbon trading/offset scheme.

Feed efficiency in beef cattle

Providing feed to animals is a major input cost in most animal production systems. The utilisation of the feed consumed by an animal involves complex 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 Australia residual feed intake (RFI) has been chosen as the feed efficiency trait for genetic improvement programs in beef cattle. It is also called net feed intake (NFI). Residual feed intake represents the amount of feed consumed, net of the animal's requirements for maintenance of body weight and production (Arthur et al. 2001b). It is measured 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 are those that eat less than expected and have lower RFI values relative to inefficient animals.

Genetics of feed efficiency

The genetic control of RFI 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 1. The available estimates of genetic variation cover 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 there is the potential to genetically improve the efficiency of feed utilisation by beef cattle through selection for low RFI. RFI has strong positive genetic correlations with feed intake and other measures of feed efficiency (e.g. feed conversion ratio), and a weak to moderate correlation with fatness. The available information suggests that RFI is not genetically correlated with other traits of economic importance in beef cattle. Reviews by Arthur and Herd (2005, 2008) contain detailed information on the genetics of RFI, including genetic correlations with other economically important traits.

Proof of concept demonstration herds

At the 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. Two generations of selection had been achieved by 1999 and there was evidence of a clear divergence between the two lines. 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 (see Table 2). The quality of the meat of cattle from the two selection lines was also found to be similar. 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 (Arthur et al. 2005).

Summary of genetics of RFI

- 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 lower quality nutrition, such as

pasture, 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 post-weaning period remain efficient throughout their lives.
- 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.

Residual feed intake and GHG emissions

The relationship between feed intake and methane production in ruminants has been known for many years, and is recognised 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 per ruminant animal, on the same feedstuff.

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. 2007). This finding therefore offers the potential to reduce methane emission from cattle without compromising productivity. To explore this potential an Australian research group (Herd et al. 2002) and a Canadian group (Okine et al. 2001) used feed intake and production data from RFI projects to calculate methane production using standard algorithms (Blaxter and Clapperton 1965).

The Australian research group used the RFI selection line data (Arthur et al. 2001c) and estimated that cattle selected for low RFI produced 15% less enteric methane per animal per day than those selected for high RFI. 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.

The results from the Canadian study 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 two groups. In both studies the GHG emissions were estimated, and not measured.

Empirical data

To obtain empirical data, where actual methane measurements have been taken to validate these findings, the Australian group

used the progeny of cattle from the RFI selection lines (Arthur et al. 2001c). Ten steers from the low RFI and 10 from the high RFI selection lines were selected out of 76 steers. All steers had just completed RFI tests. Methane was measured 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, and gas sample collections were 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).

The Canadian group used 11 extreme high and 8 extreme low and 8 medium RFI steers for calorimetry studies. These animals were obtained from 306 steers tested for RFI. The mean body weight (BW) as well as mean average daily gain (ADG) on the RFI test was similar between the low RFI (496 kg BW and 1.46 kg/day ADG) and high RFI (501 kg BW and 1.48 kg/day ADG) groups. However, the low RFI steers consumed 17% less feed 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 four-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).

From the two studies it was not clear if there are differences between low RFI and high RFI steers in methane energy loss as a percentage of gross energy intake. However, the studies clearly show that low RFI cattle emit less methane, mainly through the fact that they have lower feed intake relative to high RFI cattle for the same level of production.

In studies where respiratory hoods have been used to measure methane, there is some evidence that low RFI animals also have improved DM digestibility due to a different rumen microbial population and/or host mediated processes (e.g. rate of passage, and rumen pH), thus resulting in less methane produced per unit of dry matter intake (DMI) or gross energy intake (Nkrumah et al., 2007). It is expected that these initial findings will be confirmed as more reports from studies using respiratory hoods are published.

Implications on various diets

The available information on the relationship between RFI and methane emission indicates that there is a direct association between feed intake and methane emissions. Basically, animals that consume less feed

emit less methane. It therefore implies that where animals are fed diets of similar nutritive value (including similar digestibility), the type of ingredients used (e.g. wheat *versus* barley) is of little consequence.

Standard RFI testing protocols have been developed in Australia (Exton 2001) and they specify some standard nutritional quality of the test diet. For example, the diet for post-weaning RFI test should provide approximately 10 MJ metabolisable energy (ME)/kg dry matter (DM). For feedlot RFI tests the diet should provide approximately 12 MJ ME/kg DM. With such standardisation of testing, 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 the relationship between RFI and GHG emissions

- 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 faecal 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.

Industry implementation of RFI technology

For genetic improvement of RFI to be implemented, animals superior for RFI need to be used for breeding. The first step is to measure potential breeding animals or their relatives for RFI. Seedstock breeders can then offer such animals for sale as breeding animals with reliable genetic merit information. The majority of potential breeding animals will be measured for other economically important traits. This is because these traits are relatively easy to measure and the cost of measurement is low. Residual feed intake, however, is an expensive trait to measure. Therefore 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 for RFI there is no need to measure the whole cohort of potential breeding animals. Profitability is maximised 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 other 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 for RFI testing

Feed intake and its utilisation by cattle involve complex 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 utilisation. There is therefore a need to standardise the methodologies and procedures associated with RFI testing. Testing standards and protocols for the measurement of RFI have been established based on scientific data published by Archer et al. (1997). In consultation with industry this scientific data has been used to develop a standards manual for testing cattle for RFI (Exton 2001). This ensures that data from tests conducted at different times and at different locations can be used for genetic improvement.

Standardised estimation of genetic merit

The genetic evaluation system for beef cattle in Australia is called BREEDPLAN and it handles all traits recorded in beef cattle for all breeds. Having a centralised system ensures that there is a single national database and the procedures for computation of the genetic merit (estimated breeding value, EBV) of an animal are standardised. In Australia, standardisation of computational procedures and result reporting are achieved because of the centralisation of the system.

Industry adoption

The beef research feedlot at Tullimba (near Armidale, NSW) is currently the major RFI testing facility for cattle in Australia. More than 10,000 cattle have been tested for RFI at Tullimba and other locations in Australia, with Angus breed having the most cattle tested. Since 2002, Australia's BREEDPLAN genetic improvement program has been providing trial EBVs for RFI. This means that there is opportunity for bull buyers to purchase bulls with known genetic merit for RFI to improve their herds.

Economic benefits 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 formed the basis of the following economic analyses.

The first analysis (Exton et al., 2000) modelled a 100-cow herd run on native

pasture, with progeny being grown on improved pastures. In the production system modelled, surplus heifers were sold at 18 months of age into the domestic market and 80% of the steers were sold for feedlot finishing and subsequent sale as heavy export steers. Gross margin budget and cashflow analyses for this herd showed that, despite the initial cost of purchasing bulls genetically superior for feed efficiency, over a 25-year investment period, the internal rate of return was a healthy 61% and the net present value (NPV) of surplus income over expenses was \$21,907. This equates to an annual benefit per cow of \$8.76.

In a second analysis (Archer et al. 2004), 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 \$150 to \$450), 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.

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.

Managing barriers to adoption A review by Arthur et al. (2004) highlighted some of the barriers to adoption. Research conducted since then has led to a better understanding of RFI and its benefits to seedstock and commercial beef producers. Some of the barriers and how they are being managed are as follows:

- The complexity of automatic feeders has limited the on-farm use of such equipment, and RFI testing is now predominantly done at centralised test stations.

- There was a general lack of appreciation in the beef industry of the importance of feed costs to enterprise profitability. However, Australian feedlot managers now have a good appreciation of the importance of the cost of feed to their enterprises. The recent droughts and high grain prices have strengthened 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 not available. Although it is still desirable to be able to accurately measure individual animal feed intake at pasture, a study by Herd et al. (2004) reporting that low RFI cattle (which are usually tested on prepared diets) are also efficient on pasture, has made this need less critical.
- The cost of identifying animals with superior RFI is high. The simplest solution is to bring down the RFI measurement cost. For most other economically important traits every potential breeding bull is measured. For RFI however, the high cost of measurement means that, in practice, not all potential breeding bulls will be measured. The finding by Archer et al. (2004) that profit was maximised where 10-20% of all potential breeding bulls were tested for RFI translates to a great cost saving to the individual seedstock breeder. The cost of testing for RFI has come down to about \$150, much lower than the \$300 used in previous estimates.
- There is currently intensive research on DNA markers for RFI in Australia and overseas. Some of these markers have been commercialised and others are to follow soon. The use of DNA information in genetic improvement is currently being developed and it is hoped that the price of identifying cattle that are genetically superior for RFI will come down even further.

Summary of industry implementation

- Quality standards for testing cattle for RFI have been developed and implemented.
- Standardised data processing and EBV computation have been implemented through BREEDPLAN.
- 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.
- In spite of certain barriers to adoption, RFI technology is already being adopted by

the beef industry, with more than 10,000 cattle tested for RFI.

Carbon trading environment

The economic benefit from the reduction of feed costs to the enterprise will be the driver for adoption of RFI technology in the beef industry. The potential financial benefit through the carbon trading system will be a welcome by-product of selection. Hence the estimation of this financial benefit from carbon trading does not take into account the cost of adopting the RFI technology.

Financial benefit from carbon trading

Using data from the Australian research projects on RFI, Alford et al. (2006) undertook 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, in which bulls of superior RFI were purchased in year 1, the cumulative total of enteric methane abatement during 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 (CO₂ E) which could be valued given access to a carbon trading scheme. Using a per tonne of CO₂ value 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 \$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. It should also be noted that the saving in feed costs from using low RFI cattle is likely to be more than five times the value of the carbon credits.

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 84,400t, 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 programs, 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.

Procedures for quantification and auditing of emissions

For any GHG reduction protocol to be acceptable it has to follow IPCC (2006) guidelines, be based on science, be quantifiable and be auditable.

Quantification of GHG reduction The production of methane from enteric fermentation in cattle can be measured directly in respiration 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. But they can be, and have been, used to quantify the relationship between low RFI and reduction in methane production through 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 protocol development 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.

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 animals for sale. It is expected that breeding stock for sale will have BREEDPLAN EBVs for RFI and accuracies as part of the sale information.
 - The cow-calf manager will purchase breeding stock with BREEDPLAN EBVs for RFI from a seedstock 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 BREEDPLAN EBV for RFI. If one of the parents does not have a BREEDPLAN EBV, its EBV can be assumed to be zero. Selection for RFI is relatively new in the industry and has not been practised in most beef herds. As a consequence, the assumption of a value of zero (being breed average for RFI) for RFI EBV for non-BREEDPLAN animals is valid.
- Apart from those retained by the manager for replacement, it is expected that most 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 abattoir and wholesale/retail outlets process and sell the beef to the consumer. If any of the practitioners in this sector are 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 for a particular trait is set to zero for all the animals born in that year. This allows genetic improvement relative to the base year to be tracked over years ahead. 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 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 that were tested for RFI 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).

Estimating reductions in GHG emissions The 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 the current year.

Verification strategies The phenotypic measure of RFI and EBVs for RFI will be used as the basis for any protocol development. As indicated, 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. The only other step that 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 Australia's National Livestock Identification System (NLIS).

Cattle specific GHG protocol issues There are issues that unresolved will become barriers to adoption of GHG reduction protocols in cattle. These include:

- Ownership of the carbon credit. The beef cattle industry is made up of several sectors, and only few vertically integrated businesses. An animal will typically change ownership a number of times from conception to slaughter. The linkage of the protocol with the NLIS makes it easier to identify the owner of the cattle at any point in time. However, it is not easy to determine who owns the carbon

credits. Is it the seedstock breeder who originally produced the parent(s), or the cow-calf manager who produced the progeny or the feedlot operator who fed the cattle but may not own them? The issue of ownership of the carbon credits needs to be worked through and agreed upon.

- Social barriers. The cattle community and the general public have some scepticism in relation to the science of climate change in general, and the government policies that drive GHG reductions. Efforts should be made to win the trust of these stakeholders.

General conclusion

Selection for RFI is a relatively new genetic improvement tool in beef cattle to reduce the cost of production. Currently it has a low level of adoption in the beef industry, but the rate and level of adoption has the potential to increase as the cost of identifying superior animals reduces.

Selection for low RFI is associated with reduction in GHG emissions by cattle and could play a role in any carbon trading scheme implemented in Australia.

The expectation is that the economic benefit from the reduction of feed costs to the enterprise will be the driver for adoption of RFI technology. The potential financial benefit through the carbon trading system will be a welcome by-product of selection.

In the province of Alberta in Canada, a GHG reduction protocol based on selection for RFI has been developed and it is in the final stages of the approval process (Climate Change Central 2010). After approval the protocol will be used in the carbon offset program of the province.

For any GHG reduction protocol to be acceptable in a carbon trading/offset environment, it needs to follow IPCC (2006) guidelines, be based on science, be quantifiable and be auditable. In the beef industry in Australia there are already quality assurance systems in place that can be fine-tuned to meet these criteria. Scientific information currently available is adequate for the development of GHG emission reduction protocols for cattle raised for slaughter. Selection for RFI also has an impact of GHG emissions from the breeding herd. However, information currently available lacks the degree of accuracy needed for protocol development. It is therefore recommended that funding be provided to continue the research on the relationships among RFI, cow feed intake and maternal productivity traits.

Acknowledgements

Funding provided by Industry and Investment NSW, Meat and Livestock Australia, and the Beef Cooperative Research Centre to support the various Australian research projects on feed efficiency and methane production is acknowledged. The guidance by Dr Roger Hegarty on the thinking about mitigation of GHG emissions is gratefully appreciated.

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Appendix

Table 1. Heritability estimates (\pm 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 \pm 0.08	Herd and Bishop (2000)
Angus	Australia	1180	0.39 \pm 0.03	Arthur et al. (2001a)
Charolais	France	792	0.39 \pm 0.04	Arthur et al. (2001b)
Mixed	Australia	1481	0.18 \pm 0.06	Robinson and Oddy (2004)
Mixed	Canada	2284	0.38 \pm 0.07	Schenkel et al. (2004)
Wagyu	Japan	740	0.24 \pm 0.11	Hoque et al. (2006)
Composite	Canada	464	0.21 \pm 0.12	Nkrumah et al. (2007)
Brahman	Australia	680	0.24 \pm 0.11	Barwick et al. (2009)
Tropical Composites	Australia	783	0.38 \pm 0.12	Barwick et al. (2009)

Table 2. Least squares means (\pm standard errors) for growth, feed efficiency, reproduction, maternal productivity and methane production in beef cattle divergently selected for residual feed intake (RFI)

Traits	Generations of selection	Selection line		Significance
		Low RFI	High RFI	
Growth and feed efficiency	2.0			
Weaning weight (kg)		232.5 \pm 3.1	228.3 \pm 2.9	n.s.
Yearling weight (kg)		384.3 \pm 6.9	380.7 \pm 6.7	n.s.
Average daily gain (kg)		1.44 \pm 0.03	1.40 \pm 0.03	n.s.
P8 fat depth (mm)		6.7 \pm 0.3	8.8 \pm 0.3	*
Eye muscle area, (cm ²)		72.1 \pm 0.8	74.2 \pm 0.7	n.s.
Daily feed intake (kg)		9.4 \pm 0.3	10.6 \pm 0.3	*
Feed conversion ratio		6.6 \pm 0.2	7.8 \pm 0.2	*
Residual feed intake (kg/day)		-0.54 \pm 0.12	0.71 \pm 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 \pm 0.3	7.8 \pm 0.3	n.s.
Wt of calf weaned (kg)		191.3 \pm 8.4	198.4 \pm 7.7	n.s.
Methane production in steers ^C	2.4			
Daily feed intake (kg)		8.38	14.13	*
Average daily gain (ADG ,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

^ASource: Arthur et al. 2005.

^BPer cow exposed to bull.

^CSource: Hegarty et al. 2007.

* P<0.05; n.s. P>0.05.