NSW GOVERNMENT | Department of Primary Industries

FILLING THE RESEARCH GAP PROGRAM

NATIONAL LIVESTOCK METHANE PROGRAM

Genetic technologies to reduce methane emissions from Australian beef cattle

RESEARCH PROJECT - FINAL REPORT

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Genetic technologies to reduce methane emissions from Australian beef cattle

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More information

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EXECUTIVE SUMMARY

This project has delivered tools and knowledge to assist producers to breed productive, lower emissions cattle, using validated methodologies that will assist them to earn CFI credits.

Genetic merit of methane emissions can now be described by estimated breeding values and costed into profit indexes in BREEDPLAN®. These include feed-associated methane, improved feed efficiency, and methane differences at same feed intake. Economic weights have been modelled with varying carbon prices. Industry recording of methane production by cattle has been initiated and is on-going. Early results show genetic variation in methane traits.

The project has produced the first and most comprehensive estimates of genetic parameters in the world for methane traits in beef cattle. The results indicate that selection for reduced methane yield would lead to reduced emissions without impacting productivity. The expected selection response per year for methane traits was 0.4% to 0.5% of the mean for these traits – suggesting 10 years of selection could lead to a 4% t0 5% reduction in methane yield using DNA-based genomic breeding values. This compares favourably with, milk yield in dairy cattle, a much easier trait to measure, where roughly a 1.5% gain per year is achieved.

NOTE: Report appendices have not been included with this publication. Many have been published elsewhere, or are in the process of being submitted for publication, and should be available shortly. Please contact the authors for more detail.

BACKGROUND

Enteric methane emissions from grazing beef cattle were estimated to be 37MT CO2-e in 2010, or 6.4% of our National greenhouse-gas emissions, and would be costed at $851million (@$23/tonne). Our federal and state governments and society generally, expects livestock farmers to try to reduce these emissions. As an incentive to reduce emissions the previous federal government introduced the Carbon Farming Initiative (CFI). Under the CFI, adoption of approved technology resulting in a 1% reduction in GHG emissions could generate $8.15million in carbon credits annually. Even modest rates of adoption of breeding for genetic reduction in methane from the southern Australian beef cattle herd would produce this result. This project seeks to fill the research gap enabling development of new breeding technology that when adopted would return a future carbon credit income stream exceeding $8million/year.

Our Australian research is showing that there is natural variation between beef animals in methane emissions and in feed intake. For industry adoption of a breeding solution this project will fill two major research gaps: 1.Determine how much underlying genetic variation is present, the heritability and genetic associations with other production traits; 2. Develop new enabling technology to allow cattle producers to identify and use with confidence low-methane bulls.

The project will implement industry recording of methane production by animals from the major Australian breed societies, and the merit of the sires for methane mitigation widely published. Methane emissions will be costed into the breeding values and profit indexes used to describe the genetic merit of cattle in our national genetic evaluation system BREEDPLAN®. Divergent selection on methane production will be continued to reveal any unfavourable consequences, and are a proven powerful design for the discovery of DNA markers with which to identify superior cattle.

The project aims were to:

1. Develop new profit indexes and breeding values to allow cattle producers to identify and purchase superior bulls whose offspring will have lower methane emissions.

2. Put in place the infrastructure to test the progeny of future elite sires from the major Australian cattle breeds and rank the sires by EBV for methane and profit indexes with methane costed. These bulls will be among the elite sires used widely in AI through their breeds and impacting the future of genetic change.

3. Produce the new knowledge of the phenotypic and genetic relationships between methane production traits and other important production traits required for inclusion in, and adjustment of, the BREEDPLAN® model for genetic evaluation

4. Use modern genomic technologies to improve accuracy of EBV for methane production traits using information from DNA data to help identify larger numbers of superior bulls for lower methane emissions than would otherwise be possible to measure on large numbers of industry animals.

The breeding technologies developed will be science-based methods capable of earning carbon credits under the CFI.

The outcome will be that beef cattle producers are able to buy bulls to breed future generations of cattle that are highly productive with naturally lower methane emissions.

METHODOLOGY

Activity 1 Provide beef producers with genetic tools to reduce methane emissions

Leader: Dr Steve Barwick, Principal Research Scientist, Animal Breeding and Genetics Unit, the University of New England, Armidale, NSW.

Methodology:

- Selection index modelling to investigate ability to account for and cost methane emissions in current selection indexes using traits already recorded
- Selection index modelling to investigate impact of inclusion of feed intake and net feed intake (NFI; a measure of feed efficiency) on ability to breed for lower methane emissions
- Selection index modelling to investigate impact of inclusion of traits quantifying methane emissions on the ability to breed for lower methane emissions
- Development of specific “low methane” selection index that may include traits such as methane yield, feed intake, NFI and cow mature size
- Produce profit indexes with methane costed for leading sires for major cattle breeds in southern Australia and release to industry for review.
- Report on the merit of a breeding solution as a greenhouse-gas (GHG) mitigation methodology under the CFI.

Output: New profit indexes and breeding values to allow cattle producers to identify and purchase superior bulls whose offspring will have naturally lower methane emissions.

Activity 2 Industry implementation of methane measurement

Leader: Professor Roger Hegarty, the University of New England, Armidale, NSW.

Methodology:

- Implement measurement of methane production on a large number of industry animals by installing methane recorders at the “Tullimba” research feedlot, near Armidale NSW, and put in place data checking and linkage into databases.
- Establish and deploy technology and protocols for routine measurement of methane emissions from cows at pasture.
- Obtain large number of methane phenotypes (in addition to other production traits) on industry cattle populations, specifically targeting Beef Information Nucleus (BIN) animals, to provide industry data records to calculate EBV and phenotypic and genetic correlations with other important production traits.
- Quantify and cost emissions by industry cattle through BINs, rank their sires, produce EBV and profit indexes for sires with methane measurements.
- Animals measured will initially be steers on a feedlot ration.
- Extend this to measure methane emissions by related females at pasture.

Output: Future elite sires from Australian cattle breeds ranked by EBV for methane and profit indexes with methane costed. These bulls will be among the elite sires used widely in AI through their breeds and will have a major impact on future genetic change in commercial cattle herds.

Activity 3 Quantify genetic relationships between methane production traits and other production traits, and understand the underpinning biology

Leaders: Dr Kath Donoghue, Livestock Research Officer, NSW Department of Primary Industries, Trangie, NSW.

Dr Robert Herd, Principal Research Scientist, NSW Department of Primary Industries, Armidale, NSW.

Methodology:

- Measure response in methane production traits and other production traits, including feed intake, to continued divergent selection on methane yield (methane produced per unit feed eaten) in NSW DPI cattle divergent methane selection lines.
- Estimate genetic correlations between methane traits and other production traits for use in development of BREEDPLAN selection indexes.
- Investigate repeatability of methane production traits across time, physiological stage and diet (i.e. in young bulls and heifers, steers in feedlot, cows on pasture).
- Collect biological samples from high and low methane cattle to share across the National Livestock Methane Program (NLMP) network of collaborators.
- Continue divergent selection of these animals to obtain extreme methane yield phenotypes which will show the direction of any change in other animal characteristics before they are detected or become widespread (if unfavourable) in industry cattle, as well as for DNA marker discovery (genomics). Our refereed journal papers show the power of using divergent selection lines for this purpose.

Output: Knowledge of the phenotypic and genetic relationships between methane production traits and other important production traits for inclusion in, and adjustment of, the BREEDPLAN® model for genetic evaluation.

Activity 4 DNA markers for low methane cattle (genomics).

Leaders: Associate Professor Ben Hayes, Latrobe University and the Victorian Department of Primary Industries, Bundoora, Vic.

Dr Paul Arthur, Senior Principal Research Scientist, NSW Department of Primary Industries, Camden, NSW.

Methodology:

- Use NSW DPI methane selection lines to investigate single nucleotide polymorphisms (SNPs; small differences in DNA sequence) for methane yield. The previous NSW DPI feed efficiency selection lines proved to be a powerful resource population for discovery of genes and DNA markers for feed efficiency in the CRC for Beef Genetic Technologies. Our refereed journal papers show the power of using divergent selection lines for this purpose.
- Extend gene discovery from the NSW DPI methane selection-line cattle to cattle recorded for methane in the industry-cattle BIN program, and to pedigreed sheep and dairy cattle recorded for methane in Australia and New Zealand, and overseas livestock populations being recorded within the Global Research Alliance (GRA) for livestock methane mitigation.
- Use extreme methane yield phenotypes to undertake gene expression research to help find DNA markers and to identify biochemical pathways associated with variation in methane production.

- Incorporate DNA marker information into EBV for industry implementation of breeding to reduce methane emissions.

Output: Increased accuracy of EBV for methane production traits using information from DNA data to help cattle producers select superior bulls whose offspring will have naturally lower methane emissions.

RESULTS

Activity 1. Provide beef producers with genetic tools to reduce methane emissions

The attached report (Final report appendix 1) outlines the approach and progress towards incorporating methane emissions in the multi-trait selection indexes used for genetic improvement in the Australian beef industry. Climate change and its contributors involve many factors. The purpose here was to be able to facilitate reduction of methane emissions while jointly valuing improvement of productivity.

The first step is to include the cost of feed-associated methane in the breeding objective. The ability to include methane differences at the same feed intake is then also considered so these can be included when methane is able to be widely recorded and estimated breeding values (EBVs) for methane are available.

The feed requirement associated with trait change is estimated for all classes of animals for each trait of the breeding objective. This is over all periods of the year, as methane emissions occur all year-round. The amount of methane that is associated with feed requirement, and with residual feed intake, is estimated for each trait using relationships from the literature. Other alternatives can also be used. There are further steps in deriving the global warming potential of methane emissions, in CO2 equivalents, using the properties of CO2 and the internationally-accepted global warming constant. Lastly, a user-defined estimate of the price of carbon per tonne, on a CO2 equivalent basis, is used to assess the carbon cost of methane for each trait.

Industry genetic trends that may occur for methane are illustrated. Among the things they show is that selection to reduce residual methane (i.e., methane differences at the same feed intake) is more likely to lead to reduced total methane if feed-associated methane is also being reduced (eg. by increasing feed efficiency). The need to reduce methane emissions is thus a strong additional reason for increasing feed efficiency. Facilitating selection to increase feed efficiency (by reducing net feed intake), while improving other traits, was part of this project and there were some important developments for that. Indexes with residual feed intake EBVs included were made available for industry trialling. Adoption of these indexes is being considered by eg. the Angus breed, and this is likely in the near future.

The effect of incorporating feed intake-associated methane in indexes is akin to increasing the cost of each unit of feed. Developments for incorporating feed-associated methane followed the above strategy and included estimating the feed requirement associated with production for all classes of animal (in young animals, components for maintenance and gain; in cows, components for maintenance, gain, gestation and lactation), at all times of the year, for any beef production system; prediction of the methane associated with the feed requirement change that occurs when each trait is improved; prediction of the methane that is associated with change in each of the residual feed intake traits; and translation of methane quantities into CO2 equivalents, considering the chemistry of methane and the internationally-recognised global warming constant. Additionally, it included development of a new web-based questionnaire for describing the commercial beef production system, including provision for nominating (and varying) the price of carbon (ie., price per tonne, CO2 equiv.); calculating the carbon cost of the feed intake-associated methane associated with trait change; and development of a carbon report for all breeding objective traits, summarising carbon cost calculations for all classes of animals.

How trait economic values change with the price of carbon is illustrated for a selection of breeding objective traits. As carbon price increases to around $300 per tonne, the economic value of increasing finished sale liveweight falls to zero. With few exceptions, economic values of traits become more negative as the price of carbon increases, the rate of the fall showing the sensitivity of the improvement to carbon price. At higher carbon price, breeding to increase carcase meat percentage becomes a little more important relative to most other traits, as

increase in carcase meat percentage is unaffected by carbon price. The importance of reducing residual feed intake (RFI; increasing feed efficiency) in the feedlot increases more markedly with the price of carbon. The importance of improving cow weaning rate decreases as carbon price increases, serving as a reminder that the benefits from increasing reproduction rate, when other production is constant, also depend on cost levels.

The economic values calculated include the cost of feed-associated enteric methane. To also include methane and nitrous oxide emissions from manure, project calculations suggest these costs can be scaled up by approximately 18% for animals at pasture and 67% for animals in the feedlot.

Developments for incorporating residual methane in indexes involved construction of genetic matrices with the parameter estimates obtained within the project for residual methane traits; inclusion of methane cost for periods where there would usually be surplus pasture (ie. where cost of the feed required would usually be lower or zero); and provisional inclusion in the genetic matrix of EBVs for net methane (pasture) and net methane (feedlot). The use of 'net' here follows the convention adopted in the industry for RFI, where EBVs for RFI are known as net feed intake EBVs.

To fully incorporate methane in selection indexes it is important that the residual methane breeding objective traits are taken into account. Where it is possible for net feed intake and methane to be measured in industry, physically or genomically, and for EBVs for these to be available for inclusion in selection indexes, desirable changes are likely to occur in each of methane emission, feed efficiency and productivity.

Web facilities were developed to allow indexes with methane costing to be derived on-line and accessible to industry. Graphs that show the changes in methane and in methane per unit of product resulting from selection on any index will also be displayable on the web. Arrangements are in place for a specialist web-programmer to complete these displays.

To construct the above graphs, use is made of new methods, developed in the project, for deriving the accuracy of indexes of EBVs, where the EBVs themselves differ in the information they contain, and for predicting the gains resulting from selection on those indexes. A summary is presented of the methods that are able to be used to separate and accumulate methane and methane per unit of product outcomes for selection on any index.

Industry feedback suggests there is particular interest in being able to demonstrate changes occurring in methane per unit of product. Reductions in methane per unit of product will occur from selection on indexes that incorporate methane cost, and some will occur simply from productivity increase.

A successful workshop was conducted for breed societies and technical representatives. The two stages through which industry can achieve emphasis on reducing methane were seen as being:

1. Cost feed-associated methane in the breeding objective. Construct the selection index of existing EBVs. Selection emphases, rankings, and consequences for methane all change as a result of costing the feed-associated methane in the objective. Total methane is expected to be reduced; how much reduction there is will change with the circumstance. Methane per unit of product will be reduced. The methane reductions result from changed usage of feed, including from increases in feed efficiency.

2. Cost feed-associated methane and residual methane in the breeding objective. Achieve industry measurement of methane (eg. of residual methane), allowing derivation of methane EBVs. Construct the selection index of existing and methane EBVs. Selection emphases, rankings, and consequences for methane all change as a result of both costing methane in the objective and methane EBVs being available. Total methane is more certain to be reduced, and

there will be a greater reduction in methane per unit of product. The methane reductions result not only from changed usage of feed, but also from change to the mechanisms reducing methane per unit of feed.

Activity 2. Industry implementation of methane measurement

Methane is the main source of greenhouse gas (GHG) from ruminants, and is produced during the process of microbial fermentation of plant material mainly in the rumen. Reducing the enteric methane production is therefore essential in any GHG emissions reduction strategy in livestock. For genetic improvement it is essential to accurately measure individual animal methane production (MPR) of large numbers of cattle to estimate the genetic merit of each potential breeding animal for the methane traits. The focus of this activity was to measure methane in large numbers of industry cattle, starting with steers in the feedlot. The ultimate aim was to develop estimated breeding values for methane traits for use in genetic improvement. Five batches (total of 548) of Australian Angus and one batch (total 107) of Australian Charolais Beef Information Nucleus herd steers which were undertaking a net feed intake test at the University of New England “Tullimba” research feedlot, near Armidale NSW, were measured for MPR. The MPR was measured using GreenFeed Emission Monitoring (GEM) units, which provide short term MPR measurement anytime a steer visits the unit. Approximately two-thirds of the steers from each breed visited the GEM unit for MPR measurement; most of them more than 20 times within a period which ranged from 50 to 66 days depending on the batch. There were significant ($P < 0.05$) sire differences in MPR, MPR per unit feed intake, MPR per unit body weight and MPR per unit average daily gain. In general, the sire differences were significant between the top and bottom five sires for each of the methane traits. The presence of significant sire differences in the methane traits indicates the presence of genetic variation for methane traits when measured by GEM units. For full details of this study, see Final report appendix 2A. The data generated through this work will be available for the generation of EBVs and genetic relationships using Breedplan.

Pasture based studies of Angus Australia registered animals (steers and heifers) have been completed (see Final report Appendix 7), demonstrating variation between animals on pasture. More recently the Trangie divergent selection herd has been enrolled in the Angus BIN program, and a number of cows and bulls from this herd have been measured on pasture using GEMs.

A number of technical issues arose with the use of GEM units. Approximately half of the BIN animals did not achieve a useful methane test record whilst they had access to the GEM units, because the units often had to be turned off, sometimes during critical animal training periods. Whilst it appears that useful data was lost due to these problems, the project was still able to generate methane test results for more than 650 of the BIN animals tested. Future work will focus on continued development of recording technologies, for example developing a single machine to monitor feed intake and emissions simultaneously, so that all BIN cattle can be measured.

On the 5 March 2015 the Project team met with the Angus Society and technical representatives of other cattle breeds to review project results. They were with provided the results showing genetic variation in methane traits in cattle, progress with implementing methane traits into the BREEDPLAN system for cattle genetic evaluation and improvement, and how trial EBV for their cattle could be generated. At the direction of the Breed Societies, trial EBVs for industry cattle have not been released. Trial EBVs have been generated for the Trangie BIN herd, and values for these are available in the attached report “Genetic parameters for methane production in Australian beef cattle”, Donoghue et al. 2015, (Final report appendix 4), and have been shared with the Breed Societies.

A survey of beef industry attitudes to greenhouse-gas and methane emissions from cattle and the possibility of a breeding solution to reduce emissions was conducted over the life of the project (see Final report appendix 2B). These have shown a shift in attitudes, with increasing awareness of the importance of reducing methane emissions, and the awareness of the ability to

breed cattle for naturally lower emissions. It is planned that the results from these surveys will form the basis of an industry conference paper.

The beef industry supported the project throughout by provision of access to BIN cattle for methane measurement, cattle pedigrees and feed-intake data. Further consultation – which may include development of methane trading opportunities under the CFI – will be required for the eventual industry adoption of methane measurement and breeding tools.

Activity 3. Quantify genetic relationships between methane production traits and other production traits, and understand the underpinning biology

Methane selection lines and quantifying genetic relationships

High and Low selection lines for methane yield (MY) were created in each of two performance-recorded Angus research herds during the 2011 mating season. A report is attached (Final report appendix 3) on the divergence of the selection lines, as assessed by the performance of the 2013 born progeny. There was no significant selection line by herd interaction. Approximately 0.77 generations of selection were achieved. There was a significant ($P<0.05$) divergence between the two lines in the selected trait, methane yield. This was also reflected in the significant ($P<0.05$) selection line differences in the residual methane (actual minus expected methane production) traits and also in the estimated breeding values for these traits. There were no significant selection line differences in birth, weaning and yearling weights. The attached report has been submitted as a draft paper to the 21st Biennial Conference of the Association for the Advancement of Animal Breeding and Genetics 2015.

The attached paper (Final report appendix 4) reports the heritability estimates for methane traits in beef cattle, using records from 1,043 young Angus bulls and heifers measured for methane production in respiration chambers. Methane traits evaluated included dry matter intake (DMI) during the methane measurement period, methane production rate (MPR), methane yield (MY; MPR/DMI), and methane intensity (MI; MPR per unit weight). Four forms of residual MPR (RMP), which is a measure of actual minus predicted MPR, were evaluated. For the first 3 forms, predicted MPR was calculated using published equations. For the fourth (RMPR), predicted MPR was obtained by regression of MPR on DMI. Weight traits evaluated were birth (BWT), weaning (WWT), yearling (YWT) and final (FWT) weight. Body composition traits included ultrasound measures of eye muscle area (EMA), rump fat depth (P8FAT), rib fat depth (RIBFAT) and intramuscular fat percentage (IMF). Heritabilities for MPR, MY, MI and RMP traits were moderate (0.19 to 0.28), indicating that there is potential to use genetic improvement to reduce methane emissions in livestock. MPR was moderately genetically correlated with MY (0.50) and all four RMP traits (0.32 to 0.63). However, MPR was also moderately to highly correlated with EMA and the growth traits (WWT, YWT and FWT) both phenotypically (0.28 to 0.61) and genetically (0.40 to 0.86). Methane yield and the four RMP traits, however, were lowly correlated, phenotypically (-0.06 to 0.10) and genetically (-0.18 to 0.45), with the weight and body composition traits. All the RMP traits were strongly genetically correlated with MY (0.99). These results indicate that selection for lower MPR could have a negative impact on weight and body composition traits in beef cattle. Selection for reduced MY, however, would lead to reduced MPR without impacting animal productivity. The use of a ratio trait, like MY, in animal breeding is generally undesirable, and thus selection on any of the four RMP traits is a better alternative.

Early data was used to publish a conference paper and scientific journal paper:

Herd RM, Arthur PF, Bird SH, Donoghue KA, Hegarty RS (2014) Genetic variation in methane traits in beef cattle. In 'Proceedings of the 10th World Congress of Genetics Applied to Livestock Production', Paper 038, 3 pages. (Final report appendix 12)

Herd RM, Donoghue KA, Arthur PF, Bird SH, Bird-Gardiner T, Hegarty RS (2014) Measures of methane production and their phenotypic relationships with growth and body composition traits in beef cattle. Journal of Animal Science. 92:5267-5274. (Final Report appendix 13)

The updated data and attached report (Final Report appendix 4) has been submitted as a draft paper to the 21st Biennial Conference of the Association for the Advancement of Animal Breeding and Genetics 2015.

Understanding underpinning biology

The attached paper (Final report appendix 5) reports results for 136 yearling-age Angus heifers and bulls which were tested for methane production in respiration chambers, and rumen fluid samples taken 3 hours post-feeding analysed for concentrations of volatile fatty acids (VFAs). A subsample of animals also had repeat rumen samples taken 24 hours after feeding. The animals were fed a roughage ration offered at 1.2-times maintenance throughout the testing period. Concentrations of the major VFAs (acetate, propionate and butyrate) and their proportions in the 3 hours post-feeding sample were strongly associated with methane production rate (correlation coefficients up to 0.62), but less strongly with methane yield and residual methane production (correlation coefficients up to 0.17 and 0.28, respectively). Many of the relationships of VFA concentrations with methane emissions apparent in the 3hour measurement were reversed at 24 hours. Taking a rumen fluid sample during peak fermentation did reveal stronger associations between methane emissions and VFA concentrations than previously reported for samples collected 24 hours after feeding. These stronger relationships open the possibility of using VFA concentrations in rumen samples obtained at peak fermentation as indicator traits for methane emissions. For genetic selection, more careful scrutiny of VFA as markers for methane emissions is still warranted.

Earlier VFA results for 532 animals born in 2009 and 2011, who were tested for methane and sampled for rumen fluid and have been published:

Herd RM, Bird SH, Donoghue KA, Arthur PA, and Hegarty RS (2013) Phenotypic associations between methane production traits, volatile fatty acids and animal breeding traits. In 'Proceedings of the 20th Biennial Conference of the Association for the Advancement of Animal Breeding and Genetics 2013', pages 286-289. (Final report appendix 11)

The attached report has been submitted as a draft paper to the 21st Biennial Conference of the Association for the Advancement of Animal Breeding and Genetics 2015.

Rumen microbiology, based on duplicates of the rumen samples taken for VFA samples, will be investigated by Ben Hayes (VicDEPI) and Stuart Denman (CSIRO). They are project leaders for other National Livestock Methane Program projects, and these samples are part of collaborative arrangements. These samples have been despatched and are currently being analysed.

Repeatability of methane production traits

Records on 1,043 young Angus heifer and bull progeny from 73 sires, measured for methane production in respiration chambers were used to evaluate the accuracy of a 1-day measurement relative to a 2-day measurement duration (see Final report appendix 6). The traits assessed were dry matter intake (DMI), methane production rate (MPR), methane yield (MPR per unit DMI), and four residual methane (RMP) traits. The RMP traits were computed as actual MPR minus expected MPR, where the expected MPR were calculated from three different published and widely used equations. The expected MPR for the fourth was computed by regressing MPR on DMI, using the data from the study. Variance components, heritability, phenotypic and genetic correlations, and the efficiency of selection using 1-day compared with 2-day measurement were used as assessment criteria. The environmental variance for the 2-day measurement was slightly lower than that of the 1-day measurement for all the traits studied, indicating that the addition of an extra day of data was effective in reducing the amount of unexplained variation in each trait. However these minor reductions did not have a major impact on accuracy, hence very high phenotypic (rp of 0.91 to 0.99) and genetic (rg of 0.99 for each trait) correlations were obtained between the two measurement durations. Lowering MPR per se, may have a detrimental impact on ruminant productivity through a correlated reduction in feed intake, hence MY and the RMP traits are likely to be the traits of interest for genetic improvement. Efficiency of selection for MY and the RMP traits ranged from 0.96 to 0.99, which

implies that there would be less than 5% loss in efficiency by adopting a 1-day relative to a 2-day methane measurement duration. The throughput of the respiration chamber facility can be increased by adopting a 1-day measurement duration. The attached report has been submitted as a draft paper to the 6th Greenhouse Gas and Animal Agriculture Conference in February 2016.

Since daily methane production (DMP; gCH4/d) is strongly correlated with feed intake, the breeding of cattle that require less feed to achieve a desired rate of average daily gain (ADG) by selection for a low residual feed intake (RFI) can be expected to reduce DMP and also emission intensity (Ei; g CH4/kg ADG). An experiment was conducted (see Final report appendix 7) to compare DMP and Ei of Angus cattle genetically divergent for RFI and 400-day weight. In a 6-week grazing study, 64 yearling-age cattle (30 steers, 34 heifers) were grazed on temperate pastures, with heifers and steers grazing separate paddocks. Liveweight was monitored weekly and DMP of individual cattle was measured by a GreenFeed emission monitoring unit (GEM) in each paddock. Thirty-nine of the possible 64 animals had emission data recorded for 15 or more days, and only data for these animals were analysed. For these cattle, regression against their mid-parent estimated breeding value for post-weaning RFI (RFI-EBV) showed that lower RFI-EBV were associated with heavier liveweight (LW) at the start of test. Predicted dry matter-intake (pDMI), predicted DMP and measured DMP were all negatively correlated with RFI-EBV ($P<0.05$), whilst ADG, Ei and predicted methane yield (pMY; g CH4/kg DMI) were not correlated with RFI-EBV ($P>0.1$). DMP was positively correlated with animal LW and ADG ($P<0.05$). The associations between ADG and its dependent traits Ei and pMY and predicted feed conversion ratio (pFCR; kg pDMI/kg ADG) were strongly negative ($r=-0.82$, -0.57 and -0.85, $P<0.001$) implying that faster daily growth by cattle was accompanied by lower methane Ei and MY and improved feed conversion. These results show that cattle genetically divergent for RFI do not necessarily differ in ADG, Ei or pMY on pasture and that, if heavier, cattle with lower RFI-EBV can actually have higher DMP while grazing moderate quality pastures. These relationships are currently being investigated for animals from the methane divergent selection lines at Trangie following a similar methodology. The attached paper has been submitted as a draft publication to the peer-reviewed journal Animal Production Science, in February 2015.

Progress in Activity 4. DNA markers for low methane cattle (genomics)

The attached paper (Final report appendix 8) reports on the genomic studies using DNA of 1020 Angus bulls and heifers from the methane yield selection lines. The DNA was analysed for single nucleotide polymorphisms (SNPs small differences in DNA sequence) for the methane traits. Methane emissions for beef cattle are heritable, whether measured as methane production, methane yield (methane production/dry matter intake), or residual methane (observed methane production – expected methane production). This suggests methane emissions could be reduced by selection. Genomic selection is perhaps the most feasible approach to implement for the beef industry, given the high cost of measuring methane production from individual cattle. We derive genomic estimated breeding values (GEBV) for methane traits from a reference set of 747 Angus animals measured for methane traits, and genotyped for 630K SNP. The accuracy of GEBV was evaluated in a cohort of 273 Angus animals. Accuracies ranged from 0.29, for methane yield, to 0.35 for residual methane. Selection on GEBV using the genomic prediction equations derived here could reduce emissions for beef cattle by roughly 5% over 10 years.

The attached paper (Final Report appendix 8) has been submitted to the 21st Biennial Conference of the Association for the Advancement of Animal Breeding and Genetics 2015.

DISCUSSION

The project aimed to:

1. Develop new profit indexes and breeding values to allow cattle producers to identify and purchase superior bulls whose offspring will have lower methane emissions.

2. Put in place the infrastructure to test the progeny of future elite sires from the major Australian cattle breeds and rank the sires by EBV for methane and profit indexes with methane costed. These bulls will be among the elite sires used widely in AI through their breeds and impacting the future of genetic change.

3. Produce the new knowledge of the phenotypic and genetic relationships between methane production traits and other important production traits required for inclusion in, and adjustment of, the BREEDPLAN® model for genetic evaluation

4. Use modern genomic technologies to improve accuracy of EBV for methane production traits using information from DNA data to help identify larger numbers of superior bulls for lower methane emissions than would otherwise be possible to measure on large numbers of industry animals.

The breeding technologies developed were to be science-based methods capable of earning carbon credits under the CFI. The project has met all progress milestones, including achieving significant project objectives.

BREEDPLAN is Australia's national system of genetic evaluation for beef cattle and provides estimated breeding values (EBV) for a range of important production traits. These EBV, together with information on future income earned and costs incurred by the progeny of the bulls, are used to compute $Indexes reflecting the relative economic value of bulls. We have completed activities to generate methane EBVs and methane-costed $ indexes, and have been able to generate reports and web-based tools to demonstrate how these selection tools will influence genetic trends, and how different carbon prices might affect cattle breeding objectives. This will highlight how cattle breeders can earn credits under the CFI, reducing emissions by utilising EBVs and indexes which value feed-related methane emissions, including Net Feed Intake. We have generated a number of reports for these, and have communicated these outcomes with industry representatives.

Some project activities are continuing, particularly to continue collecting industry cattle data. A number of technical issues earlier encountered with GEM units used to measure industry cattle methane emissions have been resolved, and we have agreement with the cattle Breed Societies to continue to measure their BIN cattle. Results for BIN cattle have been reported to the Breed Societies. The reliability of the GEM units continues to improve as a number of issues described in previous progress reports have been solved. The outcome of this activity is that the Australian beef industry now has a facility for on-going collection of methane emission data for elite sires, sires that will potentially be used widely and have a major impact in genetic improvement of Australian cattle

Measurement activities at the UNE respiration chamber facility were completed in November 2014, and the records used to calculate genetic relationships, as well as investigating other questions, such as the efficiency of the test length, and relationships with other measures, such as rumen VFA. The prepared papers detailed in this report (and attached as appendices) have been a great achievement, and we are preparing to publish them as soon as possible. The data has been submitted to the NLMP database.

The results of the genomic selection is quite encouraging, with accuracy of the genomic EBVs of 0.3 for all methane traits. The selection response per year for methane yield and methane intensity would be 0.084 g/kg DMI and 0.002g/kg liveweight respectively. This is 0.4% and 0.5% of the mean for these traits – suggesting 10 years of selection could lead to a 4% reduction in methane yield, or a 5% reduction in methane intensity, using the genomic breeding values

derived with the data set used here. This compares quite favourably with, for example milk yield in dairy cattle, a much easier trait to measure, where roughly a 1.5% gain per year is achieved.

The completion of sampling and measurement activities and the analysis of the results have been a significant achievement for the project, with results identifying useful tools and knowledge, which will allow producers to breed animals for naturally lower methane emissions.

FUTURE RESEARCH NEEDS

This project has delivered its expected outcome. With the information and genetic tools developed by this project, cattle producers will be able to buy bulls to breed future generations of cattle that are highly productive with lower methane emissions, using validated methodologies capable of earning carbon credits under the Carbon Farming Initiative (CFI), which is being transitioned to the Emissions Reduction Fund (ERF). Breeding for low NFI is now on the positive list for earning credits in the CFI, and a draft methodology exists. At this stage industry has not produced or published any $-indexes which include methane costing, either included in existing indexes or with additional methane traits included. Industry implementation of a breeding solution will require consideration of the role of breed societies and/or major seedstock bull suppliers in aggregation and distribution of carbon credits, which may depend on how the price of carbon changes and how the carbon market influences on-farm productivity. Further research will be required to complete the process of approving this methodology and for producers to have projects approved to earn credits using this methodology.

The framework is in place for methane data to be included in BREEDPLAN analysis, whether or not these results are incorporated or published as $-indexes. This means that further research can continue to improve the accuracy of these predictions, and determine the genetic correlations of methane traits with other traits. In particular collecting more methane measurements from more industry animals will be valuable in answering questions about the impact of breeding for reduced emissions on productivity drivers such as feed intake, carcase weight, carcase composition traits (particularly intra-muscular fat), and female fertility. Projects such as the Beef Information Nucleus testing provide useful opportunities for this type of research, but other research opportunities may also provide this data. With the appropriate data the full value of the genetic tools developed in this project can be realised.

Collecting industry data would benefit from further research in to the deployment of GEMs, including their reliability and accuracy. There has been some preliminary work to develop a GEM unit which simultaneously monitors feed intake. This unit should provide a useful technology for monitoring emissions.

The research on the measurement of methane traits on females at pasture is in its infancy and the use of GEM units to collect data from females at pasture needs to continue. Very few animals have been measured on pasture and measurement protocols are currently being developed and trialled. Continued funding is required to progress the work on measuring methane on females at pasture.

On-going breeding and testing of the divergent selection herd will also be useful in answering some of the above questions. These animals will also provide a useful resource for more intensive research, such as better understanding rumen microbe populations, rumen dynamics and diet digestibility. They will provide a useful source for genetic material such as DNA and RNA, to improve understanding of how genomes and possibly specific genes influence emissions.

PUBLICATIONS

Website link to lead organisation project information:

http://www.dpi.nsw.gov.au/agriculture/resources/climate-and-weather and follow links to “Enteric Methane Research” http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/532694/agriculture-resources-climate-enteric-methane.pdf

Specific Project Conference Papers and Journal Papers (published to date):

Barwick SA, Tier B, Swan AA, Henzell AL (2013) Estimation of accuracies and expected genetic change from selection for selection indexes that use multiple-trait predictions of breeding values. Journal of Animal Breeding and Genetics 130, 341-348. (Final report appendix 9)

Donoghue KA, Herd RM, Bird SH, Arthur PF, Hegarty RS (2013) Preliminary genetic parameters for methane yield in Australian beef cattle. In 'Proceedings of the Association for the Advancement of Animal Breeding and Genetics’. Vol. 20:290-293. (Final report appendix 10)

Herd RM, Bird SH, Donoghue KA, Arthur PF, Hegarty RF (2013) Phenotypic associations between methane production traits, volatile fatty acids and animal breeding traits. In ‘Proceedings of the Association for the Advancement of Animal Breeding and Genetics’. Vol. 20:286-289. (Final report appendix 11)

Herd RM, Arthur PF, Bird SH, Donoghue KA, Hegarty RS (2014) Genetic variation in methane traits in beef cattle. In 'Proceedings of the 10th World Congress of Genetics Applied to Livestock Production', Paper 038, 3 pages. (Final report appendix 12)

Herd RM, Arthur PF, Donoghue KA, Bird SH, Bird-Gardiner T, Hegarty RS (2014) Measures of methane production and their phenotypic relationships with growth and body composition traits in beef cattle. Journal of Animal Science. 92:5267-5274. (Final report appendix 13)

Table 1: All project communications (to date).

Date	Activity	Details	Key messages	Key contacts
25 Nov 2012	Newspaper story	Abgastest fur Klimastunder (cattle methane research, reporter Von Andrea Six) in “NZZ am Sonntag” pages 66-67. (a Swiss German-language daily newspaper).	Opportunities through animal breeding to lower methane emissions exist. Australia engaged in research to reduce livestock GHG emissions.	Robert Herd
27-29 Nov 2012	Talk	Delivered a talk entitled “Genetic technologies to reduce methane emissions from Australian beef cattle” and fielded questions after talk and between conference sessions. Venue Melbourne, VIC. CCRSPI Conference, a forum for industry, politicians, media, government, scientists and the general public (about 400 delegates).	Opportunities through animal breeding to lower methane emissions exist. Australia engaged in research to reduce livestock GHG emissions.	Kath Donoghue
26-30 Nov 2012	Scientific conference attendance	Arthur, P. F., Herd, R. M., Donoghue, K. A., Bird, S. H. & Hegarty, R. S. (2012). Natural variation in methane emissions among progeny of Angus bulls. In Proceedings of the 15th AAAP Animal Science Congress, (Ed S. Koonawootrittriron). Thailand.	Opportunities through animal breeding to lower methane emissions exist. Australia engaged in research to reduce livestock GHG emissions.	Paul Arthur
28 Feb 2013	Briefing and facilities tour	Briefed Director and scientists from the National Institute of Animal Science, Suwon, Korea, on the breeding low methane cattle project, and lead an inspection of the cattle methane research facility. UNE, Armidale NSW. (10 people, including NSA DPI and UNE staff hosting their visit).	Opportunities through animal breeding to lower methane emissions exist. Australia engaged in international collaborations to reduce livestock GHG emissions, and they could join in.	Robert Herd
22 Feb 2013	Field Day	In conjunction with the Australian Angus Society, the day focused on results from the Angus Sire Benching Program, and included a brief presentation on opportunities from breeding for improved feed efficiency, and a poster display and handouts on the breeding low methane cattle project. Held at the UNE "Tullimba" Research Feedlot, Armidale NSW. Leading seedstock cattle breeders, local beef producers and NSW DPI, UNE, ABRI and CSIRO research and extension staff involved in cattle breeding (70 participants).	Opportunities from genetic improvement in feed efficiency and selection for lower methane emissions exist.	Robert Herd
15 Mar 2013	Webpage story	"Visiting US scientist to speak at UNE on cattle feed efficiency". Announcement of a mini-field day on beef cattle feed efficiency and our methane research. Field-day to be held at UNE, Armidale NSW, 27 March 2013. http://blog.une.edu.au/news/2013/03/15/visiting-us-scientist-to-speak-at-une-on-cattle-feed-efficiency/. http://www.angusaustralia.com.au/component/content/article/8-front-page-news/1145-visiting-us-scientist-to-speak-	Announcement of a mini-field day on beef cattle feed efficiency and our methane research.	Robert Herd

Date	Activity	Details	Key messages	Key contacts
		on-cattle-feed-efficiency-.html.		
20 Mar 2013	Newspaper story	"Beef's fresh outlook". Report that includes an invitation to a mini-field day on beef cattle feed efficiency and our methane research. Field-day held to be at UNE, Armidale NSW, 27 March 2013. In 'The Armidale Express' 20 March 2013, page 2, and 'The Armidale Independent' 20 March 2013, page 15.	Invitation to a mini-field day on beef cattle feed efficiency and our methane research.	Robert Herd
27 Mar 2013	Mini-field day	Update of beef cattle feed efficiency and methane research. Included guest lecture by Professer Daniel Shike from the University of Illinois speaking on recent advances in feed efficiency R&D in the USA, static poster displays and handouts on NLMP cattle and sheep projects underway in Armidale, and inspection of the 10 cattle respiration chambers on the UNE campus where methane production by cattle is measured. Field-day convened by NSW DPI, the Australian Society of Animal production (ASAP) and the Angus Society of Australia. Held at UNE, Armidale NSW. Local beef producers and NSW DPI, UNE and CSIRO research and extension staff.	Opportunities from genetic improvement in feed efficiency and selection for lower methane emissions exist and will become available to beef cattle producers through the national beef improvement system BREEDPLAN.	Robert Herd
Jul 2013	Journal paper	Bolormaa S, Pryce JE, Kemper K, Savin K, Hayes BJ, Barendse W, Zhang Y, Reich M, Mason BA, Bunch RJ, Harrison BE, Reverter A, Herd RM, Tier B, Graser H-U, Goddard ME (2013) Accuracy of prediction of genomic breeding values for residual feed intake, carcass traits and meat quality traits in Bos taurus, Bos indicus, and composite beef cattle. *Journal of Animal Science* 91, 3088-3104. (Final report appendix 14)	DNA information can predict breeding values for hard-to-measure traits like feed efficiency and methane emissions	Robert Herd
9 Aug 2013	Lecture	Donoghue, K., Herd, R., Bird, S. & Arthur, P. (2013). "Can genetic improvement be used to reduce methane emissions in Australian beef cattle?" In Graham Centre Beef Forum, plus 3 page paper in Forum proceedings. Charles Sturt University, Wagga Wagga, NSW	Opportunities exist through animal breeding to lower methane emissions.	Kath Donoghue
21 Aug 2013	Lecture	Herd, R. "Breeding cattle that naturally emit less methane". UNE Feedlot Management Course. UNE, Armidale NSW, Approx. 40 students. UNE Feedlot Management Course	Opportunities exist through animal breeding to lower methane emissions. Australia engaged in research to reduce livestock GHG emissions.	Robert Herd
4 Sept 2013	Finalists in Australian Museum Eureka Prizes 2013	The awards ceremony consisted of a number of presentations and an event flyer outlining our project objectives and activities, award dinner Sydney Town Hall, Sydney NSW. Related media coverage: The Land (2013). "Eureka: DPI in running". In The Land Newspaper 8 August 2013, page 77. Nugent, V. (2013). "Busters take a bow". In The Country Leader Newspaper, 12 August 2013, Tamworth, NSW. Nugent, V. (2013). "Busters take a bow". In The Country Leader Newspaper, supplement to The Armidale Express,	Project team engaged in world-class research to reduce livestock GHG emissions.	Robert Herd

Date	Activity	Details	Key messages	Key contacts
		Wednesday 14 August 2013. Armidale, NSW. Nugent, V. (2013). “Eureka, nomination for burp busters a real gas”. In The Armidale Express Newspaper, 7 August 2013. Armidale, NSW. Herd, R. (2013). “Joint Department of Primary Industries and University of New England research cattle methane team is a finalist in the prestigious Australian Museum Eureka Prize”. In 08:30 News ABC Radio New England North West, 5 September 2013. Tamworth NSW. Herd, R. (2013). “Joint University of New England and Department of Primary Industries research project is a finalist in the prestigious Australian Museum Eureka Prize”. In 12:30 News ABC Radio New England North West, 4 September 2013. Tamworth NSW. Herd, R. (2013). “Joint University of New England and Department of Primary Industries research project is a finalist in the prestigious Australian Museum Eureka Prize”. In 12:30 News ABC Radio Central West NSW, 4 September 2013. Orange NSW.		
18 Oct 2013	Radio interview	Herd, R. (2013). “DPI researchers present animal breeding and genetics findings at AAABG conference in New Zealand”. Radio interview with Anna Leece, Macquarie network radio station 2GZ and FM 105-1 Orange and Dubbo.	NSW DPI scientists working in national collaborative projects to research breeding for lower methane emissions in cattle.	Robert Herd
Octobe r 2013	Journal paper	Barwick SA, Tier B, Swan AA, Henzell AL (2013) Estimation of accuracies and expected genetic change from selection for selection indexes that use multiple-trait predictions of breeding values. *Journal of Animal Breeding and Genetics* 130, 341-348. (Final report appendix 9)	Tools to quantify how methane production traits and animal production traits will change when there is selection on breeding indexes.	Steve Barwick
15-20 Oct 2013	Conference paper and presentation	Arthur PF, Herd RM (2013) Selection for feed efficiency plays a major role in greenhouse gas mitigation in cattle. In 'Proceedings of the 11th World Conference on Animal Production', Communication WCAP2013-1-04-007, pp. 67-68. Presentation to the 11th World Conference on Animal Production, Beijing, China.	Opportunities through animal breeding for improved feed efficiency can lower methane emissions and improve animal productivity.	Paul Arthur
21-23 Oct 2013	Conference paper and presentation (2)	Herd RM, Bird SH, Donoghue KA, Arthur PF, Hegarty RF (2013) Phenotypic associations between methane production traits, volatile fatty acids and animal breeding traits. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* 20:286-289. (Final report appendix 11) Donoghue KA, Herd RM, Bird SH, Arthur PF, Hegarty RF (2013) Preliminary genetic parameters for methane yield in Australian beef cattle. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* 20:290-293. (Final report appendix 10) Presentations at the international scientific conference of the Association for the Advancement of Animal Breeding and Genetics, Napier, New Zealand.	Project team engaged in world-class research to reduce livestock GHG emissions. Opportunities exist through animal breeding to lower methane emissions.	Robert Herd and Kath Donoghue

Date	Activity	Details	Key messages	Key contacts
22 Oct 2013	Lecture	Mortimer S, Herd R (2013) “Breeding cattle that naturally emit less methane” lecture to Scots High School Bathurst students. Trangie NSW.	Opportunities exist through animal breeding to lower methane emissions.	Sue Mortimer
29-30 Oct 2013	Lectures (2)	Arthur P, Herd R (2013) “Physiological basis of feed efficiency in beef cattle”. Invited presentation to VIC DEPI DMI and FCE Research Forum, Melbourne, Vic. Herd R (2013) “Industry implementation of FCE and methane”. Invited presentation to VIC DEPI DMI and FCE Research Forum, Melbourne, Vic.	Opportunities exist through animal breeding for feed efficiency to lower methane emissions.	Robert Herd
30 Oct 2013	TV interview	Herd R (2013) "Breeding cattle for lower methane greenhouse gas". Interview for NHK TV (Japan's national broadcaster), Armidale NSW, (yet to go to air).	Opportunities exist through animal breeding to lower methane emissions.	Robert Herd
Nov to Dec 2013	Newspaper articles	Herd, R. (2013). Cattle on test for methane. The Daily Examiner newspaper, Grafton NSW. page 18. 15 November 2013. Herd, R. (2013). World-first high feed cattle research at Glen Innes. North West Magazine, newspaper insert. Mudgee NSW. page 4. 18 November 2013. Mansbridge, B. (2013). Measuring feed efficiency on pasture. The Land newspaper website. http://www.theland.com.au/news/agriculture/livestock/cattle-beef/measuring-feed-efficiency-on-pasture/2679141.aspx. 22 November 2013. Mansbridge, B. (2013). Measuring feed efficiency. The Land newspaper. Richmond NSW. pages 61-62. 21 November 2013. Brook, A. (2013). Glen Innes hosts high feed study. In Hunter Valley Town & Country Magazine, newspaper insert, page 7, 25 November 2013. Herd, R. (2013). Feed efficiency measured in the paddock. The Bombala Times newspaper, Bombala NSW. page 13. 11 December 2013. Herd, R. (2013). New feed-efficient cattle study more than hot air. Coffs Harbour Advocate. Coffs Harbour NSW. page 57. 30 November 2013. Herd, R. (2013). Assessing the full spectrum. The Land newspaper. page 61. 21 November 2013. Herd, R. (2013). Research a world first. Country Leader Magazine, newspaper insert to The Armidale Express. Armidale NSW. page 11. 4 December 2013. Also an insert to regional papers: Inverell Times, Tenterfield Star, Guyra Argus, Glen Innes Examiner, Quirindi Advocate, Walcha News, Northern Daily Leader and the Moree Champion.	Measurement of methane emissions by steers and heifers on pasture and in feedlot.	Robert Herd
29 Jan 2014	Newspaper article	Robertson, G. & Herd, R. (2014). Student steps on the gas. The Armidale Express. 29 January 2014, page 5.	Article about Karly O'Hara's UNE GRASS placement in the cattle methane project.	Robert Herd

Date	Activity	Details	Key messages	Key contacts
4 Mar 2014	Field-day lecture	Herd, R. Attended Australian Angus Society Feed-Back Day on the Angus Sire Benching Program, including presented a talk on methane research project and took questions, "Tullimba" Research Feedlot, Armidale NSW.	Opportunities exist through animal breeding to lower methane emissions.	Robert Herd
15 Apr 2014	Field-day lecture	Attended Australian Angus Society Feed-Back Day on the Angus Sire Benching Program, including presented lecture "Breeding to reduce methane emissions from beef cattle" and took questions, "Tullimba" Research Feedlot, Armidale NSW.	Consultation with Angus Society members over new Breeding Value for methane and costing methane in their $-indexes.	Robert Herd
June 2014	Newspaper article	“Reducing cattle-produced methane”. Story on the cattle methane breeding project team. In the Livestock Annual 2014 - published by The Country Leader Newspaper June 2014, Tamworth, NSW.	Opportunities exist through animal breeding to lower methane emissions.	Robert Herd
7 Aug 2014	Field-day lecture	Hegarty, R. “Greenhouse gas emissions & beef production”, The Business of Beef Forum, Blayney Shire Community Centre	Opportunities exist through animal breeding to lower methane emissions.	Roger Hegarty
11 Aug 2014	Radio interview	"NSW scientists sought on international stage". 2SM and regional stations radio interview on DPI scientists about to head off to the World Congress on Genetics Applied to Livestock Production in Vancouver, Canada.	Opportunities exist through animal breeding to lower methane emissions.	Robert Herd
11 Aug 2014	Media interview	"NSW scientists sought on international stage". Interview with Robin King for the Australian Rural Communication Network, on DPI scientists about to head off to the World Congress on Genetics Applied to Livestock Production in Vancouver, Canada.	Opportunities exist through animal breeding to lower methane emissions.	Robert Herd
13 Aug 2014	Lecture	Arthur, P. (2014). Can we breed cattle that emit less methane? Seminar at the University of Alberta, Edmonton, Alberta, Canada.	Peer-review of our research.	Paul Arthur
August 2014	Refereed scientific conference paper published	Herd, R. M., Arthur, P. A., Bird, S. H., Donoghue, K. A. & Hegarty, R. S. (2014). Genetic variation in methane traits in beef cattle. In. Proceedings of the 10th World Congress of Genetics Applied to Livestock Production, Paper 038, Vancouver, Canada. (Final report appendix 12)	Peer-reviewed paper confirming the rigour of our research and results.	Robert Herd
17 Aug 2014	Scientific conference lecture	Herd, R. M., Velazco, J., Hegarty, R. S. & Arthur, P. F. (2014). “Feed efficiency and methane research – Australia”. Invited presentation to ASGGN (the Global Research Alliance Animal Selection, Genetics and Genomics Network) satellite workshop, preceding the 10th World Congress of Genetics Applied to Livestock Production. Vancouver, Canada.	Peer-review of our research that confirmed the rigour of our research and results.	Robert Herd
19 Aug 2014	Scientific conference	Herd, R. “Genetic variation in methane traits in beef cattle”. Invited oral presentation to the 10th World Congress of Genetics Applied to Livestock Production. Vancouver,	Peer-review of our research that confirmed the rigour	Robert Herd

Date	Activity	Details	Key messages	Key contacts
	lecture	Canada.	of our research and results.	
19 Aug 2014	Lecture	Suarez, M. Lecture on livestock methane and our research to: UNE Feedlot Management Course. UNE, Armidale NSW, Approx. 40 students.	Opportunities exist through animal breeding to lower methane emissions. Australia engaged in research to reduce livestock GHG emissions.	Robert Herd
2 Oct 2014	Media release	"New bulls to boost DPI beef herd". NSW DPI Media Release. 2 October 2014. http://www.dpi.nsw.gov.au/aboutus/news/all/2014/new-bulls-to-boost-dpi-beef-herd	Genetic upgrade of Trangie herd, linking Angus Society, enrolment of high and low methane sires in the Elite Sire Benchmarking program, recommended by the NLMP external breeding advisor.	Robert Herd
October 2014	Newspaper articles	"New bulls major boost for beef research project". In 'Western Magazine', 6 October 2014. This magazine is distributed into 26 newspapers across western NSW. Page 6. "Angus bulls a boost for beef project". In 'Narromine News & Trangie Advocate. 8 October 2014. Page 12. "New bloodlines for Trangie herd". In 'Wellington Times. 8 October 2014. Page 7.	Genetic upgrade of Trangie herd, linking Angus Society, enrolment of high and low methane sires in the Elite Sire Benchmarking program, recommended by the NLMP external breeding advisor.	Robert Herd
14 Oct 2014	Lecture	Hegarty R (2014) Presented our cattle methane breeding research to "NSW Beef Producer Forum", plus tour of cattle methane facility, Armidale, NSW. 60 participants.	Opportunities exist through animal breeding to lower methane emissions.	Roger Hegarty
20 Oct 2014	E-booklet published	Lines-Kelly, R. (2014). "Enteric methane research - A summary of current knowledge and research". With contributions from H. Oddy, R. Herd, T. Bird-Gardiner and N. Jennings. The NSW Department of Primary Industries, Orange, NSW, E-Booklet: 41pages. Available at http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/532694/agriculture-resources-climate-enteric-methane.pdf	A summary of current knowledge and research on enteric methane emissions for livestock producers and extension staff.	Robert Herd
20 Oct 2014	Meeting and tour	Meet with Professor John Wallace (The Rowett Institute, University of Aberdeen, Scotland) and Professor Noelle Cockett from Utah State University, USA, to brief them on our feed efficiency and methane research, and lead a tour of our cattle facilities, UNE Armidale, 20 October 2014	Australia engaged in research to reduce livestock GHG emissions.	Robert Herd
3 Nov 2014	Newsletter article	Wright, P. (2014) Nomination of DPI Scientists for Top Award. Story on nomination of R. Herd for the 2014 NSW	Contribution to livestock methane	Robert Herd

Date	Activity	Details	Key messages	Key contacts
		Science and Engineering Awards. https://dpiactive.dpi.nsw.gov.au/nomination-of-dpi-scientists-for-top-award/	research	
4-5 Nov 2014	Meeting and seminar	Herd R. (2014) Lead a research team meeting on progress within the breeding low methane cattle project and planning for the new genetics upgrade and cow phenotyping future research projects, including presented a seminar of "Feed efficiency and methane" in Australia. Trangie Agricultural Research Centre, NSW, 4-5 November 2014. Trangie NSW	Opportunities exist through animal breeding to lower methane emissions.	Robert Herd
5 Nov 2014	Newsletter article	Lines-Kelly, R. (2014) New online booklet explains enteric methane research. NSW Trade and Investment intranet: Max Express newsletter. Issue 228. 5 November 2014. Orange, NSW. NSW Trade and Investment http://intranet.industry.nsw.gov.au/express/archive/141105	A summary of current knowledge and research on enteric methane emissions for livestock producers and extension staff.	Robert Herd
November 2014	Scientific journal article published	R. M. Herd, P. F. Arthur, K. A. Donoghue, S. H. Bird, T. Bird-Gardiner and R. S. Hegarty (2014). Measures of methane production and their phenotypic relationships with growth and body composition traits in beef cattle. Published: Journal of Animal Science. 92:5267-5274 (Final report appendix 13)	Peer-reviewed paper confirming the rigour of our research and results.	Robert Herd
11 Nov 2014	Meeting and seminar	Herd R. (2014) Participated in NLMP Science Review Workshop, Armidale NSW, 11 November 2014. Presented technical progress update on the cattle methane project. Armidale NSW	Opportunities exist through animal breeding to lower methane emissions.	Robert Herd
January 2015	Refereed scientific conference paper published	Lee S. J., Herd R. M. and Pitchford W. S. (2015). Long term impacts of selection for feed efficiency on production characteristics in the cow herd. Invited paper - US Northern States Beef Conference of the American Association of Animal Science, January 2015	Opportunities exist through animal breeding to lower methane emissions.	Robert Herd
January 2015	Draft ERF Methodology Scope.	Cohn P., Fennessy P. and Herd R. (2015). Reducing emissions by selective breeding beef cattle using BREEDPLAN Estimated Breeding Values. Draft ERF Methodology Scope. (Final report appendix 15)	Opportunities exist through animal breeding to lower methane emissions.	Robert Herd
13 Jan 2015	Seminar and tour	Herd R., Smith H. and Cameron M. (2015) Introduction to Animal Science Research, seminar and inspection of facilities, to Year 10 and 11 High School students, in The ConocoPhillips Science Experience at UNE. 13 January 2015. 18 students plus 2 supervisors.	Opportunities exist through animal breeding to lower methane emissions.	Robert Herd
28 Jan 2015	Newspaper article	Maquire D. (2015) "Student gets grassed up on methane data". Report on GRASS student Thomas Mailler working with Helen Smith on measuring methane from cattle at UNE. In The Armidale Express, Page 4, 28 January 2015.	Article about Tom Mailler's UNE GRASS placement in the cattle methane	Helen Smith

Date	Activity	Details	Key messages	Key contacts
		Armidale NSW.	project.	
30 Jan 2015	Seminar and tour	Smith H. and Weber C. (2015) Overview of livestock methane research in Armidale, seminar and research facility tour, to university agricultural science students, in a Global Pathfinder study tour for students from GwanWon Nat't University, South Korea. 30 January 2015. 5 students and 1 professor.	Opportunities exist through animal breeding to lower methane emissions. Australia engaged in research to reduce livestock GHG emissions.	Helen Smith
5 Feb 2015	Meeting and seminar	Herd R. (2015) Participated in a DPI research planning meeting for sheep and cattle methane breeding projects, and gave presentation "Are high emitters always high?", at Armidale BIC, 5 February 2015	Opportunities exist through animal breeding to lower methane emissions.	Robert Herd
11 Feb 2015	Scientific journal paper submitted	Charmley E., Williams S. R. O., Moate P. J., Hegarty R. S., Herd R. M., Oddy V. H., Reyenga P., Staunton K. M. and Anderson A. (2015) A unified relationship between methane emissions and intake for Australian cattle receiving over 70% of their diet as forages. Revision Submitted to: Journal of Animal Science. 11 February 2015 (Final report appendix 16)	Uses Australian cattle methane emission data collated across NLMP projects to establish new prediction equations for cattle in the Australian GHG inventory.	Ed Charmley
14 Feb 2015	Presentation	Arthur P. and 'others (2015). Trangie beef cattle research: Then and Now. Powerpoint for Tangie Agricultural Research Centre Centenary Open Day, 14 February 2015	Opportunities exist through animal breeding to lower methane emissions.	Paul Arthur
14 Feb 2015	Flyer	Bird-Gardiner T. and others (2015) TARC Centenary Farm Tour handout, for Tangie Agricultural Research Centre Centenary Open Day, 14 February 2015	Opportunities exist through animal breeding to lower methane emissions.	Tracie Bird-Gardiner
14 Feb 2015	Poster	Bird-Gardiner, T., Herd, R. “MEASURING METHANE PRODUCTION WITH GREENFEED MACHINES”. Displayed at Trangie Centenary Field Day.	Opportunities exist through animal breeding to lower methane emissions.	Tracie Bird-Gardiner
19 Feb 2015	Newspaper Article	Goodwin, S. “Blazing new feed trails; Selecting for greener cattle” In The Land p.67. 19 February 2015.	Opportunities exist through animal breeding to lower methane emissions.	Robert Herd
5 Mar 2015	Seminar	Presentation and discussion with the Breedplan Technical Liaison Group titled “Genetic Technologies to reduce methane emissions from Australian beef cattle”. 14 participants from 5 organisations. 2 presentations. (Final report appendix 1)	Opportunities exist through animal breeding to lower methane emissions.	Steve Barwick
15 Apr 2015	Field-day talk	Helen Smith. Presentation and questions about Greenfeed Emissions Units and methane measurement of industry sires with board members from Angus Australia.	Opportunities exist through animal breeding to lower	Helen Smith

Date	Activity	Details	Key messages	Key contacts
			methane emissions.	

NOTE: Report appendices have not been included with this publication. Many have been published elsewhere, or are in the process of being submitted for publication, and should be available shortly. Please contact the authors for more detail.