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CONTENTS

FROM THE PGgRc CHAIR

New Zealand pastures produce some of the most emissions-efficient ruminant-sourced products in the world, including nutrient-dense meat and milk.

We should celebrate our ability to produce far more than we require to help nourish our small New Zealand population. Beef, lamb, venison and milk products are shipped to the four corners of the globe, supporting the nutritional needs of millions of people, and earning valuable export dollars for the New Zealand economy.

Yet because of our small population, a relatively small industrial and manufacturing sector, and our significant renewable energy infrastructure, agriculture makes up almost 50% of New Zealand greenhouse gas (GHG) emissions.

As the world experiences the effects of climate change, the capabilities, knowledge and intellectual property developed by the Pastoral Greenhouse Gas Research Consortium (PGgRc) may prove to be key in enabling the New Zealand pasture-based production system to achieve the combined goals of producing products the world desires, increasing export returns to New Zealand, and significantly reducing emissions.

Moreover, success could mean that we not only continue to provide the world with emissions-efficient food but also technologies that can be used to reduce emissions in other food chains. In this respect, the PGgRc focus on developing practical and affordable vaccines or prolonged-action inhibitors for New Zealand dairy and dry stock may have the potential to be applied in a wide range of global livestock production systems.

I know I can speak on behalf of the PGgRc Board in saying that we are committed to making the most out of the hard work and prior investments made by the PGgRc's partners and collaborators. PGgRc has created a portfolio of over 50 granted patents from seven patent families. The high quality research that has underpinned this intellectual property is exemplified through the publication of over 100 papers in peer reviewed international scientific journals.

I would like to thank Mark Aspin for his commitment and dedication in managing PGgRc and all it has delivered.

Recent announcements by the New Zealand Government of significantly increased investment in GHG mitigation research and technology development through the new Centre for Climate Action on Agricultural Emissions are encouraging and will provide an avenue for more extensive work on solutions that can be created based on PGgRc IP.

Jeremy Hill MNZM
Chair, PGgRc Board

FOREWORD

"Ruminant livestock methane emissions are driven predominantly by the amount of feed eaten."

"Our role was to deliver ways to decouple methane and nitrous oxide from the amount of feed eaten."

These two statements have been the motivation behind this document, representing a sustained commitment by the farming sector, research and government organisations to understand and address the challenge of reducing agriculture's methane and nitrous oxide emissions.

While some of this commitment can be measured in the $90 million investment over almost two decades, the truth is that this mission by the PGgRc has prospered through the dedicated commitment of all the people involved in this initiative.

And while challenges remain, our perseverance has advanced four mitigation solutions that could be deployed in the future to reduce GHG emissions.

The understanding and knowledge of livestock GHG emissions has advanced significantly since the consortium was established two decades ago.

There are no longer concerns that methane reduction will halt productivity. While some initial encouraging options have been rejected, the investment is being focused on opportunities that are demonstrating promise.

There are still many criteria to fulfil before the best options are delivered to farmers, but we know that reductions are possible, and the sector partners, along with New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC), need to persevere to deliver them.

I've had the privilege to lead the PGgRc operation and want to express my gratitude to everyone who has been involved; you all have been supportive and committed to meeting this challenge. While that gratitude is owed to many people, there are a few who should be singled out and recognised.

The PGgRc board of directors has steadfastly brought a collegial and proactive energy to driving progress through the investment, seeking to confirm and advance the solutions we need. Since its inception, the partners have provided more than 30 people as directors who have committed to supporting this mission. All have provided a positive contribution and most especially I have benefited from the direct support from the Board Chairs; Mark Leslie, Rick Pridmore and Jeremy Hill, to all – thank you.

Along with the Directors, I also acknowledge the special relationship we have had with the PGgRc observers from the Ministry of Business Innovation and Employment (MBIE) and the Ministry for Primary Industries (MPI). Their support and guidance have been at times challenging, but always invaluable.

The PGgRc investment has been about harnessing science and we owe a big debt to our research teams who have developed our programmes. Much of this work has been done with AgResearch and without a doubt the unsung hero for us has been Dr Peter Janssen. While he has been well supported by excellent research teams, Peter has been the front man and guided a rigorous scientific approach to finding solutions that can work for our farmers. We owe you Peter, and all the scientists and support staff, a big thank you. We would not be where we are without you.

Keeping with the research investment, we also recognise that our progress has been as an active member of the NZAGRC, led by Dr Harry Clark, who along with the team at the centre has enhanced our investment across the methane research space.

Both parties have been very clear that by working together, the industry and government agencies will create a better outcome. Harry, your leadership and support throughout this period has been immense and appreciated.

From the beginning, we have been focused on investing and working collectively on behalf of all livestock farmers to deliver solutions.

While at times it has been an uphill struggle, this has not dampened the support we have felt from farmers who never hold back in asking the direct questions on when we will have something for them to use, and the follow-up comment that "this is important work we need to do".

So there remains unfinished business for all of the PGgRc's sector partners. With the formation and activity within He Waka Eke Noa and the recent budget announcements on investment by the Government, we are confident our progress to date can be built on and accelerated so cost effective solutions for farmers can be achieved in the future.

Mark Aspin
PGgRc Manager
2022

INTRODUCTION

Since 2003, the PGgRc has invested over $90 million in exploring technology-based solutions that New Zealand pastoral farmers can use to reduce GHG emissions from the sector, while increasing productivity.

During that time, the PGgRc has built a significant base of valuable scientific knowledge and essential capability, especially in the field of ruminant methane – the powerful GHG produced by ruminant livestock that makes up around 35% of New Zealand's total emissions.

As the first group in the world to sequence the genome of a ruminant methanogen, the organisms responsible for producing methane in the rumen, the PGgRc opened the door to finding the weaknesses of these organisms. Off the back of this, significant work has been progressed in the field of methane mitigation to benefit the sheep, beef, dairy and deer industries.

Working with the NZAGRC and in a 50/50 funding partnership with MBIE, the PGgRc has advanced four broad areas of methane mitigation solutions: forage and feed, genetics, development of methane inhibitors and the novel approach of developing a vaccine.

This comprehensive approach taken in New Zealand and by the PGgRc is world-leading. With the end of the MBIE contract in 2021, the PGgRc completed a 10-year programme of methane mitigation research. This report highlights the achievements, the challenges along the way and the path forward to delivering solutions to farmers.

- Genetic selection is now being rolled out to sheep breeders with the PGgRc-funded development of the world's first breeding value for low methane-emitting sheep – with no negative side effects. Those learnings are now being applied to develop genetic cattle selection.
- The PGgRc has also demonstrated the potential of low-emissions feed to reduce methane and built essential knowledge around how that happens, paving the way for low-GHG feeds that will give options to New Zealand farmers.
- Some of the most groundbreaking work has been in methane inhibitors, with the PGgRc having successfully advanced inhibitors that can be delivered by an intra-ruminal capsule for both sheep and cattle. This work is being further progressed with an international commercialisation partner.
- In the most challenging area of work, the PGgRc has developed the scientific foundations and strategies for the development of a methane vaccine delivered to saliva to target methanogens in the rumen.

The need for effective mitigation solutions for farmers is even stronger than when the PGgRc was formed. The sector's changing physical and regulatory environment brings new urgency and complexity to this challenge, as well as potential new opportunities from growing global interest and research into technology-based solutions.

With the completion of the MBIE contract, the PGgRc moves into a new phase where the significant Intellectual Property (IP) and capabilities developed will be used as the basis for new partnerships to further advance possible solutions that can be used by New Zealand farmers.

The PGgRc partners retains custody of the IP and know-how that has been generated. This provides a strong base for accelerating and increasing future development of solutions that New Zealand farmers will be able to access and benefit from.

A core focus will be accelerating work on methane inhibitors and in particular the vaccine, an extremely challenging area of work that will have significant advantages in that it can work across species and farming systems. If we succeed, a methane vaccine will be a game-changer for the sector.

These solutions will feed into the broader suite of tools available to farmers that can be used in combination to maximise GHG emission reductions.

Moving forward, the sector will play its part in supporting the New Zealand Government in meeting its international GHG reduction targets through its Nationally Determined Contribution (NDC) under the Paris Agreement and the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) process.

We also want to ensure New Zealand farmers remain the most GHG-efficient in the world, an advantage of where we live on the planet and our efficient pastoral farming systems.

This must be a collective effort reflecting the shared interests of all New Zealand livestock farmers, and for the sector to work together to ensure alignment and coordination of effort across the innovation pathway.

BACKGROUND

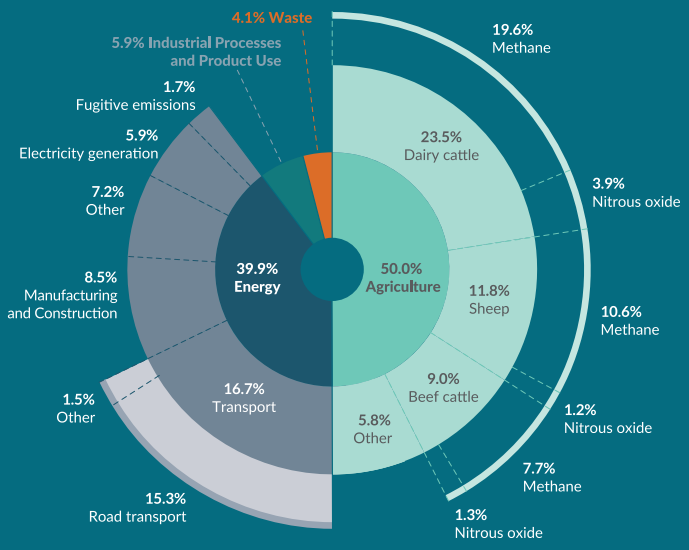
Agriculture and climate change

Agriculture is a major contributor to New Zealand's economy, representing more than half of the country's exports. It is also responsible for about 50% of the nation's gross greenhouse emissions, 44% of which are from methane (CH_4) and 11% from nitrous oxide (N_2O)[1].

Agriculture's share of total emissions is unusually high compared to other developed nations, reflecting New Zealand's strong primary production base and high use of renewable energy sources for electricity generation.

On the world scale, New Zealand contributes 0.16% of global emissions, and therefore New Zealand agriculture 0.08%. While New Zealand makes only a small contribution to global emissions, the country's reputation as a trading nation means we have an obligation to contribute fairly towards the global effort to reduce GHG emissions and the risks from climate change. Moreover, a breakthrough for the New Zealand livestock sector has the potential to be applied to global livestock, which account for approximately 15% of total global GHG emissions.

Figure 2: Gross greenhouse gas emissions in 2020 by sector, sub-category and gas type



Breakdown of emissions by sector (Agriculture, Energy, Industrial Processes and Product Use (IPPU), and Waste), and sub-category, and greenhouse gas by type. The emissions contribution from Tokelau is too small to be shown in the figure.

PGgRc history

Formed in 2002 to reduce methane emissions from ruminant animals across the sheep, beef, dairy and deer industries, the PGgRc (at the time known as the Methane Consortium) began rebuilding New Zealand's research capabilities and human capital in the field of rumen science.

This was at a time when the Government was seeking ways to accelerate research into reducing agricultural GHG emissions to help achieve its obligations under the Kyoto Protocol, the international treaty that extended the 1992 United Nations Framework Convention on Climate Change (UNFCC), committing state parties to reduce GHGs, based on the scientific consensus that human-sourced global warming was occurring.

The PGgRc represented a commitment by the pastoral sector to invest in addressing livestock methane and nitrous oxide emissions while maintaining productivity on a 50/50 funding basis with government.

Since then, scientists have received funding for GHG mitigation research from the PGgRc, the NZAGRC, MPI's Sustainable Land Management and Climate Change (SLMACC) fund and the Global Research Alliance on Agricultural Emissions (GRA).

In the initial years, with the sparse knowledge available around mitigating livestock emissions in New Zealand pastoral systems, the PGgRc took a broad approach, channeling investment into reviewing existing scientific literature narrowing down areas of interest.

"There was a lot of material with potential and a lot of it didn't work in New Zealand's outdoor grazing systems," says Dr Gerald Rys, Principal Advisor, Office of the Chief Science Advisor, Ministry for Primary Industries.

"Compared to feedlot systems, we have a significant challenge in New Zealand in achieving a continuous impact on ruminant methane. During those early years, it was a process of elimination, and we narrowed our interests down to four areas; methane inhibitors, vaccine, feed and forage and genetic selection and looked at different elements within those."

During this period, the PGgRc also led pioneering work with the sequencing of the first rumen methanogen genome, published in 2010 and establishing underpinning knowledge of the

[1] New Zealand Greenhouse Gas Inventory -1990-2020 https://environment.govt.nz/publications/new-zealands-greenhouse-gas-inventory-1990-2020-snapshot/

microbiome of the rumen. Both have been critical to ongoing research.

In 2009, the NZAGRC was created to build on existing research, partnering with others to accelerate the process of bringing cost-effective, simple solutions to New Zealand farms. Since then, the PGgRc has worked in close partnership with the NZAGRC on a programme of work dedicated to technologies that reduce agricultural emissions.

"The early fundamental and pioneering work done by the PGgRc gave the NZAGRC a flying start," says Dr Harry Clark, Director New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC), "We were able to build on that working together in a very positive and open collaborative approach to achieving the same ends and what is best for New Zealand Inc."

While the PGgRc has focused specifically on four broad areas of methane mitigation work, in developing these solutions, researchers have worked to understand:

- GHG credentials – are they scientifically proven to work in New Zealand pastoral farming systems?
- Quality – does it compromise animal health, food quality, environmental and consumer needs?
- Commercialisation – what is the path to market for each solution?
- Economics – what is the cost to deliver, will it provide an economic benefit to farmers?

"New Zealand is recognised as being at the forefront globally of research in the mitigation of livestock emissions. This reputation is built on the PGgRc, the NZAGRC, and this very novel and trailblazing co-operation between industry, science and government to bring strong effect to addressing a problem. As well as generating significant Intellectual Property, we're now at the stage where we're close to getting cost-effective tools out to farmers with proof of concept for inhibitors, genetic selection being rolled out, and the science to support a vaccine and feed and forage systems," says Dr Rys.

Our greenhouse gas emissions reductions targets

The PGgRc's research supports New Zealand in achieving its domestic and international GHG emission targets. (See appendix 2)

"Aotearoa New Zealand has a powerful story to tell with our sustainable food systems. We need to invest more in telling that story at every opportunity," says Lee Stewart, Head of Corporate Sustainability at Fonterra.

As a nation with a low-carbon dairy footprint, New Zealand also needs to turbo-charge funding of agricultural GHG mitigation technologies as scrutiny of our sustainability credentials and the pace of change globally ramps up.

"With the further rise of conscious consumers, increasing action by governments locally and globally and mobilisation of sustainable finance at a scale never see before, New Zealand needs to think and act bigger," says Lee, who has over 15 years' working internationally as a sustainability strategist with mid-to-large enterprises.

"Through the Pastoral Greenhouse Gas Research Consortium, our scientists have developed potentially world-leading agricultural GHG mitigation technologies. The urgency now is to accelerate their development, solve our biggest climate change problem and take this story to the world."

Ultimately, New Zealand needs to be more ambitious and invest in the opportunity to be a sustainable food basket for the world – or risk losing its reputation with some of its biggest customers.

Lee Stewart

ACHIEVEMENTS

In 2021, the PGgRc finished more than a decade of work researching and developing the essential science that will give New Zealand farmers practical options for reducing methane.

Deep and groundbreaking science has been traversed, building new knowledge and scientific methods for New Zealand farming systems that can now be carried forward to deliver practical options for New Zealand's farmers.

Publication and patents:

The investment has resulted in over 100 presentations and publications across all of the science disciplines the PGgRc portfolio encompassed. In addition, we have secured over 40 patents globally across seven patent families, supporting our development of a methane vaccine and small molecule inhibitors. This Intellectual Property management will continue to ensure that there is a sound opportunity for commercial deployment of these mitigation solutions.

Further details of the patents and publications can be found in appendix 2.

Mitigation Solution Profiles: identifying what is needed to make mitigation technologies fit-for-purpose.

Along with direct investment to develop four technologies for reducing methane, the PGgRc has facilitated the development of Mitigation Solution Profiles (MSPs) of all the current significant possibilities for reducing either methane or nitrous oxide emissions to understand their progress status, and to identify opportunities, risks, gaps and priorities. Examples of the MSPs developed are included in the next section on mitigation technologies.

Building on this, PGgRc staff and directors were closely involved with MPI and the Fit for a Better World strategy to develop an ambitious and comprehensive R&D plan through the Biological Emissions Reduction Science Accelerator (BERSA), involving government, science and the livestock sectors.

The acclerator confirmed what is required in a GHG mitigation, evaluated what technologies are currently being developed and what is required to make them adoptable and has drawn up a science and mātauranga plan to deliver these rapidly to the sector.

In May 2022, the Government announced the formation of the Centre for Climate Action on Agricultural Emissions (CCAAE) and initial funding of $338m to work with NZAGRC and the sector to make this plan a reality. This mechanism will be the vehicle which will take the PGgRc developments through to delivery to New Zealand farmers.

PROGRESS SUMMARY

The following pages profile the four technology areas the PGgRc has focused its investment on and advanced in the last 10 years and outlines summaries of their MSPs.

Methane inhibitors

Methane inhibitors or feed additives offer a real opportunity to lower emissions by reducing the activity of methane-producing microbes (methanogens) in the digestive systems (rumen) of ruminant livestock.

What we know

AgResearch scientists have advanced a range of potent molecules capable of reducing methane by 20-30% without any negative effects on the animal.

They have demonstrated these molecules work in the animal and can be delivered using a slow-release bolus or capsule that resides in the rumen over a 40-to-60-day period. In future this may be possible with an annual dosage.

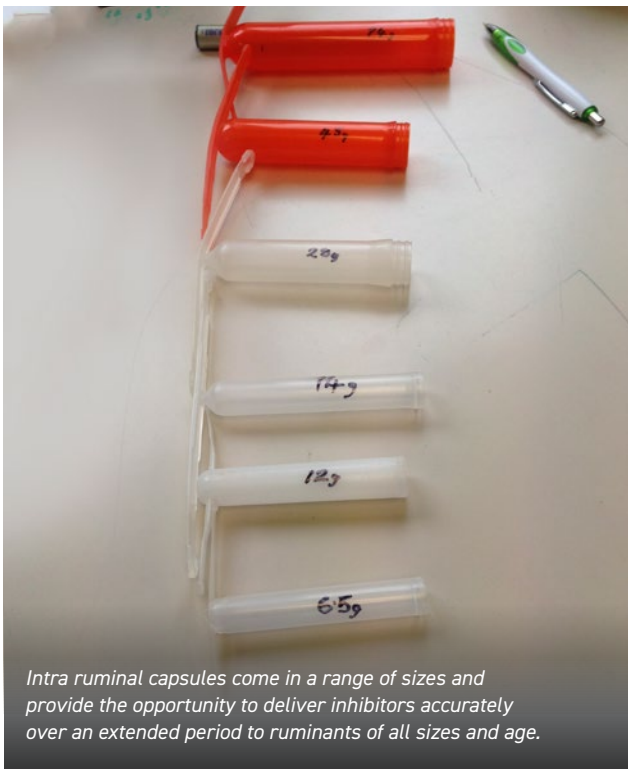
"We think it can work on all livestock types from sheep, deer, beef cattle, dairy cattle and dairy goats to dairy sheep and all farming systems from rolling and hill country, drystock to the full range of dairy systems." says Dr Ron Ronimus, Senior Research Scientist, AgResearch. "And the Global Rumen Census has demonstrated that it could work across the world."

PGgRc has also established robust new intellectual property around the methane inhibitor molecules, with AgResearch identifying targetable biochemical pathways as well as developing new and more efficient scientific methodologies for microbial research, including lower cost screening tools for inhibitor discovery.

Working in a challenging environment

To be effective, a methane inhibitor needs to be present and active in the challenging environment of the rumen while the animal is digesting its feed, and to target just methanogens without affecting digestion – or the health of the animal and the environment. It also needs to work for grazing animals.

"A core goal of our work is to develop inhibitors that work for low-intensity pastoral farming. If the inhibitor is delivered in every bite of feed, that works for a feedlot system." says Dr Ronimus, "The challenge here is that we're working with grazing animals, so we need compounds that are potent enough to work in a capsule form at a very low dose rate."



Intra ruminal capsules come in a range of sizes and provide the opportunity to deliver inhibitors accurately over an extended period to ruminants of all sizes and age.

As well as advancing potent inhibitor compounds that can be delivered via a slow-release intra-rumen bolus, PGgRc scientists worked on developing compounds for feed, supplements and potentially water delivery.

Developing the inhibitor pipeline

Identifying potential inhibitors has involved a complex sequence of screening assays and tests to identify compounds that suppress methanogens without unwanted side effects.

Over ten million compounds have been screened by computer analysis to identify the most promising inhibitors, which are then tested in bioassays against methanogen enzymes or in test tubes against pure methanogen cultures.

Then the potential inhibitors are tested in a rumen in vitro (RiV) - a flask of rumen fluid, containing methanogens and all other microbes present in the rumen to probe for any impacts on fermentations.

Checks are also run for any toxicity before the potential inhibitors are trialed for four days in sheep using respiration chambers that allow scientists to measure feed intake and methane emissions. This further refined the selection to compounds that

"We've identified two classes of inhibitor compounds along with a selection in reserve that are going forward for longer-term animal trials working with our international collaborator,"
Dr Ron Ronimus, Senior Research Scientist and Project Lead AgResearch

show methane inhibition without affecting rumen function.

Based on these trials and further analysis, several classes of compounds have undergone 16-30 day trials on sheep in respiration chambers. The list that goes forward to these longer-term respiration chamber trials is constantly revised as new discoveries are made.

Testing on target species

Supported by the PGgRc, DairyNZ has also been working closely with AgResearch to test the technology with full intake lactating cows, building on AgResearch's studies on dry livestock in respiration chambers.

"We need to understand not only the efficacy of the treatment on lactating cows, which eat twice as much as dry livestock, but to ensure that any compounds delivered to the animals have no detrimental impacts on health and productivity," says DairyNZ scientist, Dr Elena Minnee.

"The team we have working on methane inhibitors are at the forefront of this science globally. When we were looking for commercial partners, unbeknownst to us, an interested party did their due diligence and asked who they should work with in this field. They were pointed to our team."
Dr Ian Boddy, PGgRc Commercialisation Consultant

Commercialisation

The PGgRc has established an international partnership for the methane inhibitor programme as part of the strategy to commercialise this mitigation and deliver it to New Zealand farmers and globally. This involves long-term, on-farm trials with the goal of delivering inhibitors that can reduce methane from livestock by 20-30%. Tests will also be carried out to thoroughly rule out any impact on the animal's health, welfare and productivity and ensure no residues or food safety concerns.

PROFILE: Phill Everest

Phill and Jos Everest

"To be good for NZ Inc., emissions mitigations must be fit-for-purpose for our outdoor pastoral farming systems in New Zealand," says dairy farmer and ag consultant Phill Everest.

"We can't just add something to feed, that won't work for the way we farm in New Zealand. However, farmers now have some tools such as sheep genetics which provide cumulative, long-term reductions in emissions per unit of output. And that's now being applied to cattle. The methane inhibitor is also an area that all farmers are hungry for. To me, the direct-to-rumen delivery through a bolus is really promising for pastoral farming and is where we need to keep strongly focused."

At the Everest family Flemington Farm in Ashburton, there's a strong focus on the environment and reducing emissions.

"We're doing a lot of small things that might seem to have a small impact, but cumulatively we're starting to make progress."

This includes using urease coated urea as well as using different feeds, such as low-protein fodder beet in the autumn to lower protein intake and consequent nitrogen loss and greenhouse gas emissions, and to precondition cows before going away for winter grazing.

To ensure the plantain population is maintained in pastures they also over sow plantain (Ecotain), chicory and clover seed each year in maintenance fertiliser dressings to maintain a higher percentage in the sward, further addressing nitrogen loss and greenhouse gases.

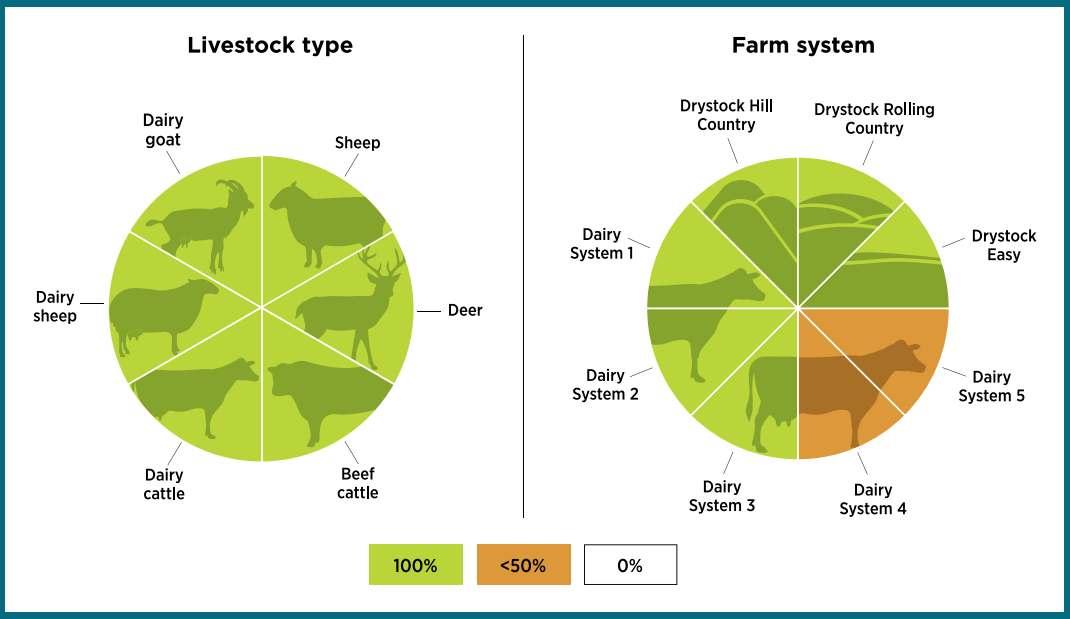
"This is a win-win for us. It's small but it all adds up. And now the research is showing us why certain feeds can make a difference to methane emissions through how it affects the rate of passage through the rumen. That's really good information for farmers. Ultimately, farmers need to have a package of tools available to them to ensure they can meet the targets in front of them in a way that's economic, practical, sustainable and globally competitive."

Mitigation Solution Profile: Methane Inhibitor for direct rumen delivery

Description: *An active compound that targets methanogens in the rumen, to reduce the methane they produce. The compound is delivered through a capsule or bolus inserted into the rumen which slowly releases the compound.*

Current status: Not currently on the market in New Zealand or globally. Various compounds are being researched in New Zealand and globally, mainly as a feed additive. Methane inhibitors are likely to require regulatory approval for use in New Zealand and the regulatory system for this is emerging and is likely to be the same or similar to those used for animal remedies currently (Agricultural Compounds and Veterinary Medicines, Environmental Protection Authority etc). Compounds discovered are likely to take 7-15 years from proof of concept to availability on the market (depending on regulatory processes).

Applicability by species and farm type:



This technology could be used in any species and would work in most farm systems except some dairy systems where it would likely be more efficient for farmers to use the compound as a feed additive.

Potential reductions per animal per day:

Up to 30% depending on the efficacy of the inhibitory compound.

Potential national reductions per annum:

Key variables are the inhibitory effect, duration of use and rate of use. For example, a capsule with a 30% reduction effect, used for 100 days by 50% of pastoral livestock, could reduce total national methane emissions by 4% per annum, while a capsule with a 90% reduction effect per animal used to the same extent could achieve 12% less total national methane emissions per annum.

Advantages and opportunities	Work still to be done
• Capsule delivery method enables direct application for all livestock across most existing farm systems, using a known farm practice. • Potential to combine inhibitory compound with therapeutics used routinely for animal health to increase attractiveness and cost effectiveness. • Targets methane specifically and use is able to be monitored, verified and reported on. • Potential for global application. • Could be accelerated by possibility to adapt a globally developed and approved compound for use in New Zealand.	• Explore fast track regulatory pathways in NZ, including approvals, ability to make GHG reduction claims and inclusion in national GHG inventories. • Attract investment in development or adaptation for the NZ market of products using scientifically validated compounds. • Full life-cycle assessment of complete device must demonstrate net benefit of use. • Livestock product testing to maintain NZ reputation as a food producer, including for food safety and quality, animal welfare and sustainability. • Explore potential to increase efficacy and impact through early life use. • Ensuring cost and viability of delivery at farm level.

Overall: This technology is attractive due to the ability to directly target methane, along with broad applicability in New Zealand farm systems, and use of a known delivery method. A long-acting capsule (e.g. 300 days) would reduce the number of times it would need to be delivered to achieve maximum reduction by the compound being active most of the year. It requires further research and commercial investment to confirm effective compounds, ensure cost-effective availability for New Zealand farmers, along with expeditious regulatory approval and carbon accounting processes. The economics of using this mitigation are yet to be fully understood.

Mitigation Solution Profile: Methane Inhibitor for feed additive delivery

Description: An active compound that targets methanogens in the rumen, to reduce the methane they produce, that is delivered as a supplement in feed or added to a total mixed ration.

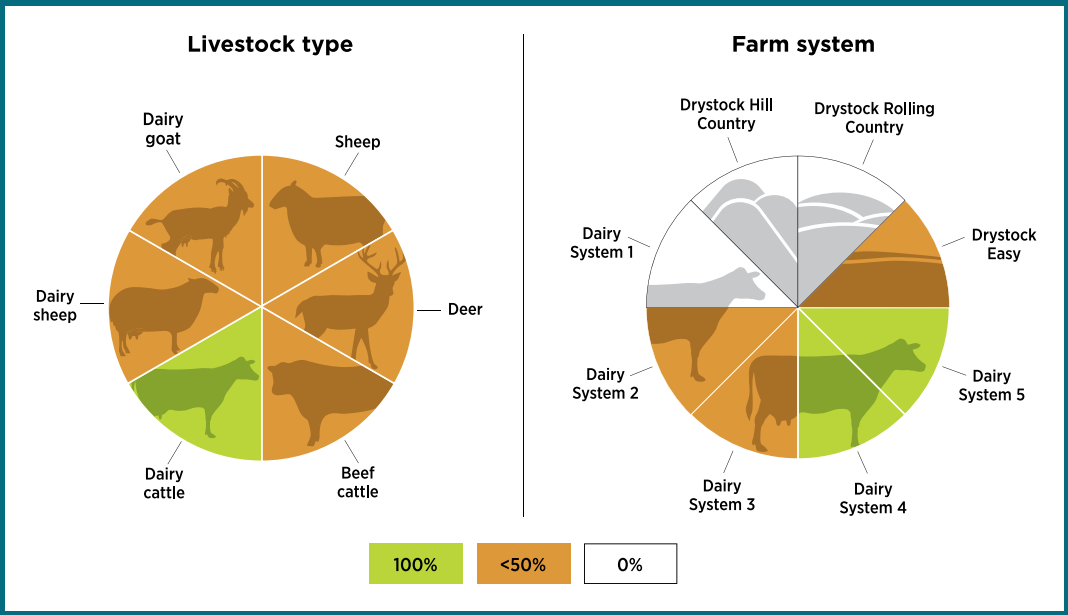
Current status: Not currently on the market in New Zealand. Various compounds are being actively researched and becoming available globally, mainly as a feed additive that would be used in total mixed ration (TMR) feeding systems. Methane inhibitors are likely to require regulatory approval for use in New Zealand and the regulatory system for this is emerging and is likely to be the same or similar to those used for animal remedies currently (ACVM, EPA etc).

The most advanced of these, with a scientific publication record, is **Bovaer™** from Royal DSM, which has recently achieved regulatory approval for release in Europe. Depending on the status of New Zealand regulatory systems, this could be released in New Zealand soon.

An additional feed additive currently under research is **seaweed** (Asparagopsis species), patented and licensed from Future Feed, Australia. Several New Zealand based research organisations and private companies are also investigating the potential of New Zealand seaweeds including Asparagopsis species for use as a methane inhibitor.

Neither of these additives have been fully tested in New Zealand pastoral farming conditions where they would be most likely offered as a daily or possibly twice daily supplement.

Applicability by species and farm type:



This technology could be used in any species however it would work only in farm systems where livestock are intensely managed and can receive daily treatments. Residues from the additive would need to be fully understood and may still impact their application to non-lactating livestock even where meat withholding periods are in place.

Potential reductions per animal per day:

In the range of 5%, depending on proximity to ruminant eating and duration or residence time in the rumen.

Potential national reductions per annum:

Key variables are the inhibitory effect, duration of use and rate of use. To be effective, these compounds need to be present in the rumen when feed is digested and therefore to achieve significant impacts on GHG they need to be fed daily for a reasonable period, e.g. a compound providing a daily 30% reduction in methane would need to be fed for ~120 days to reduce annual methane by 10% .

The need for daily administration and our predominantly grazing systems reduce the potential impact of a feed supplement mitigation.

Advantages and opportunities	Work still to be done
• Targets methane specifically and use is able to be monitored, verified and reported on. • Potential for global application. • Could be accelerated by adapting a globally developed and approved compound for use in New Zealand. • Supplement feeding is readily applicable in all dairy farms and more intense dry stock systems. • Accurate supplement feeding to individual livestock systems are available now and could be used for carbon calculation support.	• Explore fast track regulatory pathways in NZ, including approvals, ability to make GHG reduction claims and inclusion in national GHG inventories • Attract investment in development or adaptation for the NZ market of products using scientifically validated compounds. • Full lifecycle assessment of complete additive must demonstrate net benefit of use. • Impacts on grazing livestock productivity will need to be understood and unlikely to equal what has been reported in a TMR situation. • Finished product testing to maintain NZ reputation as a food producer, including for food safety and quality, animal welfare and sustainability. • Explore potential to increase efficacy and impact through early life use. • Ensuring cost and viability of delivery at farm level.

Overall: This technology is the leading approach globally and attractive due to the ability to directly target methane, and its likely acceptance in other international livestock markets as well. It requires further research and commercial investment to confirm effective compounds, ensure cost-effective availability for New Zealand farmers, along with expeditious regulatory approval and carbon accounting processes. The economics of using this mitigation are yet to be fully understood.

Methane vaccines

AgResearch scientists have advanced a large body of work toward developing a vaccine that reduces methane emissions from ruminant animals, suitable for New Zealand pastoral farming systems.

The goal of the work is to produce a vaccine that stimulates the animal's immune system to generate antibodies in saliva that target proteins on methane-producing microbes (methanogens) in the rumen, restricting their growth and ability to produce methane.

A vaccine would have to achieve a minimum 20% emissions reduction per animal, without reducing productivity, to be worthwhile developing – but there is potential for 30% or more.

"The industry-led research advanced by the PGgRc into ruminant methane mitigations means New Zealand has a head-start globally, demonstrating leadership and putting New Zealand at the centre of research. Now other countries such as the UK, Ireland, US and Canada, where methane is creeping up the agenda, are looking to collaborate with New Zealand." Hayden Montgomery, Special Representative for the Global Research Alliance based at the Ministry for Primary Industries.

If successful, this would be a world-first.

What we have found

To date, prototype vaccination trials in sheep have not yet successfully reduced methane emissions. However, lab research has demonstrated that:

- A vaccine can produce sufficiently high levels of antibodies in the saliva of sheep and cattle
- These antibodies will bind onto the corresponding cell components (antigens) of methanogens in the rumen fluid, and have an effect on those cells
- Many antigens are common to the different species and strains of methanogens
- Antibodies will bind onto these antigens across the full range of target methanogen species, within the rumen fluid.

Research is now focused on identifying the right antigens that will induce antibodies that inhibit the growth and function of methanogens in the rumen. In December 2019, an international panel was engaged to review the vaccine programme and confirmed the value and appropriateness of this research approach.

"We can develop antigens and we can get animals to produce antibodies against them. But getting that to work so that we get an impact on methanogens in the rumen is the hurdle that we are currently working on" says Dr Peter Janssen, AgResearch Grassland Research Centre.

"We have some antigens that look promising and may use model antigens to understand the barriers to getting antibodies to attach to the antigens."

Enabled by the sequencing of the methanogen genome achieved earlier in the PGgRc programme, scientists are now systematically testing a list of proteins that are predicted to be able to be targeted by a vaccine.

This work involves comprehensive studies to understand the abundance of these antigenic proteins on methanogens, which affects how easily they can be targeted by a vaccine, as well as how effectively antibodies can bind to the proteins as well as how they perform in the rumen.

"The rumen is the biggest potential barrier, a large fermentation vat set up to degrade plant material." says Dr Neil Wedlock, AgResearch Senior Scientist and Project Lead. "We know that antibodies do survive in the rumen, but they have to be able to perform in this complex environment."

"We're not at the stage yet where we have proof of concept in an animal, but with every trial we do, we develop new knowledge and tools that further advance our work. If we can get this to work, our vaccine will work across beef, sheep and deer; it can be applied for reducing animal emissions globally."

Producing better antigens

The PGgRc has initiated collaborations with Victoria University of Wellington and University of Technology Sydney, to find new ways of producing antigens. Bringing new skill sets into the vaccine programme through PGgRc's support has allowed the research to follow the science as new discoveries are made.

"Specific parts of antigens result in different immune responses, and informed selection of antigenic components will lead to the production of more effective antibodies", says Dr Wedlock.

PROFILE: George Moss

George Moss

"The reality is that climate change is happening harder and faster than what the modelling anticipated," says Waikato dairy farmer George Moss.

"And methane is an extremely potent greenhouse gas. Yes, it's short-lived, but every kilogram we can pull out enhances the ability of the planet to find an equilibrium.

"So, low-methane genetics is a critical tool in giving farmers small incremental gains with no impact on productivity that will become part of the national flock over time. We know that the science is difficult and expensive to apply with cattle, but it's critical.

"I'm also hanging out for the development of a long-term methane inhibitor bolus that will give farmers gains without impacting on productivity and for a vaccine – but that's a long way off. Likewise, the work around forage rape and fodder beet as tools to reduce methane has real potential.

"Ultimately, with the technology and measures available to farmers right now, we have a good shot of achieving our 2030 target of 10% reductions. But targets are going to get tougher. We are going to need significant technological breakthroughs to achieve 2050 targets and beyond.

"The marketplace also expects that New Zealand will retain its low footprint per unit of product and at the same time, our overseas competitors will potentially catch up to us through technological advancements that allow them to achieve major reductions with the likes of what's happening in Bavaria.

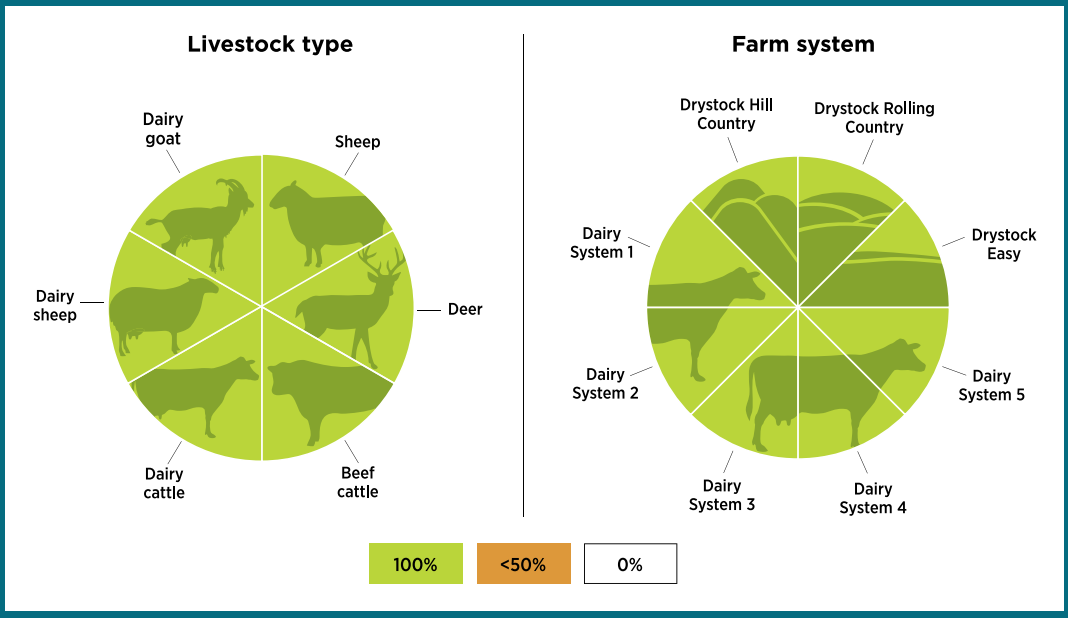
"Ultimately, we need to urgently accelerate the science to achieve the technological breakthroughs we need for major reductions. And we have to do it together, across the board, if NZ Inc. is going to keep its advantage and remain productive."

Mitigation Solution Profile: Methane Vaccine

Description: *Specific antibodies produced by the host animal in response to (usually) injected antigens (specific peptides and proteins) from rumen methanogens that are delivered in saliva to the rumen where they can target the methanogen's critical physiological pathways and hinder their growth.*

Current status: Not currently on the market in New Zealand or globally. The concept has been developed to target other rumen microbes, so is considered feasible. In laboratory tests, pure methanogen cultures have been impacted by antibodies. To date, there has not been a demonstrated measured reduction of methane in vaccinated livestock measured through respiratory chambers. Research to this point has identified barriers that are being addressed and has not identified that it won't be possible to vaccinate to reduce methane from ruminants.

Applicability by species and farm type:



This technology could be used in any ruminants and would work in all farm systems.

Potential reductions per animal per day:

Unknown but in the range of 20% depending on the efficacy of the vaccine on methanogen species.

Potential national reductions per annum:

Key variables are the inhibitory effect from vaccine on the target species that accounts for 70% of rumen methane, longevity of vaccination and requirement for boosting to maintain that. For example, a vaccine with a 30% reduction effect, used annually by 50% of pastoral livestock, could reduce total national methane emissions by 15% per annum. Realistically 100% adoption is unlikely, but if 80% was achieved, then this would rise to a 24% reduction.

Advantages and opportunities	Work still to be done
• It would apply to all animals and all livestock systems. • Farmers already very familiar with the technology; vaccine manufacture and distribution channels well established. • Should be more consistent and easier to use than inhibitors and other products which rely on more significant integration into farm management practices. • Targets methane specifically and use is able to be monitored, verified and reported on, with nil residues. • Potential for global application. • Could be incorporated into existing farm vaccination processes.	• Unproven technology at animal scale, proof of function required. • Explore fast track regulatory pathways in NZ, including approvals, ability to make GHG reduction claims and inclusion in national GHG inventory. • Finished product testing to maintain NZ reputation as a food producer, including for food safety and quality, animal welfare and sustainability. • Explore potential to increase efficacy and impact through early life use. • Ensuring cost and viability of delivery at farm level.

Overall: The solution has significant promise due to its widespread applicability but has not demonstrated proof of function of reduced methane in livestock yet. The programme of research is focussed on identifying and overcoming the barriers to demonstrating this or confirming a vaccine mitigation is not possible.

A methane vaccine would be the highly adoptable solution farmers are hoping for. The business case is only going to get stronger as emissions become priced or from a social license perspective. A technology like this could be decisive in terms of the role that ruminant based meat and dairy products play in the global food system. The economics of using this mitigation are yet to be fully understood.

Low-methane feeds and forage supplements

There is now a significant body of knowledge demonstrating the potential for dietary manipulation as a practical and cost-effective tool to help reduce emissions of methane and nitrous oxide.

Many different feeds have been analysed and some are showing promise, in particular brassica rape and plantain. However, research has not yet identified definitive ways to reduce emissions from pasture-based livestock by diet alone.

Research is also continuing to look at the impacts on other environmental factors and farm productivity, to ensure whole-system effects are understood.

"We have moved our thinking from having one crop or one inhibitor that is going to be the solution to having a variety of tools across forage, inhibitors, vaccines and breeding that will give us the 25% reduction in agricultural emissions that we are looking for," says Dr David Pacheco, AgResearch Science Objective Leader – Climate Change Adaptation & Mitigation; Principal Scientist – Animal Nutrition & Physiology.

"Some of the most significant achievements of the research programme relate to the new knowledge generated about New Zealand conditions and the mechanisms by which emissions reductions occur.

"For instance, we know from experiments that increasing the rate of passage of feed through the rumen changes the metabolism of methanogens and reduces methane emissions. Likewise, through our experiments we have identified that pH plays a role in mediating methane levels, although it is not a sole factor.

"These are fundamental insights that we can use in designing methane control, in trying to select forages or even design forages to give you the desired trait."

What we have found

Since 2009, emissions have been measured almost exclusively using sheep in respiration chambers, now considered to be the standard method for estimating methane emissions from ruminant animals as the environment can be controlled, feed intake monitored accurately and measurements made in stable and reliable way.

Brassica crops and pH

Brassicas have been tested extensively and show promise in reducing methane emissions. Forage rape has been most extensively tested. Key findings include:

- Sheep fed with 75% of forage rape produced 6% less methane (per unit of feed eaten) than sheep fed 100% ryegrass. Sheep fed 100% forage rape produced 32% less methane than the ones feed only ryegrass.
- Feeding 25% and 50% of the dry matter eaten as forage rape was not different in terms of methane per unit feed eaten than 100 % ryegrass.

Subsequent PGgRc and NZAGRC funding has shown that altering the ruminal pH of sheep fed forage rape also affects methane emissions.

"When supplemented with sodium bicarbonate, an increase in ruminal pH was associated with an increase in methane emissions." says Dr Pacheco, "After stopping the supplementation, ruminal pH and methane emissions return to a lower level. These results suggest that lower methane emissions for sheep fed forage rape might, at least partially, be related to lower ruminal pH when this crop is fed."

Additionally, PGgRc and NZAGRC funding supported work on a mathematical model of the hydrogen–methanogen dynamics in the rumen.

"This model contributes to the integration of knowledge that will allow us to mathematically explore methane mitigation strategies in the rumen," says Dr Pacheco.

Net benefits from forage rape

While brassicas show promise in reducing methane emissions, it appears that in some circumstances they can significantly increase nitrous oxide emissions and may have implications for animal health. If these issues can be overcome, greater use of forage rape could yield an overall net benefit in GHG reductions.

With this is mind, PGgRc funded research in 2019 to assess the overall effect on net GHG emissions of livestock grazing forage rape. The study compared urine patches from both sheep and cattle applied to forage rape and to pasture (rye grass and clover) over six weeks in three different seasonal and locational trials.

Based on results and a set of underlying assumptions, the study estimated that forage rape delivered a net benefit of GHG reduction for dairy cattle of around 22% per cow over the six weeks, equating to a 2% reduction per cow annually.

"Before we go about increasing forage rape as an effective mitigation option in the agricultural GHG inventory, we needed to understand its full impact." says Dr Cecile de Klein, Principal Scientist, Environmental Science AgResearch "This study provides some very good evidence that it delivers an overall net benefit, which supports a case for considering forage rape's inclusion in the GHG inventory."

Fodder beet

Fodder beet can reduce methane emissions by around 20%, but only when included at high levels in the diet (greater than 70%). The results are also variable and, in some circumstances, could be caused by short-term digestive disruptions rather than genuine long-term emissions reductions.

Plantain

A study funded by the NZAGRC has also found plantain shows promise in reducing methane. Non-lactating cows fed 100% plantain produced 16% less methane, on average, than cows fed 100% ryegrass.

A further PGgRc-funded DairyNZ study has also found plantain shows promise in reducing methane emissions in lactating cows, with some seasonal variations.

The study was carried out as part of DairyNZ's wider research to determine what levels of plantain are needed reduce a cow's urinary nitrogen and in turn nitrate leaching.

"We want to make sure that while we're addressing our freshwater quality issues, we're not causing another problem elsewhere by creating a greenhouse gas issue." says DairyNZ scientist Dr Elena Minnee, "With the help of PGgRc and the AgResearch mobile greenfeed units, we have been able to carry out those studies."

In autumn, mid-lactating cows fed 80% plantain produced 18% less methane on average per unit of feed than cows fed 100% ryegrass. On a per unit of milk produced basis, this translates to a 24% methane reduction.

In spring however, with early-lactating cows there was no significant difference in yield.

"While clearly there are seasonal properties of feed that impact methane yield, overall this study tells us that plantain can have a two for one positive benefit for our industry, reducing nitrogen and potentially, being integrated into a system to take advantage of any methane reductions."

Other feeds/feed additives

Among the many non-pasture feeds tested (including white clover, chicory, various silages, PKE and maize grain), some showed early promise, but none have shown sustained reductions in methane emissions when compared with pasture.

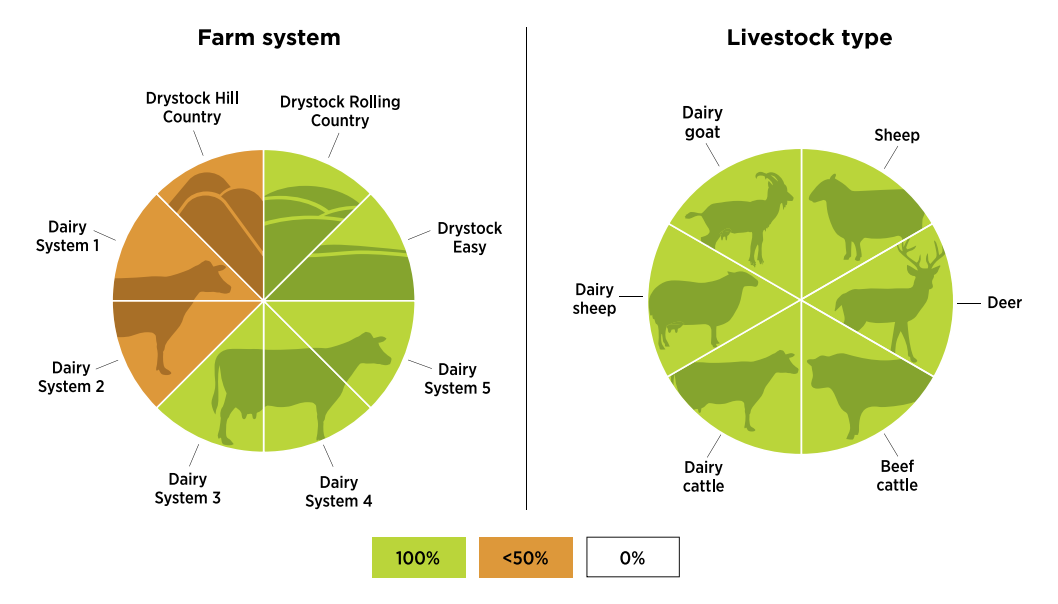
Other non-pasture feed additives such as garlic and essential oils have been shown to reduce methane but ruled out as they taint milk and are too costly. Likewise, some antibiotics and growth promoters have been shown to reduce methane emissions in intensive feedlot systems but have limited effects in pasture-based systems. There can also be strong market resistance to the use of such substances.

Mitigation Solution Profile: Brassica rape as a forage crop

Description: *A forage species that reduces methane delivered through diet manipulation with an annual forage crop. Thought to act by speeding up rumen turnover as highly digestible feed, rather than a plant component effect.*

Current status: Possible now where land can be cultivated and sown. When fed as 100% of diet, it has potential to reduce methane output by 25% per day. It is in the process of being added to the Greenhouse Gas inventory. However, recent information indicates that a minimum level in the diet, (60-70%) may be needed to make this practical to achieve. As this crop is fed generally through direct grazing, the possible nitrous oxide impact has also been assessed and may reduce the GHG reduction potential by 3%.

Applicability by species and farm type:



This technology could be used in any species and would work in most farm systems except hill country. However, within New Zealand farm systems, forage crops play a minor role in ruminant diets, providing 5-10% annually and are used to fill strategic shortfalls that can't be met by pasture.

Potential reductions per animal per day:

Up to 25% per day if 100% of livestock diet, reduced in wet conditions to 22% due to increased nitrous oxide emissions, but this will be managed through good management practice.

Potential national reductions per annum:

Key variables are the duration and rate of use. For example, a 25% reduction effect, used for 42 days by 15% of dairy cows, could reduce total national methane emissions by 3.75% per annum, while a 25% reduction effect, used for 42 days by 5% of sheep could achieve 1.25% total national methane emissions per annum. Cumulatively across the entire livestock sector, this amounts to an estimated 2.5% of national methane emissions.

Advantages and opportunities	Work still to be done
• Already in use in NZ farming systems to supplement pasture supply providing up to 6 weeks of alternative forage. • No known impacts to product quality.	• Inclusion in national GHG inventory. • Address the perceptions and animal welfare challenges of feeding crops in wet and muddy conditions where animals have no dry land under foot. • Understand the implications around slightly elevating nitrous oxide emissions at sometimes of the year when grown and fed out as a crop. • Peer review publications confirming impact for both methane and nitrous oxide. • Peer-reviewed publications confirming areas of crop planted annually to identify the total annual impact.

Overall: This technology is already available and has broad applicability, but it has modest GHG impacts in New Zealand farm systems. It requires further validation to be able to be counted in the GHG inventory. The economics of using this mitigation are yet to be fully understood.

Breeding low-emitting sheep

New Zealand sheep breeders can now measure their sheep and rank them for breeding based on methane emissions.

In this world-first, award-winning 10-year PGgRc and NZAGRC-funded research programme. AgResearch scientists identified low- methane-emitting sheep and supported the development of a methane breeding value that has since been incorporated into breeding indices. A similar breeding programme for dairy cattle and deer is now underway.

How we got here

Research into the potential to breed for low methane-emitting traits in sheep started in 2007, funded by PGgRc and MPI's Sustainable Land Management and Climate Change fund.

"Until now, the only way farmers could lower on-farm emissions has been to constantly improve their overall farming efficiency," says AgResearch Senior Scientist and Project Lead Dr Suzanne Rowe.

"What we have produced, starting from a point of not knowing whether emitting methane was an animal trait or not, are breeding values for low-emitting sheep and to harness existing genetics and breeding infrastructure to make that available to farmers."

Low- and high-emitting sheep were established by measuring the methane emissions and daily feed intakes of over 1,300 animals.

To do this, researchers designed and developed respiration chambers where sheep are held comfortably and fed for 2 days while air samples are analysed. This work established that some sheep naturally emit less methane per kilogram of food eaten than others. The research found that this variation is statistically significant.

Aligned NZAGRC funding also enabled low-emitting animals to be genotyped for gene markers that when coupled with the measurement data identify the low-emission trait and expressed as a breeding value.

Since then, research has confirmed a genetic basis for the variation in methane emissions between animals, meaning the reduced-emission trait is passed on from generation to generation resulting in a cumulative reduction each year.

"On our productive farm breeding research flock where all desirable genetic traits are included, we're seeing around a 2-3% difference in emissions per year," says Dr Suzanne Rowe. "So, we are advancing quickly. In industry, what we're anticipating is around a 1% drop in emissions per year, if it's incorporated into standard breeding programmes that farmers adopt. That's a steady incremental annual gain."

Two additional generations have subsequently been bred from these flocks and the low- and high-emitting sheep are now estimated to differ on average by around 16% since selection starting with a 4% difference in 2008. Ongoing NZAGRC funding ensures that these flocks are maintained over time.

Engaging breeders

In 2020/21, the sheep-breeding programme made research breeding values for low-methane emissions available to selected ram breeders through Beef + Lamb Genetics supported by the PGgRc. This provided 2,040 measurements from commercial breeding flocks.

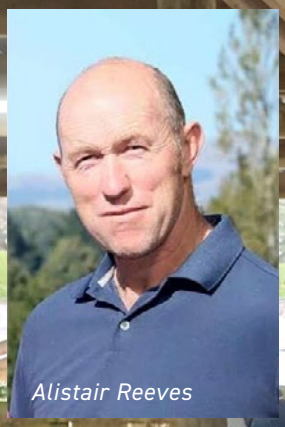
As breeders and producers consider incorporating methane-breeding values into their own breeding programmes, the selection lines continue to provide a vital demonstration that this is a safe and practical mitigation strategy.

"This is a major step forward." says Dr Suzanne Rowe. "At a national level for sheep, we estimate around 1% reduction in methane emissions per generation, with potential for a 10-20% reduction in total sheep emissions by 2050."

Learnings from this research are now being applied to other ruminant livestock systems, including dairy cattle and deer.

A very successful collaboration has been with the New Zealand Fund for Global Partnerships in Livestock Emissions Research (GPLER)-funded programme 'Microbes to Predict Methane'. This project used samples collected early in this research programme. Results show promise for the estimation of methane-breeding values in ruminant livestock.

PROFILE: Alistair Reeves



Alistair Reeves

Waimai romney sheep being measured for methane using AgResearch PAC trailer

"New Zealand farmers are already leading the world in producing food and fibre from a pasture-based, low-energy system that exemplifies the highest standards of animal welfare," says Waikato sheep breeder Alastair Reeves.

"And our increasingly discerning customers worldwide are happy to reward us for it. Now we need to focus on telling our story as their demand for carbon neutral systems intensifies."

Alastair manages the 800-hectare Waimai Romney Stud in the Te Akau district, farmed by the Reeves family since 1932.

Over the last three years, Waimai Romney has been methane testing rams, putting 192 per year through AgResearch's respiration chamber trailer.

"I'm doing this because I see it as being beneficial to my clients, using genetics as a sound logical way to help solve a problem that doesn't add work or cost for farmers, in no way affects productivity, and indeed, potentially enhances it," says Alastair.

Waimai Romney are pioneers in genetic breeding, with Alastair's father John leading the way using selective breeding to build resistance to facial eczema and intestinal parasites. Waimai Romney is now one of only a few Romney studs with FEGold and WormFec Gold accreditation.

"As sheep geneticists, we have to be ahead of the game. We need to be able identify outliers for certain traits and use them to make genetic gains in our breeding programmes.

"So, it's exciting to be able to select for methane and we're only able to do this thanks to PGgRc's research programme and the team at AgResearch."

In 2020, the AgResearch data showed Waimai Romney had one of the top rams in New Zealand for low methane output. He was used in the stud in 2021 and in 2022. This current year, all lambs born at Waimai Romney will have negative methane research EBVs (estimated breeding values) based on their sire and dam.

"That's getting exciting. If we can keep growing this story and make low methane sheep available to our clients, they can make incremental gains without any additional effort or loss to productivity."

Ultimately, Alastair sees this as building on the story of New Zealand provenance that discerning customers want to see, opening new opportunities for the future across the food and fibre sector, trade, tourism and hospitality.

"We believe this will be hugely beneficial for our clients, both environmentally and financially, so we're in. This is only going to add to the NZ Inc. story."

Measuring emissions in deer

All mitigation solutions have been developed to be applied across sheep, cattle, deer and goats. However, measuring emissions in deer presents specific challenges due to the animal's nature and behavioural traits.

PGgRc has funded research into using the GreenFeed automated emissions monitoring system (GAEM) with deer grazing pasture. The GAEM is a hood system integrated with an automated concentrate feeder to attract animals.

Deer eat up to 2kg dry matter per day and so have low emissions relative to cattle. Large and small GAEM systems were tested for implementation with deer. The systems were placed in the paddock with a group of deer, trained to visit the units in exchange for feed pellets. At the same time, air is drawn past the head of the animal into the system and methane determined.

The research trials have shown that it is possible to perform direct methane measurements with deer using GreenFeed. However, further modifications to the animal training and measurement protocol and to the GreenFeed unit are required to overcome specific challenges.

In addition, the PGgRc has funded studies with rumen sampling in elite deer selection animals to confirm if deer rumen have similar microbial communities to sheep and cattle - and if so, can this be extrapolated to select for methane. While the studies showed similarities, further work on a wider range of animals is needed and this will be an ongoing activity for that sector.

PROFILE: William Oliver

"High-end discerning consumers expect the premium food they buy to have a low environmental footprint and that food producers are reducing their greenhouse gas emissions," says Waikato farmer William Oliver.

William, a former board member of Deer Industry New Zealand (DINZ), runs a diverse operation wintering 20,000 stock units, including 3,500 deer, along with maize and silage production and forestry.

"All New Zealand farmers need cost-effective, practical and easily implemented solutions for mitigating emissions that will stand up to market scrutiny.

"It was exciting to hear about PGgRc progressing the science to develop methane mitigations across feed, inhibitors, vaccines and genetics.

"DINZ invested in the PGgRc with the expectation that these mitigations will help ensure deer remains competitive as a choice of stock class for New Zealand pasture-based farming systems.

"The challenge is that this science requires financial investment and time, and we really hope work on these mitigations will be accelerated, products successfully developed and come to market soon."

As a sheep and beef farmer, William has already adopted low-methane sheep genetics developed through the PGgRc.

"As a farmer, you need to strategise, use all the tools at hand to reduce emissions. We're purchasing our rams from a breeder using the low-methane breeding value, a really cost-effective way to get ahead of the game."

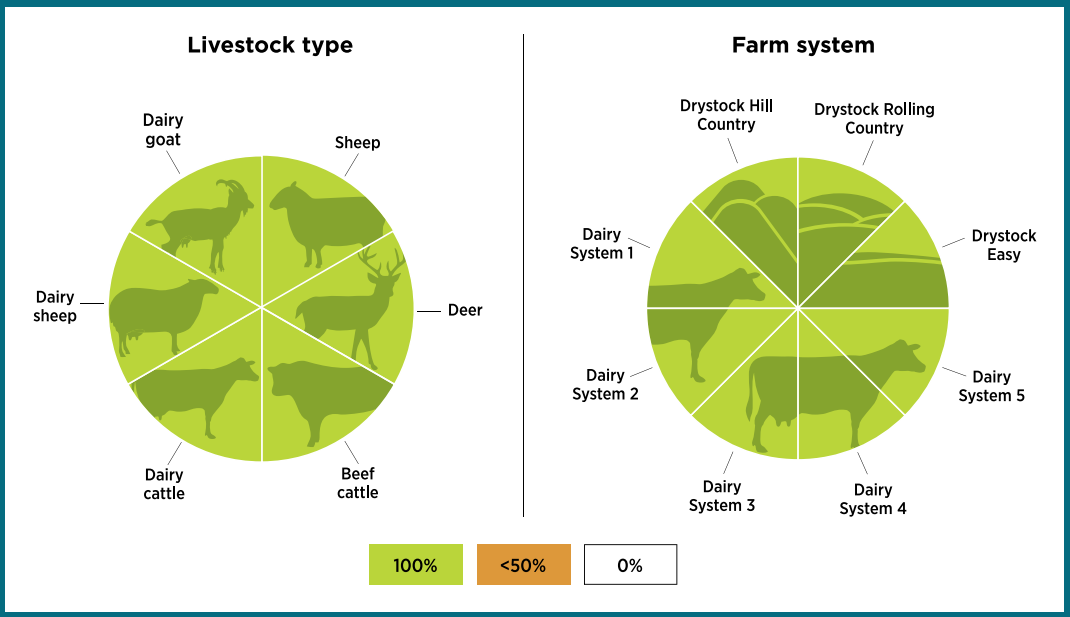
William Oliver

Mitigation Solution Profile: Genetic selection for methane reduction

Description: *Selection of genetic characteristics in livestock associated with the function of the rumen and microbes to achieve methane reductions - potential to target both the host and the microbes as a phenotype.*

Current status: Research has confirmed that genetic selection for methane is a heritable trait. Currently being rolled out in sheep in New Zealand. Dairy cattle selection currently under development through method validation with selection in elite bulls. Identification and validation of proxy methods (e.g. rumen, saliva, milk) for selection is in progress.

Applicability by species and farm type:



New Zealand has well established systems for using genetics to improve animal productivity in ruminant livestock. This technology could be used in any livestock that is using genetic selection and would work in all farm systems.

Potential reductions per animal per day:

Based on sheep work opportunity to reduce emissions at animal scale is small (1% per generation) but this would be permanent and cumulative into the future.

Potential national reductions per annum:

Estimates from methane selection in sheep that is currently being rolled out indicate around 0.8%-1.0% reduction in methane yield (gCH4/Kg DM eaten) per generation might be possible. Unknown for cattle. As we understand the trait more, it may also be possible to see further increase in impact as unlikely to run out of genetic variation potential. However, as a new trait, we will need to monitor for any potential negative effects over time. Overall, for livestock to 2050 a realistic range could be 10-20% in total.
Note on selection for nitrogen reduction: currently this is being investigated in dairy systems through the monitoring of Milk Urea Nitrogen (MUN) for low Nitrogen sires.

Advantages and opportunities	Work still to be done
• Genetic selection is a well understood approach and will provide permanent and cumulative changes to livestock emissions. • Will maintain NZ's reputation as a food producer, including for food safety and quality, animal welfare and sustainability. • No change required to farm system and regarded as a natural method and well accepted.	• Cost effective methods for selection developed and available. • Lack of current clarity about level of reductions that could be possible, particularly in cattle. • Likely to be selected alongside other traits and therefore impact diluted. Will need to understand correlation with other productivity traits. • Mechanism of making it count developed for national inventory.

Overall: It has solid appeal as it requires no change to farm system, it is known technology with well-established pathways to market and regulation - something New Zealand has a track record of doing successfully. It is at the low end of how we farm versus other technology. More 'natural' than other options, and slowness of change allows risks to be effectively monitored and mitigated.

THE FUTURE

Farmers are facing 2030 and 2050 emissions reduction targets and require acceleration of the development of the most promising new technologies, whether developed through PGgRc partnerships or elsewhere, to support farmers in achieving those targets.

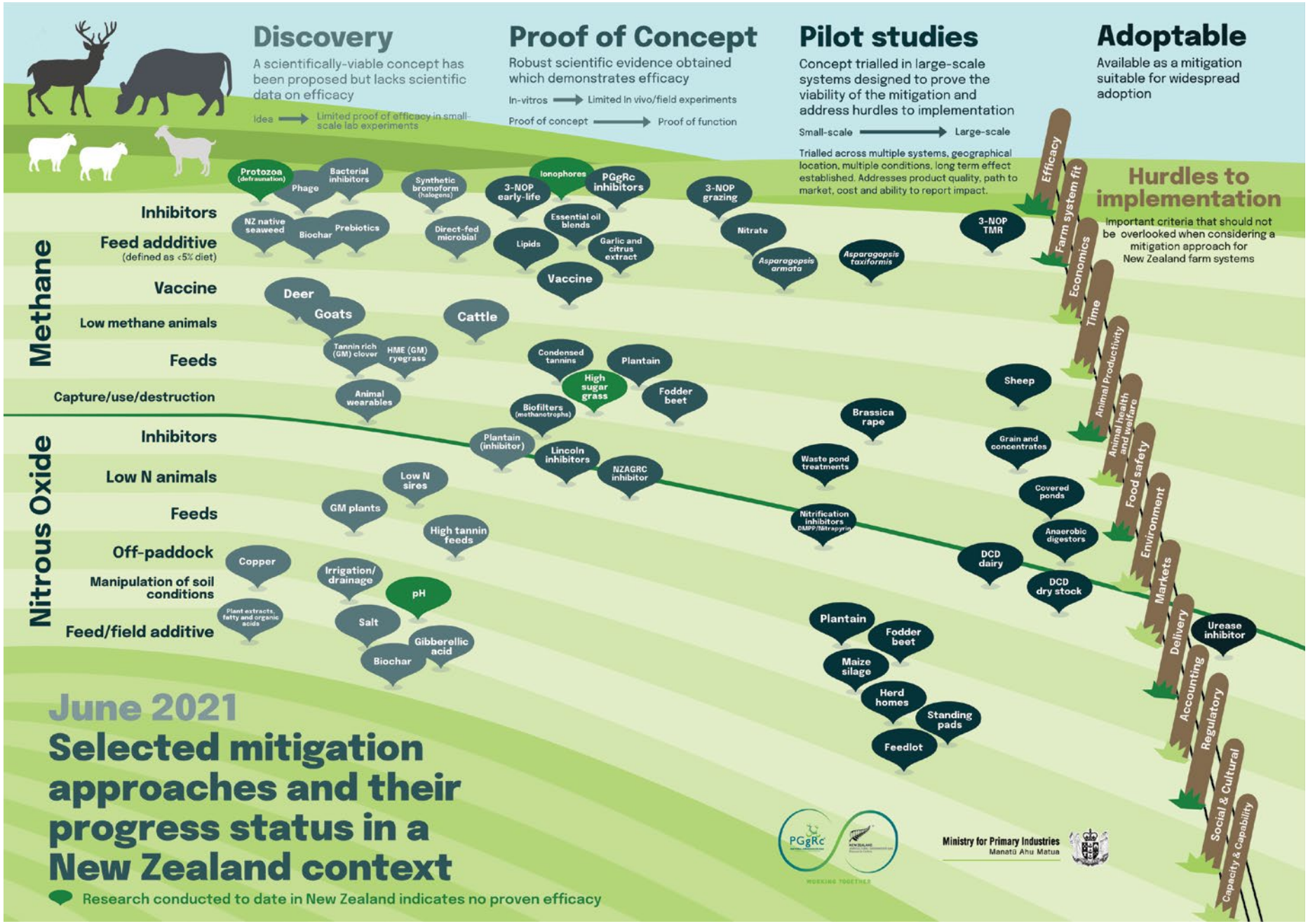
From 2022, a refreshed and different approach will take the work of the PGgRc forward and provide key services the sector needs to accelerate delivery of fit-for-purpose GHG mitigation technologies to New Zealand ruminant farmers.

This will continue the collaborative approach established through the PGgRc on behalf of pastoral farmers, while building new partnerships to achieve its purpose.

The NZAGRC will continue to be key partners in the future, reflecting the critical importance of cooperation and alignment to achieve our shared objectives of reducing ruminant emissions in New Zealand.

“The PGgRc has been an enduring and important investment for government working in partnership with industry to take agricultural greenhouse gas mitigation research to the next level.” says Dr Colin Reid, Principal Investment Manager, Ministry of Business, Innovation and Employment. “What’s been achieved in the last decade with methane inhibitors, genetics, feed and the vaccine show clear signs of promise and progress. While there is more work to do, the PGgRc has laid the foundations for building the future.”

The mitigation technology options under development to reduce NZ livestock GHG emissions, showing where they are currently on the path to market and the implementation hurdles to be met to become adoptable



Accelerating biological emissions reductions

The Biological Emissions Reduction Science Accelerator (BERSA) is a key part of the Government's climate change response and Fit for a Better World initiative, led by MPI.

What mitigation technologies are available?

The BERSA is a research and development plan for science and Mātauranga to reduce biological emissions from agriculture. It brings together the livestock industry, research communities, Māori and government in a collaborative and aligned partnership to look at ways to get the right tools and technology into farmers' hands as soon as possible.

The plan has drawn on a stock-take of current options (pg 35) available to farmers, and engagement with researchers and developers to consider priority mitigations for acceleration. Work that has been considered includes urease inhibitors, and building on the work of the PGgRc, including accelerated development of inhibitors, vaccines and increased rollout of sheep genetics and extension to other species.

Respiration chamber trailer at Blackdale Stud

The PGgRc was one of the groups involved in developing this plan, with representation on the working group.

"This accelerator benefits from the science investment of the PGgRc in the last two decades, as it offers a foundation for the development of technological solutions to methane mitigation that will be suited to New Zealand pastoral farming systems," says MPI Departmental Chief Science Advisor, Dr John Roche.

This will provide a high-level framework and plan under which the different partners come together, including PGgRc members, working collaboratively, and leveraging the respective strengths each partner brings to the table.

"The PGgRc experience demonstrates the strength of, and need for, a co-operative and collaborative approach to solving what is an extremely complex and challenging problem. It is uniquely important for New Zealand's economy and reputation that we develop ways to efficiently and cost-effectively reduce livestock greenhouse gas emissions," says Dr John Roche.

PROFILE: Leon Black

Leon and Wendy Black

Southland sheep farmers Leon and Wendy Black use and are looking to supply low-methane rams, which they see as one of the most cost-effective and easy ways for farmers to reduce their footprint and enhance productivity.

Blackdale Stud is one of the biggest family-run stud sheep operations in New Zealand, grazing more than 5000 animals on 370ha. Leon says management takes a data-led approach and that includes testing sire groups for methane emissions using the AgResearch Portable accumulation chamber (PAC) trailer.

Since measurements started, they have progressively selected lower methane emitters and are now showing 20% reduced estimated breeding values for methane. Leon, a former director on the PGgRc and past director of B+LNZ, has been a keen advocate for PGgRc's investment into researching genetic variation and supporting AgResearch's development of the PAC technology to measure the methane, oxygen and carbon dioxide emitted from sheep.

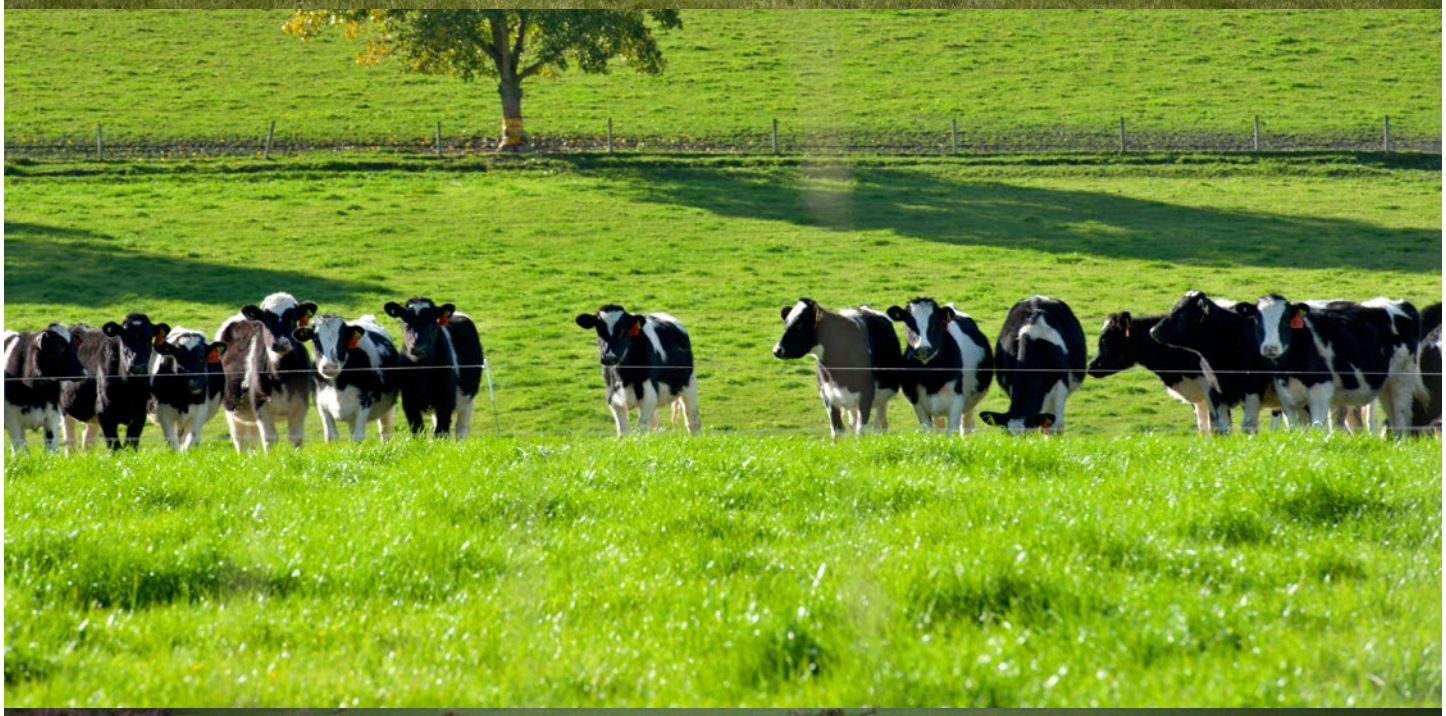
"At the time, I could see that a vaccine or inhibitor was a long way away for the sheep and beef industry," says Leon, who has held various other director roles across the industry and within breed societies.

"Farmers needed to have a viable option sooner. Ultimately, through the R&D we confirmed variability in sheep methane emissions and that it's a heritable and repeatable genetic trait.

"The bottom line is that we now have the tools to measure methane production, and through tweaking the genetics the right way, we can reduce emissions in small incremental steps, improving every generation."

Blackdale is now looking to be able to supply high-performance lower-emitting rams for its client base, which would impact about 3% of the national flock, says Leon.

"Our focus has been to try to deliver for the good of our clients using lower emitting sheep to meet their targets by 2030. We're several years away from having other viable tools but we've got this tool now that's improving the emissions profile of our flock incrementally, year by year. It's practical for farmers, it's not cost-prohibitive, doesn't involve any extra tasks and naturally flows into your flock. It also enhances production because low-emitting sheep waste less energy. It's a no-brainer."



PARTNERS

Established in 2003, the Pastoral Greenhouse Gas Research Consortium (PGgRc) is an industry-led consortium that has invested around $5 million annually, via a 50/50 funding partnership with the Ministry of Business, Innovation and Employment (MBIE), in greenhouse gas mitigation research.

Since then, the PGgRc has continued to invest in and lead the commercialisation of the methane vaccine and inhibitor mitigations through an agreement with the New Zealand Government via the Ministry for Primary Industries, assigning them Intellectual Property and requiring them to act in both parties interests.

International collaborations are led by the Global Research Alliance on Agricultural Greenhouse Gas Emissions.

The PGgRc has been funded in partnership with MBIE by:

AgResearch

Beef + Lamb New Zealand (B+LNZ)

DairyNZ

Deer Industry New Zealand

Fertiliser Association

Fonterra

Landcorp Farming

PGG Wrightson

THE BOARD

The PGgRc Board of Directors comprises a mix of expertise and experience, reflecting this long and enduring partnership between industry, science and government. The governance board oversees the programme and protects its IP under the collaboration agreement between PGgRc the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) and joint R&D&E strategy.

The Board has regularly sought advice from commercialisation, expert science and end-user advisory groups with a New Zealand Inc focus.

Jeremy Hill (Chair)

Andrew Morrison

Innes Moffat

Bruce Thorrold

Stuart Hall

Darryn Pegram

Emma Blott

ASSOCIATE MEMBERS:

For a full list of the PGgRc governance directors and Observers see appendix 1.

Ministry for Primary Industries (MPI)

National Institute of Water and Atmospheric Research (NIWA)

Ministry of Business, Innovation and Employment (MBIE)

New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC)

GLOSSARY

Antigen/antigenic - Any substance foreign to the body that evokes an immune response.

Antibody - Large protein used by the immune system to identify and neutralise foreign objects such as pathogens/antigens.

B+LNZ Genetics exists to help commercial farmers make the most profitable breeding decisions for their particular farm management system. It does this by ensuring breeding objectives are commercially focused and developing easy-to-use selection tools, such as New Zealand Maternal Worth (NZMW) and New Zealand Terminal Worth (NZTW).

Enteric methane - Naturally occurring methane generated by anaerobic fermentation, where microorganisms break down organic matter producing hydrogen, carbon dioxide and methane. This process naturally occurs in the digestive system of domesticated and wild ruminants, natural wetlands, and rice paddies.

Enteric fermentation - In ruminants, methane is produced mostly by enteric fermentation where microbes ferment plant materials, such as celluloses, fibre, starches, and sugars, in their rumen. Enteric methane is one by-product of this digestive process and is expelled by the animal through burping. Enteric methane production is strongly related to the level of intake. Mitigation tools aim to reduce the amount of methane formed from the amount of feed consumed.

Genotyping - The process of determining the DNA sequence, (a genotype), at specific positions within the genome of an individual. Sequence variations can be used as markers in linkage and association studies to determine genes relevant to specific traits or disease.

Global Partnerships in Livestock Emissions Research - The New Zealand Fund for Global Partnerships in Livestock Emissions Research (GPLER) was an international research fund set up by the New Zealand Government. It supported the Global Research Alliance on Agricultural Greenhouse Gases (GRA). From 2011 to 2020, the fund promoted global research into mitigating greenhouse gas emissions from pastoral livestock farming.

Global Research Alliance on Agricultural Greenhouse Gas Emissions (GRA) – New Zealand is a founding member of the GRA, formed in 2009 to find ways to grow more food without growing greenhouse gas emissions. The GRA promotes international cooperation and investment in research to mitigate the effect of agricultural greenhouse gas emissions. The GRA gives New Zealand scientists the opportunity to work with world-renowned institutes and researchers. It also helps

them to share knowledge and expertise with the global science community. The Ministry for Primary Industries hosts the GRA Secretariat, including the special representative Hayden Montgomery.

Methane - A short-lived greenhouse gas that degrades in the atmosphere over decades. Once in equilibrium, it can continue to be emitted at a stable rate without increasing its concentration in the atmosphere. There are two sources:

Biogenic methane produced from biological (plant and animal) sources, emitted by livestock, waste treatment and wetlands, for example. When the methane is emitted, it causes additional warming (as methane is a more potent greenhouse gas than CO_2). Over time it decays back to CO_2 without adding to the concentration of CO_2 in the long term. Biogenic methane is emitted by livestock, waste treatment and wetlands, for example.

Fossil methane emissions return geological carbon to the atmosphere that has typically been stored underground for millions of years. Releasing this methane adds to the atmospheric concentration of CO_2 as well as causing additional warming as methane. The Climate Change Response Act aims to reduce our emissions of fossil methane together with other greenhouse gases, with the exception of biogenic methane, to net zero. Examples of fossil methane sources include coal mining, natural gas leakage and methanol production from natural gas.

Nitrous oxide has a lifetime between those of CO_2 and methane. In the context of achieving the temperature goals of the Paris Agreement, it can be considered a long-lived gas.

Methanogens – microorganisms that reside primarily in the rumen where they produce methane as a byproduct of metabolising hydrogen gas from fermentation. The methane is released into the atmosphere when the animal belches. While methanogens modify the fermentation process in the rumen, they are not thought to be essential to the animal.

New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) – funded by the New Zealand Government to invest in and coordinate research aimed at helping reduce New Zealand's agricultural greenhouse gas emissions.

pH – Literally 'potential of Hydrogen', pH is the scale used to specify the acidity or alkalinity of an aqueous solution. A value of 7 represents neutrality and lower numbers indicate increasing acidity and higher numbers increasing alkalinity.

Rumen – the large first compartment of the stomach of a ruminant animal in which fibrous plant feed is broken down by digestion and the action of symbiotic microorganisms. It has regular contractions to move food around for digestion, eliminate gases (including methane) through burps and send partly digested feed (the cud) back to the mouth for chewing.

Ruminant – large hooved, herbivorous grazing or browsing animals such as cows, sheep, goats and deer, that are able to acquire nutrients from plant-based food by fermenting in a specialised stomach (the rumen) prior to digestion.

APPENDIX 1

PGgRc Directors
PGGRC Board Governance

The PGGRC is an unincorporated joint venture that operates through Pastoral Greenhouse gas Research Limited as its agent company. Since 2002 PGgRc has had 39 directors and observers appointed to the Board from across the participant organisations along with four independents.

Organisation	Directors
AgResearch	Jim Ivens, Tricia Harris, Julian Lee, Mark Ward, Peter Benfell, Warren McNabb, Greg Murison, Trevor Stuthridge, Stuart Hall
Beef + Lamb NZ	Neil Clarke, Richard Templer, Max Kennedy, Leon Black, Andrew Morrison
DairyNZ	Peter Bodecker, Damian Diack, Rick Pridmore (Chair), Bruce Thorrold
Deer Industry New Zealand	MJ Loza, Mark O'Connor, Dan Coup, Innes Moffat
Fertiliser Association	Hilton Furness, Philip Mladenov
Fonterra	Mark Leslie (Chair), Janneke Van Wagtendonk, Darryn Pegram, Emma Blott, Mark Piper, Jeremy Hill (Chair)
Landcorp Farming	Collier Isaacs, Andrew MacPherson
PGG Wrightson Seeds	Warwick Green, John McKenzie, Paul Tocker, John Stewart, Damian Lynch

Independent Directors

David Hemara, Gavin Sheath, Emma Blott, Darryn Pegram

Observers

The Consortium has also operated with associate memberships from several crown-based entities, who have provided Observers to the board.

Organisation	Observer
Ministry of Business, Innovation and Employment MBIE	Robert Matheson, Seth Campbell, Sarah McDermot, Kenny Tsui, Colin Reid, Neil Dalphin, Helen Sillars, Marc Lubbers, Max Kennedy
Ministry for Primary Industries (MPI)	Mike Jebson, Gerald Rys
National Institute of Water and Atmospheric Research NIWA	Murray Poulter
New Zealand Agricultural Greenhouse Gas Research Centre NZAGRC	Harry Clark

APPENDIX 2

Domestic targets under the Climate Change Response (Zero Carbon) Act 2019

- Reduce net emissions of all greenhouse gases (except biogenic methane) to zero by 2050
- Reduce emissions of biogenic methane to 24–47 % below 2017 levels by 2050, including to 10 per cent below 2017 levels by 2030.

International targets

Every country needs to set a Nationally Determined Contribution (NDC) under the Paris Agreement outlining the contribution countries will take towards delivering on the goals of the Paris Agreement which are to:

- Keep the global average temperature well below 2° C above pre-industrial levels, while pursuing efforts to limit the temperature increase to 1.5° C
- Strengthen the ability of countries to deal with the impacts of climate change
- Make sure that financial flows support the development of low-carbon and climate-resilient economies.

New Zealand's first Nationally Determined Contribution (NDC1) was updated on 31 October 2021

- New 2030 target (2021-2030) sets a headline target of a 50 % reduction of net emissions below our gross 2005 level by 2030
- Previous target (2013-2020) - our net emissions will be 5 % below 1990 gross GHG levels for the period 1 January 2013 to 31 December 2020. This target is under the United Nations Framework Convention on Climate Change (UNFCCC).

Other agricultural sector initiatives

He Waka Eke Noa, the Primary Sector Climate Action Partnership, was formed in 2019 and provides a joint industry and government commitment for all farmers and growers to include the mitigation of GHG emissions and adaptation to climate change in their farm business and environment plans by 2025.

While developing some of the required component parts of a strategy to reduce GHG emissions in agriculture, the He Waka Eke Noa partnership is supporting farmers to estimate their own farms' emissions and develop farm plans and enhance understanding to reduce them.

The partnership also provides that farmers will be incentivised to take actions on climate change through the development of an appropriate pricing mechanism for emissions by 2025. This has been delivered to the Government in May 2022 for their consideration as an alternative to including agriculture in the ETS from 2025.

PGGRC patents

Application No.	Title	Granted countries (no. June 2022)
PCT/NZ2008/000248	Phage ϕ-mru polynucleotides and polypeptides and uses thereof (2007)	New Zealand, Australia, Canada, United States, Mexico, Argentina, Brazil, Chile, Uruguay, China, India, Japan, Russia, South Africa, Germany, Denmark, Spain, France, United Kingdom, Ireland, France (21)
PCT/NZ2008/000247	Cell-permeabilising peptides and polypeptides for microbial cells (2007)	New Zealand, Australia, Canada, United States, Mexico, Argentina, Brazil, Chile, Uruguay, China, India, Japan, South Africa, Germany, Denmark, Spain, France, United Kingdom, Ireland, France, Netherlands (22)
PCT/NZ2008/000249	Vaccines and vaccine components for inhibition of microbial cells (2007)	New Zealand, Australia, Canada, United States, Mexico, Argentina, Brazil, Chile, Uruguay, China, India, Japan, South Africa, Denmark, France, Germany, Ireland, Italy, Netherlands, Spain, United Kingdom (21)
PCT/NZ2010/000169	Complete genome sequence of the methanogen Methanobrevibacter ruminantium (2008)	New Zealand, Australia, Canada, United States, South Africa, (5)
PCT/NZ2018/050178	The use of acetylene derivatives in ruminants	Australia, New Zealand (National phase)
PCT/NZ2021/050199	Methanogen Inhibitors	International (PCT)
PCT/NZ2021/050200	Methanogen Inhibitors	International (PCT)
Provisional 789272	Methanogen Inhibitors	Provisional
Provisional 791492	Methanogen Inhibitors	Provisional

PGgRc publications and presentations

The investment by the PGgRc has resulted in more than 160 publications and presentations since 2013, contributing significantly to the broad knowledge required to reduce agricultural greenhouse gas emissions.

We thank all the scientists and technicians who have written and developed these outputs and enabled the understanding and knowledge for this research space to grow. We also acknowledge the NZAGRC and GRA for their funding in support with us in communicating this work.

These publications underpin the core methane mitigation approaches; Genetic selection, Low GHG feeds, methanogen inhibitors and methane vaccines, along with covering the broad field of ruminant emissions documenting fundamental knowledge development that has application for all mitigation studies.

The nature of scientific publication is such that this will be an ongoing output from the PGgRc as the long-term studies and data sets started within our investment are completed and drawn on for publication.

The consortium has always worked to support scientific publication and the discipline and factual accuracy that it brings, but we have also balanced this with the need to deliver cost-effective solutions to our farmers and engage commercial parties with a unique position to achieve that. This has delayed publication of the work we have undertaken in the inhibitor and vaccine areas; we expect that as these mitigations mature more relevant publications will be released. The full list of these publications is currently being collated and updated and will be inserted into this document upon completion and periodically then updated as other publications are released.

PGgRc®

PASTORAL GREENHOUSE GAS
RESEARCH CONSORTIUM

For more information about New Zealand's agricultural greenhouse gas emissions, contact us:

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