SCIENCE PLAN

2019 - 2025

NEW ZEALAND
AGRICULTURAL GREENHOUSE GAS
Research Centre

Contents

OVERVIEW AND PURPOSE

The New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) is a core component of the New Zealand Government's approach to understanding, managing and reducing greenhouse gases in agriculture. It was established in 2009 as a partnership between the leading New Zealand research providers[1] and the Pastoral Greenhouse Gas Research Consortium (PgGRc). It is a 'virtual' centre in that the research it funds is carried out by researchers working in their own organisations. It is hosted by AgResearch and has its main office on the AgResearch Grasslands Campus in Palmerston North and a smaller office in Wellington.

The Government is investing nearly $50 million over six years in science and related activities led or coordinated by the NZAGRC. This funding is provided by the Ministry for Primary Industries (MPI) and the Ministry for Business, Innovation and Employment (MBIE) under a Memorandum of Understanding, with MPI acting as the Contractor of the NZAGRC. MBIE's investment in the NZAGRC is provided as Strategic Science Investment Fund (Programmes) (SSIF) funding[2].

The table below shows the spread of that funding from 1 July 2019 to 30 June 2025:

	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	Total
MPI	$4.85m	$4.85m	$4.85m	$4.85m	$4.85m	$4.85m	**$29.1m**
MBIE	$4.85m	$4.85m	$4.85m	$4.85m	$0	$0	**$19.4m**
Total	**$9.7m**	**$9.7m**	**$9.7m**	**$9.7m**	**$4.85m**	**$4.85m**	**$48.5m**

This document presents the Science Plan for the NZAGRC for 2019-2025, detailing how the Government's budget will be invested. It should be read in conjunction with the NZAGRC's 2019-2025 Strategic and Business Plans. Together, these documents set the governance and direction for the NZAGRC's work over the next six years and how this will help support New Zealand's climate change efforts. For context on those ambitions, please refer to the Strategic Plan.

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[1] AgResearch, DairyNZ, Manaaki Whenua Landcare Research, Lincoln University, Massey University, NIWA, Plant & Food Research and Scion

[2] SSIF Programmes investment signals are outlined in the SSIF Investment Plan, available at https://www.mbie.govt.nz/assets/436ecb3be9/strategic-science-investment-fund-investment-plan.pdf

CO-DEVELOPMENT OF THE SCIENCE PLAN

The NZAGRC maintains an ongoing open, transparent and inclusive process for identifying and prioritising research investments. This 2019-2025 Science Plan was co-developed with leading international and New Zealand scientists, senior representatives from primary sector organisations and relevant Government departments, farmers and other key individuals.

It was also informed by:

- The previous prioritisation process developed as part of the NZAGRC's 2009-2019 Strategic and Science Plans
- An independent review of the NZAGRC that took place September-November 2018
- An open call to the New Zealand research community in October 2018 to submit ideas for future agricultural greenhouse gas research, which generated over 70 high-level proposals
- Discussion and refinement of those proposals with the NZAGRC's Science Leadership Team (six principal investigators)
- A two-day science planning workshop held in April 2019 to discuss potential priorities for NZAGRC investment emerging from the open call process. The workshop was attended by prominent New Zealand and international scientists, farmers, industry representatives and people from other funding organisations and programmes
- The design principles set out in the 2019-2020 Strategic Plan.

The Science Plan will be further developed by the NZAGRC's new Science Programme Advisory Group[3] (SPAG) and with input from the Māori Advisory Group once established. It will then be approved by the NZAGRC Governance Group. This will ensure that the final agreed science programme fully aligns with funders' expectations and the NZAGRC's goal, objectives and design principles.

CURRENT PROGRESS IN MITIGATION SOLUTIONS

Two reports[4] produced by the NZAGRC for the Biological Emissions Reference Group (BERG) provide the best data on the progress being made towards lowering agricultural greenhouse gas emissions. The reports assessed a range of current and under-development mitigation

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[3] The SPAG will comprise four representatives of the NZAGRC's member organisations (research institutions), two representatives from its Stakeholder Advisory Group (representing industry interests in the NZAGRC), the PGgRC Manager and a representative each from MPI and MBIE.

[4] The two reports are: (1) Reisinger, A., et al (2017) On-farm options to reduce agricultural GHG emissions in New Zealand. Report to the Biological Emissions Reference Group. *Ministry for Primary Industries*; and (2) Reisinger, A., et al (2018) Future options to reduce biological GHG emissions on-farm: critical assumptions and national-scale impact. Report to the Biological Emissions Reference Group. *Ministry for Primary Industries.* To access the reports, see here: https://www.mpi.govt.nz/protection-and-response/environment-and-natural-resources/biological-emissions-reference-group/

options for their ability to reduce greenhouse gas emissions from New Zealand farms. They looked at technical potential alongside system fit and likely uptake to arrive at an estimate of the national mitigation potential.

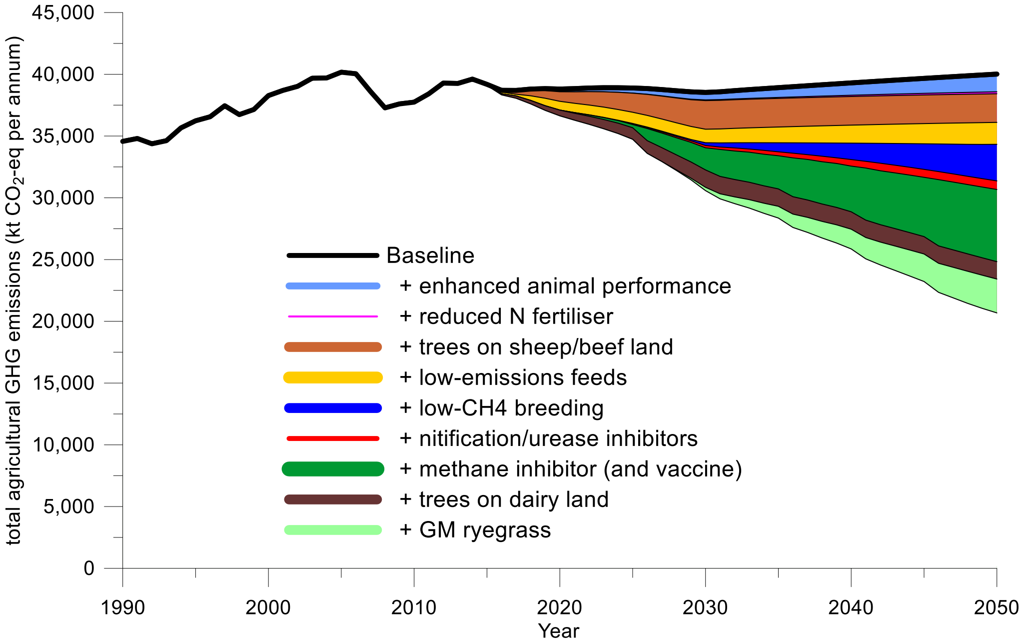
The reports evaluated the following individual mitigation options:

Approaches where the practices have already been shown to reduce emissions either by modelling or direct measurement	Approaches that are, in the main, actively being researched
Reduced N fertiliser use	Methane inhibitors
Increasing performance of individual animals	Methane vaccine
Enhanced manure management	Breeding low-emissions animals
De-intensification of dairy systems	Low-emissions feeds
Once-A-Day milking	Nitrification and urease inhibitors
Increased tree planting (without negatively affecting production)	
Removal of breeding beef cows	

The options were considered individually and in mitigation 'packages'.

Briefly, these reports suggested that greenhouse gas emissions from New Zealand's pastoral sector could be about 12-24% below 2005 levels by 2030, and 9-40% below 1990 levels by 2050 (see Figure 1). The wide range in potential outcomes resulted from different assumptions made about both efficacy and adoption rates of various mitigation options.

Figure 1. The contributions of different mitigation options to a comprehensive package of interventions with high assumed efficacy and adoption rates.



Within the overall packages of mitigations assessed for the BERG, increasing the uptake of current technologies (e.g. optimising productivity, reducing nitrogen fertiliser, improved manure management) resulted in small incremental gains. Other currently available mitigation approaches such as dairy de-intensification combined with once-a-day milking reduced emissions more significantly but were identified as carrying market challenges and potentially large economic and social risks for the country associated with such a transition. Planting more trees is already being incentivised and increased tree planting is already factored into future emissions forecasts. However, planting trees is a temporary rather than a permanent solution for reducing net greenhouse gas emissions.

The on-farm mitigation approaches that were identified in these reports as having the largest potential impact on agricultural greenhouse gas emissions were those still under development (e.g. methane inhibitors and vaccine, nitrification inhibitors, and GM ryegrass). Some of those options have proof of concept (e.g. methane inhibitor for feedlot animals), or proven benefits (e.g. nitrification inhibitors remain technically viable), while others are at various stages in development (GM ryegrass exists but its efficacy in actually reducing emissions has not yet been demonstrated; a methane vaccine is in development but has not yet demonstrated an effect in live animals). Bringing those options to market suitable for New Zealand farming systems will require further research investment with timelines to market of 5-20 years and uncertain end outcomes.

Without novel technologies, the overall potential to reduce biological greenhouse gas emissions on-farm is reduced substantially. Ongoing investment in science and commercialisation pathways to develop such mitigations is therefore critical if the agriculture sector is to contribute to more ambitious mitigation goals. The NZAGRC 2019-2025 Science

Plan focusses strongly on the need to continue the discovery and development of novel technologies.

To complement the search for novel technologies and respond to the need to reduce emissions as soon as possible, the Science Plan also includes investment in the identification, development and testing of mitigation approaches that can have more immediate impacts.

Further changes in farm systems will be required to achieve efficient mitigation. This will mean farmers will need to adapt as both the impacts of climate change and climate and other relevant policies become a reality. Research is therefore needed into modifying existing systems and the identification and testing of new approaches to land management and the development of new business models. Investment into extension will be required to assist farmers with these system changes.

Enhancing soil carbon storage is highly topical and an area of interest for many farmers. However, to date the current direction of change in soil carbon stocks within pastoral agriculture in New Zealand is poorly quantified and the identification of management practices that can reliably increase soil carbon stocks is proving to be elusive. Further investment is needed to identify and exploit the potential for enhancing soil carbon sinks.

INVESTMENT AREAS AND PRIORITIES

Overview

The investments outlined in this Science Plan are targeted towards achieving the NZAGRC's goals and objectives as set out in the 2019-2025 Strategic Plan. The underlying philosophy behind NZAGRC investments is the pursuit of high impact, excellent science. Broad stakeholder engagement and input, including partnering with and focussing on the needs of Iwi/Māori, are key elements of the investment prioritisation process. The Science Plan is not set in stone and will be evaluated frequently to ensure that the planned investments continue to meet the goals and objectives of the Strategic Plan.

Investments in 2019-2025 will build on the strong base already established in the 2009-2019 period. The most promising areas of work will continue to be supported and, where appropriate, investment increased to bring forward the date that solutions may be available. New areas of work will be advanced via a combination of filling identified gaps and/or building upon promising leads where existing research has identified mitigation potential.

The majority of the NZAGRC funding will be negotiated with New Zealand science providers using a 'best teams' approach to ensure excellent science, with teams being skills-based not institutionally-based.

Contract length will range from one to three years with all contracts being regularly reviewed to ensure that individual pieces of work remain relevant. Any major changes in direction to the science programme will be subject to broad consultation following a similar co-development process to that used to develop initial priorities. That is, broad consultation with stakeholders and scientists allied to a formal prioritisation process.

Competitive funding will be available. To ensure that new ideas and approaches are regularly identified, the NZAGRC will devote $1.5m per annum for three years to a competitive science fund. The first round will commence in 2020, with funding starting in the 2020/21 financial year. The NZAGRC already has considerable experience in running competitive science funding via its work for MPI to administer four rounds of the Global Partnerships in Livestock Emissions Research fund, established as part of New Zealand's support for the Global Research Alliance (GRA).

Briefly, the NZAGRC competitive fund will focus on new innovative approaches that need proof of concept. This may cover 'blue skies' approaches as well as potential practical solutions with sound theoretical underpinning. Maximum project length will be two years with maximum funding of $300,000 per annum. There will be a single stage application process and applications will be assessed by an independent science panel, the make-up being agreed between the NZAGRC Director, MPI and MBIE. Priorities will be discussed with the SPAG and the Stakeholder Advisory Group (STAG) and signed off by the Governance Group.

The NZAGRC will focus its science investment in six main areas:

- Methane (CH_4)
- Nitrous oxide (N_2O)
- Soil carbon
- Integrated solutions
- Outreach and policy support
- Supporting Māori aspirations

The remainder of this section gives more detail for each area of research investment for the NZAGRC over the next six years, outlining key topics and their order of priority. A common manipulating input: manipulating processes: modifying outputs framework was used to prioritise broad areas of work under the general headings of methane, nitrous oxide and soil carbon. Individual projects were then prioritised within these broad areas. The money available for investment means that research projects can be supported in all the areas assessed as high priority. In addition, some projects can be supported in some areas assessed as medium priority.

Methane

Methane arises from two principal sources in New Zealand agriculture. Enteric methane is produced by the digestion of feed by ruminant animals, and accounts for an estimated 97% of New Zealand agriculture's total agricultural methane output. The remaining 3% comes from stored or pasture-deposited animal wastes.

Methane research: prioritisation of research areas

Enteric methane

	Focus	*Description*	*Priority*
Manipulating inputs – fermentation substrate	Dietary amendment	Changing the chemical and physical composition of the diet, changing plant species and manipulating feeding patterns	Medium
Manipulating fermentation processes	Animal breeding & selection	Selecting animals with lower methane per unit of feed consumed	High
	Modifying gastro-intestinal fermentation	Manipulating hydrogen formation, alternative hydrogen sinks and digestive function	Medium
	Manipulating the gastro-intestinal microbial community	Inhibiting methanogens and manipulating interactions within the gastro-intestinal microbial community	High
Modifying outputs – capture & conversion	Biological & physio-chemical modification	Concentrating and capturing eructated methane, oxidising methane (e.g. in breath)	Low

Animal waste: prioritisation of research areas

	Focus	*Description*	*Priority*
Manipulating inputs – fermentation substrate	Pasture deposited wastes	Reduce quantity and change the quality of wastes deposited directly onto pastures	Low
	Collected and stored wastes	Change the quantity and quality of collected and stored wastes	Low
Manipulating fermentation processes	Manipulating fermentation processes in deposited and stored wastes	Inhibiting methanogens, changing anaerobic/aerobic balance, increasing methane yield or rate of production in stored wastes	Medium
Modifying outputs – capture and conversion	Biological & physio-chemical modification of stored wastes	Concentrating, capturing and oxidation processes	Medium

For more details on the methane programme, see pages 16-21.

Nitrous oxide

Agricultural nitrous oxide emissions arise from two primary sources: direct and indirect emissions from animal excreta (81%), and nitrogen (N) fertiliser application (15%).

Nitrous oxide: prioritisation of research areas

	Theme	*Description*	*Priority*
Manipulating N inputs	Plant breeding & selection	Reduce the quantity of N excreted by breeding/identifying forage plants with lower N concentrations. Breed/identify plants that change the partitioning of N excreta between dung & urine.	High
	Animal breeding & selection	Increase the efficiency of utilisation of ingested N by selecting for increased total N retention and/or increased N partitioning to dung or reduced urine N excretion.	Medium
	Dietary amendment	Manipulating animal diets through the inclusion of low protein feeds and/or additives which decrease the N concentration and volume in urine.	Low
	Fertiliser & effluent management	Optimise timing, rate and/or form of N fertiliser and effluent inputs to land	Medium
Manipulating N conversion processes	Plant management	Manipulate N absorption by roots, identify plants that produce natural N inhibitors and reduce nitrous oxide emitted directly by plants.	Medium
	Soil process management	Inhibiting urease hydrolysis, nitrification and denitrification, and reducing N leaching, ammonia volatilisation and the N_2O/N_2 ratio of denitrification products.	High
	Land management	Modify soil water management, cultivation and grazing management to influence nitrification/de-nitrification pathways.	Medium
Manipulating N_2O outputs	Atmospheric & soil chemistry	Increase the soil/atmospheric absorption capacity	Low

For more details on the nitrous oxide programme, see pages 21-23.

Soil carbon

Soil carbon storage on New Zealand grazed pastoral land is high, with 85% of the national carbon storage for all agricultural land uses (to a depth of 0.3m) managed by pastoral farmers. Therefore, pastoral soils are the predominant focus for protecting and increasing existing carbon storage.

Most New Zealand research so far has concentrated on quantifying the amount of carbon stored in soils for a given land use. Very little work has been undertaken on how to manipulate the rate at which it is stored within a given land use and, crucially, how the outcomes of any manipulations can be verified. The NZAGRC will address this neglected but critical area. In particular, the NZAGRC will examine the scope for the rate of soil carbon storage to be manipulated in soils that already have a high carbon content.

Soil carbon: prioritisation of research area

	Theme	*Description*	*Priority*
Manipulating inputs – carbon capture & supply	Changing management practices	Manipulating practices such as fertiliser regime, grazing management and tillage methods.	High
	Changing vegetation types/ characteristics within a land use	Manipulating above and below ground carbon allocation and the longevity of plant-derived carbon.	High
	Adding external carbon inputs	Applying carbon-rich amendments to increase the quantity of carbon stored in the soil, e.g. biochar.	Low
Manipulating processes – carbon transfer, incorporation & stability	Soil biology	Understanding the scope for, and manipulation of the functions of, the soil microbial community.	Medium
	Manipulating soil environment	Understanding the scope for, and manipulation of the functions of, the physical and chemical properties of the soil environment.	Medium
	Adding soil amendments	External inputs (e.g. biochar, allophanes, fertiliser, other materials) that both add stable carbon and influence processes to stabilise plant-derived carbon inputs	Medium
	Methods & models for evaluating changes in soil carbon stocks	Information and tools to calculate changes in rates of carbon storage across space and time.	High
Manipulating C outputs to atmosphere	Carbon stored in soils arises from carbon dioxide taken from the atmosphere and the practices outlined are aimed at increasing the stable carbon stored in soils, which reduces carbon outputs to the atmosphere.		

For more details on the soil carbon programme, see pages 24-26.

Integrated solutions

Farmers and growers manage complex farm systems and make daily decisions that can involve trade-offs between competing goals. This means it is essential to understand how interventions at any single point in the production process impact on other goals that a farm business might have, for example, the impact of a greenhouse gas mitigation activity on water quality or profitability. When considering changes to current systems and practices, as well as developing new ones that can achieve improved greenhouse gas mitigation outcomes, the total environmental, financial and social outcomes need to be considered. This is true not only for an individual business but for communities, catchments and New Zealand as a whole.

Regarding greenhouse gas emissions, initial modelling[5] suggests that there is scope on many farms to make modest reductions in both absolute emissions and emissions intensity using existing technologies and practices while maintaining or even increasing profitability. The joint Government/industry/Māori climate change partnership 'He Waka Eke Noa' is likely to have a strong interest in ensuring that identified current approaches to reducing emissions via the modification of existing systems are well tested and promoted. The NZAGRC will engage with He Waka Eke Noa as it evolves to understand how NZAGRC investments can support broader initiatives in this area (see also Outreach & Policy Support).

Increasingly stringent future greenhouse gas emissions-reduction targets, water quality targets, biodiversity obligations and the relative profitability of different enterprises mean that different farming models and mixes will need to be considered alongside modifications to existing systems.

The NZAGRC's integrated solutions research programme will explore the modification of existing New Zealand systems and the development of alternative systems that could involve a very different mix of enterprises and approaches. The programme will ensure that the full consequences of newly introduced technologies are assessed in an integrated manner so that any social, financial and environmental consequences are understood and quantified.

Given the broad nature of this work and the large number of potential stakeholders, the programme will be developed and conducted in partnership with other organisations. The first action will be a mapping of New Zealand's changing agri-food system environment followed by the facilitation of a strategic sector dialogue with key stakeholders to identify plausible sector futures. This 'Participatory Scenario Development' (PSD) with people from diverse backgrounds will allow the integration of different perspectives and knowledge in the co-development of a common vision of the future. This will guide subsequent research and development investments by the NZAGRC. NZAGRC research on integrated systems will focus on:

Farm systems: prioritisation of research areas

[5] https://www.mpi.govt.nz/protection-and-response/environment-and-natural-resources/biological-emissions-reference-group/

Theme	*Description*	*Priority*
Farm system analysis and design	Analyse current systems and practices and design/develop new and/or modified systems to help the primary sector meet changing social, economic and environmental challenges. Outcomes need to be considered at a range of scales.	High
System operation and demonstration	Conduct system experiments and undertake detailed system analysis to demonstrate the practical feasibility, bio-physical integrity and financial consequences of adapting current systems to make them lower greenhouse gas emitting and/or higher carbon accumulating.	Medium

For more details on the integrated systems programme, see page 27.

Supporting Māori aspirations

NZAGRC research with Iwi/Māori will build on previous and current programmes to develop farm systems and land use change options and to estimate the economic and environmental (greenhouse gas and nutrient emissions) impacts on Māori agri-businesses. The programme of work will be developed in partnership with the dedicated Maori Advisory Group once it is established. A key learning from the 2010-2019 programme was that given the often-multifaceted nature of Iwi/Māori agribusinesses, farm system changes need to be considered alongside land use change options to develop an integrated package of solutions.

Implementation of He Waka Eke Noa will also mean that there is an additional and immediate priority to help apply existing tools, models and processes to meet the requirements for Māori agri-businesses to have estimates of their greenhouse gas emissions at the farm scale (and farm plans for mitigation) by 2025.

The NZAGRC's programme will create a coalition of low-emissions Māori agri-businesses (building on the group of 30 that has been in operation since 2014) that benchmark low emissions systems using a range of indicators that align with on-farm systems and land use change scenario modelling. This is an opportunity to incorporate tikanga Māori, mātauranga Māori and ngā āhuatanga Māori. It is also an opportunity to showcase Māori agri-businesses as early adopters of sustainable climate-friendly practices and leaders in transitioning towards a high-value, low-emissions, circular bioeconomy. For more details on the Iwi/Māori programme, see page 28.

Outreach and policy support

Involvement in the promotion and adoption of mitigation technologies will be a key focus for the NZAGRC's science programme.

The He Waka Eke Noa partnership is designed to enable all farm businesses to account for their emissions at the individual farm scale by 2025 and to provide the tools and knowledge for farm businesses to reduce their emissions. It is therefore critical that knowledge generated from the NZAGRC's research programmes is communicated to farmers in a way that allows them to implement solutions in the specific context of their businesses.

Activities undertaken by the NZAGRC will be coordinated with existing and planned activities being undertaken by industry organisations (e.g. DairyNZ and Beef & Lamb), Government departments (e.g. MPI and MfE) and other science initiatives (e.g. Our Land and Water). Given the range of existing activities and organisations involved, the NZAGRC anticipates playing a supportive rather than leadership role. Initial priorities will be increasing the knowledge of rural professionals around climate change issues in general and in increasing their ability to work with their farmer clients to integrate and adopt low emission practices into their farm systems.

Between 2009-2019 the NZAGRC dedicated a small fund ($100,000 per annum) to supporting greenhouse gas policy development. For example, it funded work to identify how the greenhouse gas emissions routines in OVERSEER aligned with the routines used in the

National Greenhouse Gas Inventory. It also funded and led a study for BERG examining the potential future national impact of a range of mitigation practices and technologies. The mechanism for this policy work was that MPI and/or MfE identified priority projects, which were then recommended for funding to the NZAGRC Steering Group. This process will continue between 2019-2025.

For more details on the outreach and policy support programme, see page 29.

THE NZAGRC RESEARCH PROGRAMME - DETAILS

The Research Programme is a 'living' programme and will change as new discoveries are made and as new priorities emerge. It now contains a competitive fund and details of the research contracted await the outcome of the competitive process. The Research Programme will therefore be subject to continuous updating and full up to date details will be posted on the NZAGRC website.

The table below summarises the intended budget allocation across the NZAGRC's main areas of research, including the competitive funding component. *Note: these are indicative amounts only and may change during negotiation of the detailed milestones with different parties and providers.*

Not all funds are committed, especially in later years, as the research programme will be regularly reviewed and refreshed by the SPAG, with input from the MAG and STAG and informed by periodic review by the Science Review Panel.

Infrastructure spending (solely funded by MPI) will focus on increasing the capacity to measure methane emissions from cattle. This will be via the purchase of Greenfeed units for work on low-emitting cattle and the purchase of four additional respiration chambers for the National Methane Measurement Facility in Palmerston North. Capacity for measuring nitrous oxide emissions and carbon fluxes will be increased if funding allows. This will be committed in year 1 of the programme.

Co-funding will be sought from research providers for capital equipment purchases.

NZAGRC research funding by area and year

Area	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	Total
Methane	$1.3m	$2.7m	$2.7m	$2.7m	$1.1m	$1.1m	$11.6m
Nitrous oxide	$1.0m	$1.0m	$1.0m	$1.0m	$0.4m	$0.4m	$4.8m
Soil carbon	$1.6m	$1.4m	$1.4m	$1.4m	$0.6m	$0.6m	$7.0m
Integrated solutions	$0.6m	$0.9m	$0.9m	$0.9m	$0.4m	$0.4m	$4.1m

Iwi/Māori	$0.5m	$0.5m	$0.5m	$0.5m	$0.3m	$0.3m	$2.6m
Outreach & policy	$0.6m	$0.6m	$0.6m	$0.6m	$0.3m	$0.3m	$3m
Competitive fund	$0m	$1.5m	$1.5m	$1.5m	$1.0m	$1.0m	$6.5m
Infrastructure	$3m	$0m	$0m	$0m	$0m	$0m	$3m
Total	$8.6m	$8.6m	$8.6m	$8.6m	$4.1m	$4.1m	$42.6m

All figures are in New Zealand Dollars and are exclusive of GST. The years refer to a 1 July -30 June financial year. These figures refer to research spending only and exclude administration costs.

Methane

The PGgRc and the NZAGRC have invested nearly $6m annually in enteric methane mitigation research since 2013 and the PGgRc has a well-developed commercialisation plan for enteric methane mitigation technologies. The NZAGRC's methane programme is designed to build on this targeted and co-funded research programme to advance the discovery of cost-effective solutions within the framework of identified pathways to market. Since more than 90% of all agricultural methane emissions come from enteric fermentation, the research will concentrate almost exclusively on this.

The programme builds on work already undertaken to develop effective methane inhibitors and a methane vaccine and will extend the highly successful low methane emissions breeding programme to dairy cattle. It will support further nutritional work, focussed on obtaining more rigorous information from those feeds already identified as showing potential to reduce emissions.

Seaweed's potential for reducing methane emissions has received a large amount of publicity, but there are questions to be answered around the practicality and acceptability of feeding halogen-containing material to animals. Initial work is being funded from elsewhere (Government's budget for the GRA, MPI and Provincial Growth Fund) and the NZAGRC will keep a watching brief rather than invest.

Although small in comparison to reducing methane from enteric fermentation, reducing methane from animal wastes could provide an opportunity for livestock farmers (particularly dairy and pig farmers) to make immediate, albeit modest, emission reductions using proven and under-development technologies. The NZAGRC will invest in preparing updated information to allow farmers to make better informed decisions on the feasibility of implementing mitigation practices for waste management systems.

Feeding alternative forages to reduce enteric methane emissions

Indicative funding	$300,000/annum for two years, from 1 July 2019
Key questions	By how much does forage rape reduce methane emissions when fed only as a component of the diet? Does Plantain hold promise for reducing emissions of both methane and nitrous oxide?
Why is it a priority?	In the case of brassicas, the research will generate new knowledge and the understanding needed to support a case for brassicas to be recognised as a proven mitigation strategy in the New Zealand Greenhouse Gas Inventory. A single study indicated that a 30% inclusion of Plantain in the diets of cattle reduced methane emissions. Nitrous oxide studies suggest that a 30% inclusion of Plantain in a pasture can significantly reduce both N leaching and nitrous oxide emissions. More comprehensive data are urgently needed to confirm the promise shown by Plantain to reduce both methane and nitrous oxide emissions.
Approach	Forage rape fed consistently reduces methane emissions by approximately 30% when fed as a sole feed. However, in practice it is often fed with other feeds. A feed dilution approach is needed to generate data before concluding that this mitigation potential holds under practical feeding conditions. Similar information is needed for Plantain and a dilution approach is appropriate. This information will support and be linked to a broader industry and Government investment in the use of Plantain to reduce the environmental impacts of pastoral farming. Measurements will be made in respiration chambers where feed intake and methane can be measured with a high degree of accuracy.
Links	Links to MBIE's 'Forages for Reduced Nitrate Leaching' programme. Builds on past NZAGRC and PGgRc funded work on low emitting feeds.
Key personnel	David Pacheco & Arjan Jonker (AgResearch)

Breeding low methane-emitting dairy cattle

Indicative funding	$0.9 million per year (average) over 4 years, commencing 1 July 2019.
Key questions	Do dairy bulls exhibit phenotypic variation in methane emissions per kg of dry matter intake? How heritable is the trait? What are the best proxy measures to use in identifying low-emitting heifers and cows?
Why is it a priority?	The project work will significantly extend current knowledge of the cattle host genome's control over ruminant methane-producing processes. This project is primarily directed towards rapid industry adoption via traditional breeding methodologies and genomic selection. Previous NZAGRC and PGgRc research has developed low methane emitting sheep selection lines and selection for low emitting phenotypes is now being trialled by the industry. Breeding low emitting cattle is a logical next step.
Approach	The work proposed will focus on identifying low-emitting bulls already being tested for their general suitability as the next generation of dairy breeding bulls by LIC and CRV Ambreed. Traditional direct measurement of emissions will be undertaken when the bulls are 6-9 months old. Other work will continue existing New Zealand and international research on developing 'proxy' methods for identifying low-emitting cows and bulls. These methods are essential for the development of a full-scale national methane breeding programme where approximately 10,000 animals will need to be assessed for their methane emissions. The work will encompass microbial approaches as well as milk and blood markers. The existing high and low sheep selections lines will be maintained to assist in the search for rapid methane proxy measures. Links with bulls selected for low urinary area N excretion will be explored with CRV Ambreed.
Links	Builds on past PGgRc and NZAGRC sheep breeding programme, and several GRA projects including sheep microbiomes, Grass to Gas and cattle fermentation flagship.
Key personnel	Lorna McNaughton (LIC), Suzanne Rowe (AgResearch), Jane Kay (DairyNZ)

Novel delivery of methanogen-specific inhibitors

Indicative funding	3 years at $500,000/annum, commencing 2020/21
Key questions	Can endophytic fungi be genetically modified to consistently deliver proven small molecule methane inhibitors in the concentrations required for effective methane mitigation in grazing ruminants?
Why is it a priority?	Small molecule inhibitors have great potential to provide sustained and complete knockdown of methane emissions from ruminants. A key issue for New Zealand is how these types of compounds can be delivered to grazing ruminants in a manner that allows the full mitigation potential to be realised. Endophytic fungi infect all New Zealand pastures and if their biosynthetic pathways can be modified such that they produce inhibitory compounds, they could provide a low-cost method of delivering inhibitors to grazing ruminants. The system also has the potential to deliver other inhibitory compounds, for example, nitrous oxide inhibitors.
Approach	An existing New Zealand-funded GRA programme has delivered proof of concept that it is possible to bioengineer the biosynthetic pathways of a known methane inhibitor, lovastatin, into *E. Festucae*, a grass endophyte. The NZAGRC programme will continue to develop the bioengineering system initiated in the GRA programme (using the Victoria University patented DNA assembly technique MIDAS) so that it can produce other more potent inhibitory compounds at the desired concentrations.
Links	GRA project on endophytes
Key personnel	Emily Parker, Matt Nicholson (Victoria University); Sarah Kessans (University of Canterbury)

Development of an effective anti-methanogen vaccine

Indicative funding	$1,000,000 for 1 year[6], commencing 1 July 2020. Co-funded with PGgRc
Key questions	Are antibodies able to bind protein antigenic targets on the surface of methanogens? Do antibodies bind to methanogens in the rumen? Are cell wall components candidate antigens for a vaccine? Which protein antigens are expressed by methanogens in the rumen?
Why is this a priority?	An effective anti-methanogen vaccine holds the promise of being a universal solution as it has a large impact in terms of its efficacy, potentially infrequent administration and universal applicability across animal species. Laboratory proof of concept has already been established.
Approach	The development of an effective prototype vaccine that can change the rumen microbial population and/or reduce methane in the animal has so far proved elusive. On the other hand, in-vitro studies have demonstrated that antibodies produced by sheep in response to vaccination with specific antigens can reduce emissions in-vitro. An international think-tank was convened in December 2019 to help address this conundrum and examine whether a different approach is needed. The outcome of this think-tank was that the research was highly valuable and that the approach currently being adopted, the identification of best antigens and best adjuvants, was in general appropriate.
Links	Co-funded with PGgRc
Key personnel	Peter Janssen, Neil Wedlock & Axel Heiser (AgResearch)

[6] Funding after 2021 years dependent on progress to Proof of Concept

New approaches to reducing emissions from stored wastes

Indicative funding	1 year @ $100,000, commencing 2019/20
Key questions	Is it economic to invest in waste methane capture and conversion technologies in New Zealand? If not, are new technologies being developed that could change this?
Why is it a priority?	Although methane emissions from waste make up a small proportion of New Zealand's emissions, in many countries they are a major source of emissions and hence research investment. The technologies to reduce emissions already exist and research investment worldwide should ensure that they continue to be improved and become cheaper. A re-examination of current technologies is long overdue and although the potential for emission reductions in New Zealand is not high, they could provide an immediate route for small reductions in methane emissions.
Approach	This project will provide an update on the technical and economic potential of new approaches to reducing emissions from waste under New Zealand conditions and provide information to guide future research.
Links	TBC
Key personnel	TBC

Nitrous oxide

The NZAGRC will focus on two areas of work:

i. Continued development of effective and safe compounds that influence the rates of nitrification and denitrification
ii. Identification/testing of forage plants that by various mechanisms can reduce nitrous oxide emissions

In this part of the programme, the impact on N leaching will also be considered both as an issue in its own right and as a pathway for indirect losses of nitrous oxide. These two areas build on the existing NZAGRC programme and allied work funded by MPI with its GRA budget and can link with mitigations to reduce nitrate leaching into waterways. The forage plant work links directly to MBIE's 'Forages for reduced nitrate leaching'.

Testing, development and optimisation of a novel nitrous oxide inhibitor

Indicative funding	$400,000 for two years, commencing 1 July 2019
Key questions	How can the use or the formulation of a novel inhibitory compound be optimised to ensure increased effectiveness and longevity in the soil?
Why is this a priority?	The inhibitor DCD demonstrated that suppression of ammonia-oxidising bacteria in the soil can result in reduced emissions to both air and water. The withdrawal of DCD from the New Zealand market means that currently New Zealand farmers have limited scope to reduce nitrous oxide emissions from urine patches. Alternatives to DCD are under development in a NZ-GRA funded project but material from this work is not expected to be available for testing for 2-3 years. Independently, research funded by the NZAGRC has identified a potential novel inhibitor that in both field and laboratory trials has demonstrated similar efficacy to DCD. The short-term data needs include modes of action, further evidence of efficacy in the field and the impact upon N leaching. These have been identified as priorities to strengthen the existing patent application and to provide essential data for potential commercial partners. Longer-term data needs include effectiveness and longevity under a range of soil and environmental conditions. The advantage of this product is that it is already widely used for other purposes, is approved for use in both humans and animals, and has internationally agreed residue limits in food. The product identified by the NZAGRC will be the immediate focus of investment.
Approach	The performance of nitrification inhibitors is affected by soil and environmental conditions. A sound understanding of the quantitative relationships between microbial, soil and environmental factors and processes is critical to improving the performance of nitrification inhibitors. The effects of soil and environmental conditions on the performance of the novel nitrification inhibitors will be quantified. Recommendations for its use, based on climatic and/or soil parameters, will be tested at paddock and farm system level, including an assessment of the consequences of its long-term impacts on the environment, animal health and welfare and potential residues in animal products.
Links	MPI (e.g. Greenhouse Gas Inventory research, and work funded by SLMACC) and joint MPI (GRA)/Ravensdown-funded research
Key personnel	Paul Newton (AgResearch) and Surrinder Saggar (Manaaki-Whenua)

Low greenhouse gas plants and feeds: Identification, testing and mode of action of forage plants that can influence nitrification and denitrification process in soils.

Indicative funding	$600,000 per annum for two years, commencing 1 July 2019
Key questions	Is it possible that different plant species can influence the quantity of N excreted by grazing animals? Can different plant species change the partitioning of N between dung and urine in grazing ruminants? Can different plant species influence soil microbial processes such that emissions of nitrous oxide are reduced at the same level of soil N input?
Why is this a priority?	Nitrous oxide emissions in New Zealand are primarily driven by the quantity of N excreted by grazing ruminants. Work with tropical plants has demonstrated that some plants are able to influence nitrous oxide emissions by reducing the quantity of N excreted or by directly influencing soil N processes. Preliminary work in New Zealand has demonstrated that Plantain can influence soil and animal processes and reduce nitrous oxide and N leaching. This preliminary work needs to be confirmed.
Approach	The proposed research builds on an existing NZAGRC programme and links to comprehensive industry work on the role of plants in reducing N leaching. It will provide multi-year data on the ability of Plantain to consistently reduce nitrous oxide emissions from animal urine. Experimental approaches will include the effect of season, climate, sward age and Plantain proportion. Measurements will all be undertaken using small-scale chamber approaches.
Links	NZAGRC soil carbon paddock scale measurements; NZAGRC low methane plants, Greenhouse Gas Inventory research, SLMACC-funded research
Key personnel	Cecile de Klein & Jiaffa Luo (AgResearch); Keith Cameron & Hong Di (Lincoln University)

Soil carbon

The soil carbon programme will, for the first time in New Zealand, include a systematic long-term study designed to quantify to a given degree of accuracy the change in soil carbon stocks under different agricultural land uses over time. This will be supplemented by studies that will identify (through a combination of statistical modelling and empirical observations) the soils and their environments that have the greatest potential to increase soil carbon stocks. A third element of the programme will examine the scope for modified management practices to influence the quantity of carbon stored by New Zealand soils.

Identifying soils with the biggest potential to store more carbon

Indicative funding	1 year @ $200,000, commencing 1 July 2019
Key questions	How can we better identify the achievable carbon-stabilisation capacity of New Zealand pastoral soils?
Why is this a priority?	Not all soils have the potential to store more carbon. *A priori* identification of those soils having the most potential to store soil carbon allows efficient targeting of management practices that enhance soil carbon. An empirical model exists but needs verification across a wider range of soil types.
Approach	Test and verify that soils with a high saturation deficit have a greater capacity to stabilise new carbon inputs across a wide range of New Zealand soils. Develop a prototype farm scale mapping approach that relates soils and their properties to soil carbon sequestration potential and vulnerability to carbon loss.
Links	
Key personnel	Mike Beare, Denis Curtin, Jo Sharp (Plant & Food Research)

Quantifying the carbon currently stored in New Zealand soils and how it is changing over time

Indicative funding	$600,000 per annum for 4 years, commencing 1 July 2019
Key questions	At what rate are soil carbon stocks changing in New Zealand's agricultural soils?
Why is this a priority?	Storing additional carbon in soils provides a potential route for offsetting greenhouse gas emissions from agricultural activities. Data are lacking as to whether New Zealand agricultural soils are gaining or losing soil carbon.

	Given the multiple influences on soil carbon storage processes only a systematic long-term study will be able to provide these data.
Approach	Historic data have been used develop a sampling approach that will be able to detect a 2t/ha change for each of the broad agricultural land uses (cropland, horticulture, dairy, drystock on flat/rolling land and drystock in hill country) over samplings repeated at 3-4-year intervals. Total sample numbers are ~500. Samples will be taken by experienced teams using a standard methodology. All samples will be analysed in Manaaki Whenua's IANZ accredited laboratory.
Links	GRA-Soil sampling statistical modelling
Key personnel	Paul Mudge, Pierre Roudier, (Manaaki Whenua), Louis Schipper (University of Waikato)

Modelling changes in the rates of carbon under climate change

Indicative funding	2 years @ $300,000 per annum, commencing 1 July 2019
Key questions	How will climate change (increases in temperature, water and carbon dioxide) influence future soil carbon storage in pastoral soils?
Why is this a priority?	Soil carbon storage is strongly influenced by environmental variables. Future changes in carbon dioxide concentrations, temperature and rainfall regimes may drive changes in soil carbon storage that occur independently of management. The ability to better predict how changes in these environmental drivers will modify soil carbon stocks will be an essential first step in developing adaptive management practices.
Approach	A mix of empirical and modelling approaches will be used. Empirical studies will be undertaken using the unique FACE facility located at Flock House where the influence of temperature, water supply and elevated carbon dioxide can be studied separately and in combination. These data will be used to inform and improve a current grassland ecosystem model (Cen-W) that will be used to map potential soil carbon changes in New Zealand due to climate change.
Links	FACE research programme
Key personnel	Paul Newton, Mark Lieffering (AgResearch); Miko Kirshbaum (Manaaki Whenua)

Mitigation practices to enhance soil carbon and reduce nitrous oxide at the paddock scale

Indicative funding	$500,000 per annum for 3 years, commencing 1 July 2019
Key questions	Does the inclusion of Plantain into a ryegrass sward maintain or increase soil carbon stocks and decrease nitrous oxide emissions? What is the rate of recovery of soil carbon stock after pasture has been re-established on maize production site? What is the impact of irrigation on soil carbon stocks?
Why is this a priority?	There is evidence that Plantain reduces nitrous oxide emissions. We do not know the implications for soil carbon stock changes during the establishment and maintenance phases. Moving to low-N feeds such as maize can reduce nitrous oxide emissions but cropping in general results in losses of soil carbon. How does the length of the return to period between cropping and re-grassing influence the net carbon change over time? Irrigation can have both negative and positive impacts on soil carbon storage. Developing management practices that can maintain/increase soil carbon/nitrous oxide under irrigated pastures will bring mitigation and adaptation benefits.
Approach	Field measurements of carbon exchange and nitrous oxide emissions will be undertaken at Troughton Farm (Waikato) and Ashley Dene (Canterbury) using eddy-covariance approaches. The CenW model will be used to test scenarios of the long-term effects of irrigation management and grazing management on soil carbon stocks and test these against field observations.
Links	GRA soil carbon programme at Ashley Dene farm
Key personnel	Louis Schipper (University of Waikato), David Whitehead & Miko Kirshbaum (Manaaki Whenua)

Integrated solutions

Indicative funding	$750,000 average per year for two years commencing 1 July 2019
Key questions	How can existing farm systems best be modified to meet near-term greenhouse gas targets while maintaining profitability and meeting other environmental targets? What will future farming systems look like and what are the pathways needed to take them there?
Why is this a priority?	Farm systems are continually evolving to meet changing priorities. Addressing the climate change challenge will involve the identification of new technologies and practices and adoption and incorporation of these into existing farm systems. Farm systems of the future may look very different to those in place today due to the increased emphasis on environmental outcomes. Identifying and testing new approaches to land management is essential to understand how best to meet these outcomes.
Approach	Partnering with other entities/organisations will be at the core of this work. He Waka Eke Noa will be leading initiatives to prepare farmers for specific greenhouse gas mitigation obligations for the primary sector and the NZAGRC will work with this initiative to identify priority investment areas. A mapping and stakeholder consultation process will be used to decide priorities for investment in future farm systems.
Links	He Waka Eke Noa; Our Land and Water; MPI Sustainable Land Use Initiatives
Key personnel	TBC

Iwi/Māori research programme

Indicative Funding	3 years at $500,000 per annum commencing July 1 2019
Key questions	How can Iwi/Māori agri-businesses be supported to develop farm systems and land use change options that meet their economic, social, cultural and environmental outcomes?
Why is it a priority?	Iwi/Māori play an increasingly important role in the New Zealand primary sector and have made it clear they wish to be leaders in the search for more environmentally sustainable farming businesses. They also face special challenges with respect to climate change due to land ownership structures, decision making processes, access to capital and the multiple enterprises that often make up the farm business.
Approach	The NZAGRC programme will continue to work with representative iwi/Māori organisations to benchmark emissions from systems and to work individually with a sub-set of those benchmarked to identify new practices, land use changes, business opportunities and business models to deliver improved environmental, financial and social outcomes. Incorporating Māori knowledge, systems and cultural values (tikanga, mātauranga, ngā āhuatanga Māori) to underpin early adoption of sustainable climate friendly practices will be a focus; supporting Māori aspirations as leaders in transitioning towards a high value, low emission, circular bioeconomy. A key message from the past programme was that farm system changes need to be incorporated with land use change options to develop an integrated package of solutions.
Links	
Key personnel	Tanira Kingi (Scion); Phil Journeaux (AgFirst)

Outreach and policy support

Funding	$600,000 per annum commencing 1 July 2019
Key questions	How can the NZAGRC promote the uptake of practices and technologies that will reduce emissions of methane and nitrous oxide and increase soil carbon sequestration in the short and long term? How can the NZAGRC help develop evidence-informed policy?
Why is this a priority?	Knowledge of what steps need to be taken to start the primary sector on the road to lower emissions is recognised as being lacking across the industry. Reducing greenhouse gas emissions is not yet a routine component of integrated farm planning. Successful mitigation will depend on the identification of technologies and practices that reduce emissions and their successful adoption. The NZAGRC can provide critically needed support to broader industry initiatives to mainstream climate change thinking into general farm business planning.
Approach	Partnering with other entities/organisations will be at the core of this work. He Waka Eke Noa will be leading initiatives to prepare farmers for specific greenhouse gas mitigation obligations for the primary sector and the NZAGRC will work with this initiative to identify priority areas for support. MPI is also instigating and supporting sector initiatives to increase the capacity and capability of the sector to adopt lower-environmental impact farming practices. The NZAGRC will also support greenhouse gas policy development work as appropriate.
Links	He Waka Eke Noa; MPI Sustainable Land Use initiatives
Key personnel	Phil Journeaux (AgFirst); Laura Kearney (NZAGRC)

APPENDIX ONE: NZAGRC GOAL AND OBJECTIVES

As stated in the NZAGRC Strategic Plan 2019-2015, the NZAGRC's goal is to discover, develop and make available to New Zealand farmers and growers, products, tools and knowledge that enable the practical and cost-effective reduction of agricultural greenhouse gas emissions.

The strategic goal will be achieved through eight objectives:

1. Develop practices and technologies, and the knowledge and understanding to support future developments, that will contribute to New Zealand's 2030 and 2050 reduction targets for agricultural greenhouse gases
2. Quantify and increase the understanding of how management practices, climate and their interactions, influence soil carbon sequestration in New Zealand's agricultural soils
3. Contribute to Iwi/Māori aspirations to play a leading role in the transition to a low carbon economy
4. Be a trusted knowledge source and broker, facilitating the ongoing alignment of industry and Government funding, and securing additional resources both nationally and internationally
5. Enhance New Zealand's international reputation as a leader in agricultural greenhouse gas research by:
    i. funding an innovative research programme of international quality and standing; and
    ii. leading New Zealand's science input to the Global Research Alliance on Agricultural Greenhouse Gases (GRA)
6. Ensure that national greenhouse gas research, development and extension activities are well coordinated, developed with sector/stakeholder input and that progress in developing solutions is effectively communicated to the primary sector, Government and public
7. Enhance national capability and capacity, both human and infrastructure, to undertake agricultural greenhouse gas research, development and extension
8. Strengthen existing/build new collaborations with national and international organisations to increase the effectiveness of the NZAGRC's science programmes, Government investments in agricultural greenhouse gas mitigation, including the GRA programme, and Government-industry initiatives such as the PGgRc and He Waka Eke Noa.