OFFICE OF THE PRIME MINISTER'S CHIEF SCIENCE ADVISOR

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Chief Science Advisor

Mitigating agricultural greenhouse gas emissions: Strategies for meeting New Zealand's goals

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Dear Prime Minister

Attached please find my final report as your Chief Science Advisor. An executive summary has already been provided.

When we first met to discuss your priorities for my Office after you became Prime Minister, you asked me to report back on what the agricultural sector could do over the near and intermediate term to reduce its greenhouse gas emissions, so that New Zealand can track more effectively towards meeting its commitments under the Paris Agreement on climate action, and ultimately, the government's carbon-neutral goal.

New Zealand is seen internationally as an efficient producer of high quality food and will remain a major agricultural producer into the foreseeable future. However, maintaining agriculture's central role in our export economy will require the sector to be increasingly sympathetic to the environment. Part of that must include reducing its contributions to greenhouse gas (GHG) production, and this could be done over time probably without substantive impacts on productivity or economic returns. But doing so will likely require some complex trade-offs, consideration of new technologies, and significant changes in farming practice and land use.

In order to fully understand the landscape, my Office convened two large expert group meetings of governmental, farming and food sector stakeholders and have met with many experts from relevant sectors in smaller groups to discuss the opportunities and challenges in this complex area. My Office canvassed expert opinion on specific mitigation options and we have reviewed the scientific literature, including draft copies of analyses commissioned by the Biological Emissions Reference Group (BERG), a joint government and sector working group (due for public release in September 2018). I understand that the Productivity Commission, the Parliamentary Commissioner for the Environment and Interim Climate Change Committee (with whom I have met) will be providing Government with further evidence and/or advice on these and related issues in the future.

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My report aims to present a high-level perspective on what would be needed to achieve meaningful reductions in greenhouse gas emissions, and greater offsets, in the agricultural sector. It integrates the work of various research efforts in New Zealand and abroad, briefly reviews available on-farm mitigation options, highlights emerging opportunities, and identifies gaps in knowledge or other barriers that need to be overcome if agriculture is to be included in the New Zealand Emissions Trading Scheme (ETS), or any other policy mechanism.

The report's conclusions are driven by consideration of the highly variable nature of New Zealand geography, soil types, climate, and farming systems. This heterogeneity creates challenges for generalisation and identifying the best ways to proceed. There are actions that farmers can now take that will have some impact on GHG emissions, and some near-term technologies that could have further effect if further developed for and adopted into NZ farming systems. However, there is no current or foreseeable methodology that will provide an accurate measure of GHG emissions on an individual farm, nor of what any particular mitigation measure might achieve at a farm level. This has major implications for how to proceed.

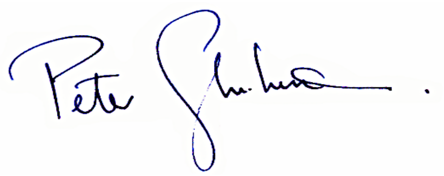
Emissions at an individual farm level can only be estimated through proxy measures using scientific models such as OVERSEER®, which is subject to some debate over its utility as a direct regulatory tool across a range of farm types, and has other issues that currently limit its usefulness. Taking these factors into account, one option that seems feasible is to use a 'farm plan' approach whereby a farmer, with expert advice and science-based input, identifies mitigation strategies he/she will be accountable for adhering to. Compliance or otherwise with an appropriate farm plan could extend to other dimensions of environmental management and to animal welfare and could be linked to any market or regulatory incentive scheme. Such an approach would require greater focus on the skillset of appropriately accredited farm advisors.

The report highlights where scientific and policy focus should be concentrated, and outlines actions in terms of farmer and industry practices as well as research and investment to speed up the development of the most promising abatement technologies and better quantification of GHG emissions. In some cases, issues of social acceptance and regulatory approvals will need to be addressed pre-emptively. It is likely that significant trade-offs will be required and there will be conflicting views: these should be acknowledged.

While I note the current consultation on a pathway to net zero carbon by 2050, the arguments for focusing on carbon dioxide and nitrous oxide and giving less emphasis to methane are in my view counter-productive, and this report does not favour avoiding a focus on methane, despite the challenges such a focus creates. It is unrealistic however to imagine that we can get to a GHG-neutral profile from agriculture without offsets in various forms.

I acknowledge Dr Anne Bardsley and Dr Stephen Goldson from my Office for their extensive contributions to this report.

Finally let me thank you for the strong support you have given me in my role as your science advisor.



PD Gluckman

Acknowledgments

Many people from a range of organisations helped to inform my Office's thinking on this complex subject. I am particularly grateful for the expert advice and input provided Harry Clark and Andy Reisinger at the NZAGRC, Cecile de Klein, John McEwan, Stewart Ledgard and colleagues at AgResearch, John Roche, Ian Ferguson, Gerald Rys and colleagues at MPI, Caroline Saunders at Lincoln University/AERU, Andrew Grant at McKinsey and co., Peter Millard at Manaaki Whenua-Landcare Research, Nick Pyke at the Foundation for Arable Research, John Caradus at Grasslanz® and Gavin Sheath (farm consultant) for input into various drafts and/or participation at expert meetings and discussions.

I am also grateful for discussions and input from the following organisations:

Ministry for the Environment
Parliamentary Commissioner for the Environment
Fonterra
DairyNZ
Beef+Lamb NZ
OVERSEER®
Federated Farmers

Abbreviations

BERG	Biological Emissions Reference Group
CH_4	methane
CO_2	carbon dioxide
DCD	di-cyandiamide
DMPP	3,4-dimethypyrazole phosphate
ETS	emissions trading scheme
GE	gene editing
GHG	greenhouse gas
GM	genetic modification
GMP	Good Management Practice
GWP	global warming potential
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
N	nitrogen
N_2O	nitrous oxide
3NOP	3-nitrooxypropanol
NZAGRC	New Zealand Agricultural Greenhouse Gas Research Centre
OH	hydroxyl radical
P	phosphorus
PFSI	Permanent Forest Sinks Initiative
PGgRc	Pastoral Greenhouse Gas Research Consortium
PKE	palm kernel extract
SLUI	Sustainable Land Use Initiative

Mitigating agricultural greenhouse gas emissions: Strategies for meeting New Zealand's goals

Executive Summary

New Zealand is in a position to lead the world in dealing with greenhouse gas (GHG) emissions from agriculture; this is based on our acknowledged expertise in agricultural and climate science, and our commitment and responsibility to act. The New Zealand agricultural sector is already world-leading in terms of the high-value, high-quality products it generates, and it supports a thriving economy. But emissions from this sector also dominate New Zealand's total emissions profile, and reducing them is important to meet both our international targets and our own goals as a nation.

We face some unique challenges. In contrast to the power and transport sectors, agriculture has fewer options to make large emissions reductions quickly and cost-effectively. Obligating farmers to reduce their emissions should not impose a disproportionate burden on them relative to their international competitors, nor relative to other sectors within New Zealand. There are no zero-emission strategies for biological GHGs, yet there are many reasons to act aggressively to reduce their emissions. This goes beyond arguments of short-lived versus long-lived gases; there are also strong market and reputational reasons for driving down agricultural emissions while making farms more efficient and sustainable.

Methane and nitrous oxide are the main GHG emissions occurring on farms. Methane, derived mainly from enteric fermentation in ruminant livestock, is a short-lived gas, but one that has contributed most to the sector's increasing emissions since 1990. Although methane does not accumulate in the atmosphere like CO_2 does, it has potent effects on near-term warming, and this potency increases with increasing rates of methane emissions over time. While noting that methane emissions from agriculture cannot, and need not be, reduced to zero, reducing global methane emissions quickly will impact the peak warming temperature and the rate at which CO_2 emissions need to be reduced. The metrics used to account for the different gases are important, particularly if biological GHGs are to be included in the ETS or similar mechanism at any level, as different metrics have implications for carbon, nitrous oxide and methane budgets.

Strategies exist now that can help reduce biological GHGs, but currently, individual strategies are only expected to have modest effects on total emissions reduction, and there are trade-offs between possible options that will require careful consideration at an individual farm situation.

The main strategies relate to:

- On-farm land-use decisions that reduce GHG emissions per unit of land area or increase carbon sinks – including forestry and other tree plantings, and horticulture blocks.
- Feeding practices, grazing and pasture management – including forage selection and the balance between stocking rates per hectare and individual performance per animal.
- Animal husbandry including breeding for high genetic merit in terms of breeding, productivity and emissions profiles.
- Animal housing and effluent management
- Precision-farming techniques – including irrigation and fertiliser management

Gains in the near-term will occur if best-practice management strategies and sustainable farming initiatives are widely adopted across the sector, and farms are managed adaptively so that new technologies can be incorporated as they become available. To ensure widespread improvements, the agricultural sector needs a system-wide approach to climate-mitigation advisory functions and the development of comprehensive, whole-farm plans which link GHG reduction to farm business, environmental/conservation and other objectives in a consistent and auditable format for reporting purposes.

Accounting for GHG emissions at the farm level is not currently supported by practical tools that farmers can use to make confident decisions about mitigation activities that in turn can be linked to fiscal incentives. Modelling-based tools such as OVERSEER® can support the development of comprehensive farm plans, but the complexity of OVERSEER® in particular raises questions about its suitability for use in the direct regulation of GHG emissions at an individual farm level across a broad range of farm systems.

It is clear that apart from substantial land-use change, reducing livestock numbers and afforestation, the main opportunities to reduce emissions significantly will depend on technological innovations; for example the development of market-acceptable nitrification inhibitors, and to rumen methane inhibitors such as 3NOP for use in pastoral systems. Developing a methanogen-inhibiting vaccine holds theoretical promise for reducing methane emissions across all ruminant livestock systems but no proof-of-concept in animals yet exists.

A mission-led approach to research will continue to be needed. Social science research is also required to understand how best to encourage early adopters and to enhance uptake of effective strategies across the sector. For the longer term, unravelling the regulatory and social licence issues around the use of new and evolving technologies will be critical for continuing scientific advancement as part of the national effort to reduce New Zealand's largest sources of GHGs.

Despite the many scientific, economic and implementation challenges, failure to take actions within the agricultural sector will not only be costly to those farmers who find themselves unprepared for change, it will also ultimately be costly to New Zealand.

Introduction – New Zealand's climate goals

The requirement to reduce greenhouse gas (GHG) emissions and the international goals to ensure their abatement are well known. On a global scale New Zealand's greenhouse gas (GHG) emissions are small, but combined with those of other small countries they make up 30% of total global emissions. Our responsibility to act is clear.

New Zealand's commitments under the Paris Agreement – to reduce absolute GHG emissions by 30 percent below 2005 levels – are driven not only by an onus of responsibility for our part in the increasingly urgent global problem of climate change, but also by what is good for New Zealand and its people. This includes our reputation as a food producing, trading and tourism-focused nation, and the value our markets place on our natural environment and the high-quality products it allows us to generate. My previous report[1] highlighted the many impacts that climate change will have on New Zealand.

In setting its targets, the New Zealand Government is strongly focused on reducing domestic emissions, and it acknowledges that significant action across multiple sectors of the economy will be required to achieve them. This is particularly true if we are to reach the declared 2050 target of becoming carbon-neutral. However, pastoral food production in isolation will always generate GHGs, and offsets in other components of the economy will always be needed.

While the science is clear about the need to reduce CO_2 emissions globally in order to limit global warming to below 2°C above pre-industrial levels, there is some debate about how aggressively we need to act to mitigate other GHG emissions, particularly methane (CH_4) emissions, to achieve this goal. This issue is particularly critical to New Zealand, because of how significant non-CO_2 gases are to our GHG emissions profile. Biological emissions from agriculture make up about 50% of New Zealand's total emissions, and 76% of these are CH_4 from enteric fermentation in ruminant livestock. The remainder comprises nitrous oxide (N_2O) emissions from soil as a result of the deposition of animal urine and manure, and synthetic fertiliser use. Globally, agricultural emissions represent over 20% of greenhouse gas emissions.

If we are to reduce our total domestic emissions, we must address emissions from all sources including biological emissions from agriculture, and this is not an easy task.

New Zealand farm trends impacting emissions

Pastoral farming in New Zealand began to significantly intensify in the 1990s, with the increasing use of nitrogen (N) fertiliser and irrigation to support high-yielding ryegrass pastures that allowed more intensive grazing. This allowed for an increase in the number of animals per hectare, which combined with improved animal genetics and breeding resulted

[1] New Zealand's changing climate and oceans: The impact of human activity and implications for the future. Office of the PMCSA, July 2013. http://www.pmcsa.org.nz/wp-content/uploads/New-Zealands-Changing-Climate-and-Oceans-report.pdf

in higher production of milk per cow in the dairy sector, and an increase in lambing rates and carcase weights in the sheep and beef sector. The drivers for this have been increased inputs of feed, fertiliser and water, improved animal genetics and animal husbandry, and an increased focus on individual animal performance.

One result of the increased fertiliser use and livestock numbers[2] has been a rise in New Zealand's total N_2O and CH_4 emissions. Over recent decades, continuous improvements in farm practices, genetic improvements, and the use of higher quality feeds and supplements have led to progressive increases in livestock productivity and reduced emissions per animal and per unit product (~1% per year), though absolute emissions rose as the increase in product output was larger than the decrease in emissions per unit of product. Droughts in 2008, 2013 and 2015-16 reduced agricultural production and emissions, such that total emissions in 2016 were 12% above 1990 levels, down from a peak of ~16% in 2006. It is estimated that gross emissions would have risen by 40% from 1990 levels if productivity improvements had not occurred.

The increase in dairy cow numbers were driven by expanded land-use for dairy farming in response to economic incentives that made dairy production a more profitable use of land previously used for other agriculture or forestry. To sustain production on either side of peak grass growth, the use high-energy of supplements and in particular with imported palm kernel extract (PKE)[3] become the norm. Because there is a direct relationship between metabolisable energy in feeds and ruminant CH_4 production, the use of such supplements raised emissions both on-farm (from livestock consumption of the feed) and off-farm from its production and transport (including emissions occurring off-shore). The increased use of nitrogen fertilisers also had a significant impact on N_2O emissions as well as nitrogen leaching and water quality in some areas.

Although dairy cow numbers have risen, there has been overall a trend of decreasing ruminant stock numbers generally, with an estimated decrease of 9% in total stock units between 2007 and 2017. There has been a dramatic drop in the total number of sheep - from 57.9 million in 1990-91 to 27.6 million in 2016-17 (-55%), while total lamb production decreased by only 8% because of increased reproductive performance. Emissions from both sheep and beef systems have been decreasing overall, but this has been mostly offset by the rise in dairy cow numbers, which drove up total emissions from agriculture until recently, when the fall in sheep emissions began to outstrip the rise in dairy emissions.[4]

Enteric CH_4 and N_2O from dairy, sheep, beef and deer livestock systems contribute over 90% of the total biological GHG emissions in New Zealand. Pastoral agriculture also

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[2] Since 1990 there has been a 600% increase in the use of N fertiliser and a 92% increase in the dairy herd population (Ministry for the Environment, 2017)

[3] Palm Kernel Extract (PKE), the most common supplement, is imported from overseas and is used particularly at the beginning and end of the season as the grass growth cycle is temperature dependent and does not match the potential of the lactational cycle.

[4] According to the latest NZ Inventory data, there was a drop in gross emissions from agriculture between 2014 and 2016 stemming from a substantial drop in sheep numbers. There was also a sizeable drop in emissions between 2006 and 2008. (Ministry for the Environment, 2017)

competes for land use with forestry, which serves as a carbon sink, thereby reducing our local CO_2-offsetting potential. Arable farming and horticulture are much less GHG intensive than pastoral farming, and therefore represent an emissions-reducing alternative land use within the primary sector, including as a diversification strategy within a livestock farm enterprise (see below).

New Zealand's unique challenge

In considering the best way forward, we must first recognise the New Zealand socioeconomic context, in which questions have been raised about how large a role pastoral agriculture should play in GHG emissions reduction. This is clearly an issue of great concern to New Zealand, where agriculture and other primary exports ($23 billion per annum) underpin the economy that supports the general wellbeing of its citizens. The debate, to a large extent, centres around whether methane, a short-lived gas that is the largest source of agricultural emissions, should be treated differently to long-lived gases (and CO_2 in particular). The Government's recent consultation on proposals for a Zero Carbon Bill has highlighted this question, outlining options for which gases should be targeted for the 'net-zero by 2050' goal. This consultation is occurring in the absence of robust, easily accessible information to inform the public debate on such a complex matter. It is important to understand the differences between these gases, and what they mean for climate change projections and mitigation options.

Achieving 'Zero Carbon'

The proposed Zero Carbon Bill is modelled on the UK Climate Change Act 2008. While indicating a strong focus on domestic emissions reductions, the options outlined in the consultation document suggest there are choices regarding how to achieve the goals it sets out by placing varying emphasis on different types of emissions. However, the choices we face are much more difficult than in the UK, where some large reductions were made relatively easily and promptly by moving the power generation sector away from coal to natural gas and to greater use of nuclear power. New Zealand's energy sector, by contrast, is already significantly decarbonised. Transport dominates the emissions profile for fossil fuel use and plans to transition towards low-carbon transport systems (e.g. electric vehicles) are beginning to be implemented. Reductions in emissions from these sectors will only touch on at most half of New Zealand's gross emissions – the remainder are biological emissions from agriculture, where fewer effective mitigation options are available.

Questions remain as to the optimal approach for Carbon Zero, considering our unique emissions profile. The intent is to set out clear targets for reduction of each type of emission through legislation so as to provide the long-term policy certainty to help drive mitigation actions as required across all sectors of the economy. This in turn will assist New Zealand to meet its domestic and international climate change goals, and enhance New Zealanders' long-term wellbeing.

The impacts of different greenhouse gases

The main anthropogenic GHGs are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), all of which warm the earth by absorbing radiant energy and insulating the planet from heat loss back into space. There are large differences in physical properties of these different GHGs in terms of their ability to absorb energy and how long they stay in the atmosphere. To allow comparison between gases with different atmospheric properties, several metrics have been developed, the most widely use of which is the global warming potential (GWP). However, because the climate impacts of these gases occur over very different time scales, the task of quantifying their individual contributions to cumulative warming via any single metric is problematic, and thus designing a policy response is not straightforward.[5]

CO_2 is a long-lived gas, meaning it accumulates in the atmosphere and takes centuries to dissipate, thus it will continue to warm the atmosphere long into the future. Methane is a short-lived gas, dissipating after about a decade, but it absorbs more energy and thus warms the atmosphere more effectively than CO_2. For international reporting purposes, the GWP for methane is 28-34 times higher than CO_2 over a 100-year timeframe. However, this GWP has changed over time and is likely to increase in the future, because as methane increases as a proportion of total atmospheric GHGs it is also removed more slowly thus allowing it to continue to warm the planet for longer.

N_2O is both potent and long-lived, remaining in the atmosphere with a half-life of around 110 years. Its GWP over 100 years is 265-298 times higher than CO_2, meaning it has both short- and long-term warming effects.

Stocks and flows

Long-lived gases like CO_2 and short-lived gases like methane have been referred to as ‘stock’ and ‘flow’ pollutants, respectively. For CO_2, because it breaks down very slowly in the atmosphere, each unit of current emissions adds to previous emissions and thus the amount of warming depends on the cumulative emissions over many centuries (the ‘stock’ of emissions in the atmosphere). For methane, because it breaks down rapidly, each unit of current emissions will be offset to some extent by the breakdown of previous emissions. Thus, the more important predictor of its warming effect is the flow of emissions over any given time period[6].

However, describing methane as a ‘flow pollutant’ does not imply that it moves through the atmosphere without causing permanent climate effects, though the effects are different from those of CO_2. Methane is a very potent warming agent in the short term, so it is contributing significantly to current warming trends. Any sustained emissions of methane will continue to contribute to warming, but reducing emissions will rapidly reduce the contribution to further warming. In addition, methane breakdown in the atmosphere leads

[5] The issue of metrics and how the different gases should be compared is an area of active investigation by a number of groups, and we understand that further evidence and advice on this matter may soon be forthcoming from the Parliamentary Commissioner for the Environment, the Productivity Commission, and the Interim Climate Change Committee.

[6] See Allen et al. (2018). *A solution to the misrepresentations of CO2-equivalent emissions of short-lived climate pollutants under ambitious mitigation*. npj Climate and Atmospheric Science, 1, article 16.

to the formation of ozone (O_3) – itself a GHG – so mitigations aimed at methane can reduce near-term warming caused by both of these gases.

The pattern of current and future methane production has implications for the speed at which CO_2 must be eliminated in order to control the peak global atmospheric temperature, which in turn has global policy implications.

Limiting peak warming

Halting the accumulation of CO_2 in the atmosphere is key to stabilising Earth's rising mean surface temperature. The sooner this occurs, the lower the cumulative amount of CO_2 that will remain in the atmosphere, and thus the lower the 'peak warming' temperature will be. Limiting peak warming to less than 2°C will require CO_2 emissions to reach net-zero by mid-century. A draft of the latest Intergovernmental Panel on Climate Change (IPCC) report[7], however, explores pathways to limit peak warming to 1.5°C to avoid the most harmful impacts of climate change. This draft report indicates that pathways consistent with 1.5°C warming will require not only rapid reductions in net global CO_2 emissions, but also rapid reductions in other gases, particularly methane (from all anthropogenic sources).

For short-lived gases like methane the annual rate of their emissions leading up to the time of peak warming is more important than their cumulative emissions. Greater reductions in the next two decades offer a higher chance of limiting warming to 1.5°C. As with CO_2, human activities, particularly ruminant farming and rice production, are currently increasing the methane concentration in the atmosphere faster than natural sinks can offset it. As more methane is added to the atmosphere, the warming problem increases (at least in the short term). The chemistry of methane in the atmosphere is such that as it builds up it creates a feedback loop that slows down its removal by hydroxyl radicals (OH). This means that over time, if the rate of methane emissions increase, methane removal will slow down and its long-term warming potency will increase. Reducing methane both delays and reduces the peak warming temperature. The delay will allow more time to bring direct CO_2 emissions to net zero.

Another important GHG for the New Zealand agricultural sector is N_2O, primarily generated from livestock urine and faeces (>80%) and by the application of nitrogen (N) fertilisers. Some have argued that N_2O makes only a small contribution to atmospheric warming, because its concentration in the atmosphere is relatively low. But because N_2O is an extremely potent GHG and is long-lived in the atmosphere, it makes a significant contribution to the overall greenhouse gas effect. Activities on farms that reduce N_2O emissions also help with reducing nitrate leaching into waterways, so such efforts provide significant co-benefits for the environment.

All options for a 2050 target that include reducing biological emissions from agriculture, and particularly the ambitious target of reaching net-zero emissions for all gases, will require transformation and innovation in the agricultural sector. Non-climate drivers such

[7] Intergovernmental Panel on Climate Change (2018) First Order Draft - IPCC Special Report on Global Warming of 1.5C: Summary for Policymakers - Document for Expert and Govt Review.

as water quality and supply regulations, and changes in consumer demand will likely also have an impact on what can be achieved. The reality is that there are no 'zero emissions' technologies available for pastoral agriculture, so eliminating these emissions completely is not feasible, but reductions are both possible and consequential. This prospect is challenging, but must be pursued.

Market forces and reputational issues

Beyond these biophysical reasons for addressing methane and nitrous oxide emissions, there are sound market and reputational reasons for doing so. A serious effort to reduce both methane and nitrous oxide will not only contribute to New Zealand's climate goals but will provide multiple co-benefits for the environment, our trading reputation, and the economy as we take a leading role in practicing climate-smart agriculture. There is already some evidence of growing consumer resistance in some sectors of global society to ruminant-based products, in part because of concerns about their impact on climate change.

There is a growing market for products that can be verified as having a low-emissions footprint, upon which New Zealand's agricultural exports can capitalise. Recognising this potential benefit on marketability, Beef + Lamb NZ (B+LNZ) is aiming for carbon neutrality for its products, and Fonterra is similarly encouraging the use of Life Cycle Assessment (LCA) methodology[8] to consider the full pre-farm and on-farm carbon lifecycle of products, from 'cradle-to-farm gate'.

The benefit of the LCA approach is that it enables a more complete picture of the emissions impact of agricultural production, and can support requests for product environmental transparency. In this regard, B+LNZ has recently unveiled its new 'Taste Pure Nature' brand trade mark,[9] underpinned by the New Zealand Farm Assurance Programme for red meat products that includes assurances of origin, traceability, biosecurity, environmental sustainability and animal health and welfare. This currently does not, but could, incorporate GHG mitigations.

Internationally, customers are looking for verification of sustainable production. This requires a method of quality assurance for sustainable farming outcomes including minimising GHG emissions, improving water quality, good soil management, enhancing biodiversity, promoting animal welfare, fair trade, etc. From a farm systems viewpoint, emissions data should be collected as one component of the full impact assessment for the farming operation. The sustainability performance of farms can be demonstrated by undertaking validated initiatives ('actions-based' measures) and/or directly measuring

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[8] The Life Cycle Assessment (LCA) approach accounts for all direct and embodied GHG emissions up to the point that a product is ready to leave the farm for processing - encouraging adoption of mitigation options vs market-divers such as GHG footprint of products. LCA is a recognised methodological framework for assessing the environmental impact of products and processes, and can be used as a decision-support tool for environmental management.

[9] To use this trademark in global markets, farms must first apply to B+LNZ for a licence. https://beeflambnz.com/news-views/beef-lamb-new-zealand-unveils-new-origin-brand

environmental outcomes ('results-based' measures) that are independently audited and certified. (e.g. 'Origin Green' in Ireland[10] and Australia's Carbon Farming Initiative[11]).

As food traceability becomes more sophisticated and trackable to an individual farm, this will have significant market implications for New Zealand's farmers and export trade. At present, New Zealand's scheme for electronic identification and tracking of livestock (National Animal Identification and Traceability [NAIT])[12] is used primarily for biosecurity purposes, but there is potential to extend it with other marker technologies including blockchain to reach into the market and the consumer, which will become important as the demand for safe and environmentally sustainable food increases.

What can farmers do to reduce agricultural emissions?

Finding ways to reduce biological GHG emissions from agriculture has been an area of significant focus for the New Zealand research community. Work is well underway to build the evidence base on what can be done at the farm scale, and the costs and opportunities of different options. This research is largely being undertaken by the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC)[13] and the Pastoral Greenhouse Gas Research Consortium (PGgRc).[14] New Zealand is also investing in a major domestic research programme to improve animal productivity, which results in lower agricultural emissions per unit of food produced. Internationally, New Zealand is the founder, secretariat, and a leading member of the Global Research Alliance on Agricultural Greenhouse Gases.[15]

The Biological Emissions Reference Group (BERG)[16] will be releasing the findings from research it has commissioned in a report in later this year. I am grateful for their provision

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[10] The Origin Green sustainability programme (https://www.origingreen.ie/) farm assessments provide farmers with bespoke feedback to help identify and implement actions to achieve cost savings and environmental gains, including calculating and reducing carbon emissions and identifying carbon hotspots and opportunities for efficiency improvement.

[11] The Carbon Farming Initiative (CFI) allows farmers and land managers to earn carbon credits by storing carbon or reducing greenhouse gas emissions on the land. These credits can then be sold to people and businesses wishing to offset their emissions. Under the CFI, they may be able to earn carbon credits from activities such as: reducing livestock emissions; increasing efficiency of fertiliser use; enhancing carbon in agricultural soil; and storing carbon through revegetation and reforestation.

[12] National Identification and Traceabiliy (NAIT) http://www.nait.co.nz/about-us/

[13] The NZAGRC is funded by the Ministry for Primary Industries, via the Primary Growth Partnership

[14] The PGgRc is jointly funded by the Ministry for Business, Innovation and Employment and various agriculture sector organisations.

[15] The Global Research Alliance (https://globalresearchalliance.org/) comprises 50 member countries from across the globe. It aims to strengthen and expand mitigation research efforts across agricultural subsectors and develop breakthrough solutions through knowledge sharing.

[16] The BERG is a joint government and sector working group comprising the following members:
Beef + Lamb New Zealand •DairyNZ Limited • Deer Industry New Zealand • Federated Farmers of New Zealand • The Fertiliser Association of New Zealand • Fonterra • Horticulture New Zealand • Ministry for Primary Industries • Ministry for the Environment

of their draft analysis to my Office. Their report will include findings on various topics, including:

- what mitigations can be implemented on-farm now, and in the future;
- what is the potential for land-use change as a mitigation measure for climate change, and the potential implications of this;
- what drives farmer decision-making in relation to climate change; and
- the costs and barriers of possible policy options to reduce biological emissions from agriculture (including options for pricing biological emissions from agriculture via the NZ Emissions Trading Scheme (NZ ETS).

These various efforts are producing some promising but limited answers, and many questions remain.

Although some mitigation strategies based on existing technologies can be implemented immediately, their potential to significantly impact New Zealand's emissions profile is not certain and will depend on complex biophysical, environmental and social interactions that need to be better understood in the context of individual farms. New Zealand farms are highly variable in terms of landscape, land use, soil characteristics, tree cover, forages, livestock mix and farm management systems. Livestock farms are particularly complex systems with multiple interacting components, and determining the best approaches to reduce GHG emissions will depend on the specific local conditions and objectives of each individual farm. A whole-system view is needed, but one that considers the particularities of the farm in question.

Modelling commissioned by the BERG suggests currently available farm management practices may be able to reduce absolute biological emissions from individual farms in the range of 2 to 10%, possibly without reducing profitability (although questions remain about the skills of farmers to achieve such modelled outcomes). However it is important to note that many of the mitigation approaches are interconnected and are not necessarily additive – some combinations cannot be used together, others may improve reductions only incrementally when combined, and in some cases reductions of one gas may result in increased emissions of other gases (referred to as 'pollution swapping'; e.g. an increase in CO_2 emissions from production of and transport of methane-reducing supplements produced off-farm). Further, individual technologies and interventions can work quite differently in different biophysical environments and are influenced by complex factors within farms, including farmer skills and knowledge.

The main options based on existing technologies and knowledge, and the caveats influencing their adoption, are described briefly below.

Land-use decisions that reduce GHG intensity or increase carbon sinks

Some farmers can consider diversifying their land use. This can include forestry planting or allocating land to specialist cropping or horticulture. The increasing global interest in plant-based milks and meats may offer opportunities for diversification, but the challenge will be to achieve economic returns to the farmer. This is less likely unless new plant breeding techniques – for which social license remains highly uncertain and controversial – are used.

While plantation forestry does not represent a permanent carbon sink, it may be an option to manage exposure to future carbon pricing. The Permanent Forestry Sink Initiative (PFSI)[17] includes incentives for retiring marginal land, however there could also be other incentives for retiring marginal land by planting conservation/native forests (e.g. via the QE2 Trust), for example, or manuka plantings for honey production.

Changing parts of a farm enterprise to specialised cropping or horticulture poses barriers in terms of farmer skills and knowledge, for which network support would be required. Alternatively, land could be leased to other specialty producers. The cost/value of the land and necessary infrastructure, capital, and labour must be considered in the mix. While incentive schemes exist for afforestation, policies encouraging carbon sequestration in forests could potentially affect agricultural land values, with flow-on effects of higher prices for crops, milk and meat reducing the cost effectiveness of carbon forestry as an offset.[18] The farmer's perception of risk will be an important influence in these decisions, which require them to maximise the efficiency of production in the remainder of their farms without increasing total GHG emissions.

Many Māori land-owners have a different perspective. For collective Māori land holdings, capital gain is not a consideration, as sale of their farmland is not on their agenda. Rather they depend entirely on immediate returns from their farm holdings and thus their interests in the above equation will need particular consideration.

Feeding practices, grazing and pasture management

Improving the animal's production efficiency means that a greater proportion of the energy in the animal feed is directed towards production of useful products (milk and meat), so emissions per unit product are reduced. Losses of methane from enteric fermentation by bacterial methanogens represents an unproductive use of dietary energy. The level of methane production from the rumen relates mainly to the quantity (dry matter intake) and quality (energy value and digestibility) of the feed the animal consumes.[19] In theory, reducing methane emissions can be accomplished by increasing the energy and digestibility of feeds so that less feed is needed to reach a given level of production. Some forages have been identified that appear to reduce methane production from ruminants (e.g. forage rape and fodder beet), but these forages generally constitute a relatively small proportion of the animal diet, and their impacts are currently limited. They can also result in pollution swapping through increased N_2O emissions, as well as potential animal health issues.

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[17] The Permanent Forest Sink Initiative (PFSI) is one of the government's sustainable forestry programmes. It enables landowners to receive carbon units through the creation of permanent forests.

[18] For examples see: Sinclair et al. (2010). *Management of carbon price exposure in the agricultural sector through the use of post-1989 forestry – case studies based on farmer data, attitudes and actions*. Prepared for Ministry of Agriculture and Forestry, Wellington.

[19] The *quantity* of feed consumed is generally measured in terms of 'dry matter intake' and is driven by the feed demand of the animal linked to live weight, production, stage of gestation etc and feed quality. The *quality* of feed is measured in terms of the useable energy value of the feed – known as 'metabolisable energy' (ME) – per kilogram of dry matter.

Livestock GHG emissions are directly related to the amount of feed consumed in the form of forage and supplements. While high-quality supplemental feeds can improve per-animal productivity, this can in some cases come at the expense of wasted pasture, higher GHG emissions, and reduced profitability, especially if the supplements are brought in from off-farm.[20]

Balancing pasture growth and utilisation is key to achieving an optimal stocking rate that results in higher productivity per animal with lower inputs (and lower cost). There is a real opportunity to reduce emissions by optimising the rate of pasture utilisation by grazing with the appropriate number of animals such that both pasture wastage and the need for supplements is reduced. This can potentially allow farmers to reduce their herd size while retaining the same level of productivity, and thus reduce overall emissions. However, this requires skill and knowledge on the part of the farmer.

Good management practice for pasture also involves minimising periods of exposed soil between forage crops/pasture to reduce the risk of erosion, overland flow and leaching of nutrients, which contributes to N_2O emissions and loss of soil carbon stocks.

With regard to N_2O emissions, using nitrogen-fixing pasture forages such as clover and lucerne can reduce the need for N fertiliser application. Research is also ongoing to identify forage plants (e.g. plantain) that can be usefully grown in New Zealand pasture conditions that can limit the formation of nitrate and nitrous oxide in soil to reduce leaching and emissions, or reduce excretion of nitrogen in animal urine, which is the most significant source of N_2O emissions.

As discussed below, New Zealand scientists have developed promising forages using genetic technologies that could be used to make major progress through higher energy, lipid rich ryegrasses which are now in field trials in the United States. However, these have not been and effectively cannot be subjected to field testing in New Zealand.

Animal husbandry

Improved animal genetics has allowed for selection of animals and herds that convert feed to product more efficiently, resulting in higher product yield with lower total input and lower emissions of both methane and nitrous oxide. Selecting for high genetic potential can result in:

- increased lambing performance (number of lambs per ewe) and lamb weight (lamb production per ewe)
- increased steer weight/head
- increased kilograms milk solids/cow

At the individual animal level this results in greater emissions per animal but less emissions per unit of product. Thus at the herd or flock level focussing on individual animal

[20] Palm Kernel Extract (PKE), the most common supplement, is imported from overseas and is used particularly at the beginning and end of the season as the grass growth cycle is temperature dependent and does not match the potential of the lactational cycle.

performance at lower stocking rates can reduce total emissions. Breeding for improved reproductive performance allows for lower animal replacement rates, reducing the requirement for holding higher stock numbers and thereby potentially reducing emissions. Similarly, measures to improve animal health also help to improve productivity and longevity of elite breeding and milking livestock, thus contributing to emissions reduction. Taken together, improved genetics have resulted in incremental decreases in GHG intensity per unit product, and these decreases will continue into the future since improved genetics is firmly embedded into the New Zealand agricultural sector.

Research has also found that certain sheep are genetically more likely to produce less methane emissions than others per unit of intake, and this trait is heritable. The potential impact of using animals having this low methane trait is currently being assessed by the sheep industry.

Animal housing and effluent management

Animal wastes are a significant source of GHG emissions. N_2O emissions occur when urine and faeces are broken down by microbes in soil. Urine patches in particular are a source of concentrated N that leaches through soil, particularly during wet conditions. CH_4 is produced from the decomposition of manure under anaerobic conditions, especially when manure is stored in ponds.

Emissions from stored manures in New Zealand are currently a minor source of emissions although stand-off pads and animal housing practices are increasingly being used by New Zealand dairy farmers. This is largely to avoid pasture and soil damage and for ease of herd management (including animal welfare) during wet winter periods. Properly designed, these facilities provide an opportunity to reduce GHG emissions from effluent through containment and treatment.

Methane emission can be mitigated by strategies employed during storage, including:

- covering effluent storage ponds for energy recovery
- keeping effluent aerobic by mechanical mixing
- carrying out solids separation to prevent solids from entering anaerobic ponds
- using a biofilter cover, comprising CH_4-consuming bacteria, on the pond surface (this is still experimental)

The use of stand-off pads during wet periods can significantly reduce N_2O emissions (30-50%) from grazed pastures. However, reductions from entire farm systems are much more limited due to an increase in N_2O emission resulting from subsequent land application of manure and from potentially increased methane emissions from stored manures. Emissions of N_2O can be reduced by applying effluent and slurry at an optimal rate to relatively dry soils or during the period when demand of nutrients for plant growth is high. Addition of a nitrification inhibitor to fresh effluent just before land application can also reduce nitrous oxide emissions, but no inhibitor is currently available for use in New Zealand (see below).

A trade-off associated with animal housing systems is the need to bring in animal feed, either as supplements or as cut-and-carry forage from pastures or arable sources. This may result in pollution swapping with CO_2 stemming from the use of fossil fuels for production and transport of such feeds. However, there are also potential ecological co-benefits, including the use of biogas methane from effluent/slurry to reduce the use of fossil fuels. Additionally, the use of effluent and slurry to partially substitute for chemical fertilisers is recommended as it improves forage and crop productivity, reduces N leaching and run-off losses and increases soil carbon storage.

A consideration with regards use of these systems in New Zealand is profitability, which is undermined not only by the capital expense, but also by reducing the competitive and comparative market advantage of milk production from grazed pasture.

Precision-farming techniques

Farmers who are 'ahead of the curve' in terms of efficient agriculture are increasingly adopting information and communication technologies (e.g. GIS, GPS, sensors, UAVs) for controlling farm variables and using the data to allow precision input application. This facilitates strategic irrigation and fertilisation, reducing N fertiliser inputs and reducing runoff. Likewise, N leaching can be reduced by improving irrigation management. Reduction of CO_2 emissions through careful management of the use of agricultural machinery can also be aided by these technologies. Skilled use of these technologies can result in increased production efficiencies and reduced GHG emissions intensity.

After initial investment, some of these technologies are likely to reduce the cost of production per unit product, so for the same investment a farmer can produce more. It should be noted that this will only result in a reduction in absolute emissions if production levels are constrained.

Accounting for emissions

With a number of potential mitigation options available, each influencing on-farm GHG emissions in a small way, how are farmers to know if their actions are making a difference? In order to reduce emissions in a meaningful way, there is a need to be able to account for them as accurately as possible, and to know what effect each strategy is having. For example, there are some approaches that can reduce the leaching of soil nutrients (notably nitrogen) into waterways, and this can have a significant effect on water quality, but in most cases their effects in reducing GHG emissions remain difficult to measure.

Farmers need to be able to make both strategic and responsive decisions about the many potential mitigation options which may or may not be useful in particular context, and to do this they require decision-support tools that reflect actual reductions and that are linked to fiscal drivers. This question remains central to New Zealand's climate change mitigation efforts in (i) being able to measure progress from farm to national scale toward GHG reduction and (ii) demonstrably fulfilling international obligations.

Unfortunately, there is no reliable way to directly and accurately measure emissions from an individual farm, although proxy estimates can be generated by modelling inputs and outputs on the farm. A key decision that will need to be made is whether to try and manage

GHG production from farms with a direct priced-based system based on some estimate of GHG emissions at an individual farm basis or at the level of a consolidator (e.g. a milk company which is then charged with putting conditions on its supplier), or to use some other approach such as a farm-plan. Ideally whatever is chosen must be fair, create incentives at the individual farm level for improved mitigation, and cope with the many differing farm systems within the New Zealand agricultural sector.

OVERSEER® is the dominant tool used for accounting for GHG emissions on some New Zealand farms, especially in the dairy sector. It is less suitable for complex farming systems involving mixed production. The OVERSEER® software was originally developed to improve management decisions around fertiliser use by modelling nitrogen (N) and phosphorus (P) movement and their loss to water through leaching and/or run-off. OVERSEER® is used by some regional councils as a regulatory tool in an effort to estimate and limit nutrient losses from farms. It is also used as a decision support tool to show the effect of changes in fertiliser use, effluent management and other farm management practices on nutrient losses that impact freshwater quality, but even here its differential use between Councils has proved controversial.

The OVERSEER® model was subsequently adapted to estimate on-farm GHG emissions, including GHG emissions per unit product (GHG intensity) as well as overall emissions. The model derives emissions from farm characteristics, feeding regimes (there being a close relationship between feed intake and methane production in a given breed) and farm system management practices, thereby providing a standardised way of estimating CH_4 and N_2O emissions to help inform decisions. Like all scientific models, and given the variability of biological systems and actual farmer behaviour, there can be significant variability between the calculated and actual GHG outputs. Further the utility of the model is subject to quite varied views across the sector. The model may not produce a precise estimate of emissions quantity and this may limit its utility as a fair base on which to set regulatory decisions affecting an individual farm. The variability also means that small effects of new treatments or changes to farm management practice cannot be assessed with confidence for practical day-to-day mitigation-related decision making.

Farm-level reporting should encourage farmers to take steps to improve their on-farm emissions performance in an ongoing and adaptive manner as their management practices evolve and as new knowledge and technologies emerge. Although OVERSEER® can be used to identify practices that reduce emissions, it can be difficult for farmers to use themselves, and does not account for all available mitigation options (e.g. tree planting outside plantations), nor does it consider costs or economic outputs and thus cannot provide a full picture to support farmer's decision-making. Although OVERSEER®can be further modified to allow for some aspects not currently included, its better use may be to provide information to assist farmers to make choices as part of a broader decision-making strategy for their farm, rather than as a direct financial/regulatory tool.

Numerous other farm management tools exist and are available to farmers[21] – the key to uptake is user confidence and trust, generated by having support and guidance on how to use them effectively. They must also fit with the particular farm system. If farmers are to be responsible and accountable for their individual emissions outcomes, they need to be able to assess incremental improvement/reduction in GHGs down to farm and sub-farm level. Ideally this would include costings for possible mitigation options and potentially, carbon credit calculations based on reduced GHG emissions (or emissions intensity), which would result in a calculation of total farm benefits from different strategies.

One way this could be achieved is through a comprehensive farm plan devised with the aid of a professional and specifically-trained farm advisor, using inputs derived through consistent and agreed methodologies to allow the farmer to explore the influence of various GHG abatement strategies on their particular farms. The methodologies could include OVERSEER®, Farmax, and/or other tools (including the use of LCA for product carbon footprinting), but would need to be approved and linked to whatever is chosen as the regulatory framework, and should be as straightforward to implement as possible. With appropriate inputs and auditing, the farm plan structure would offer the possibility that any reduction in GHG emissions could be credited as part of a carbon offset scheme, if that is the chosen policy instrument.

Policy considerations for agricultural emissions

There is a range of possible targeted policies and programmes to incentivise domestic GHG mitigation. Policies for agriculture need to take into account the different types of farm systems and farm business, the resilience of rural communities and impacts on the economy, and the competitive export market, where producers from other countries may not face the same pressures. However, as mentioned above, many of the actions that can be taken now are aimed at improved efficiencies, which should also lower production costs and increase the economic return for farmers, particular if they can capitalise on producing branded low-emissions products.

Agriculture and the ETS

Incentive structures to reduce emissions generally involve placing a price on carbon, expressed as an 'emissions unit'. Where GHGs other than CO_2 are included, they are measured in CO_2 equivalents (calculated using GWPs) to be used as tradeable credits in policy instruments such as emissions trading schemes (ETS).

The possible inclusion of agriculture in the ETS could place responsibility for meeting targets on farmers as the emitters. This would require the establishment of market mechanisms and assignment of credits (in the form of emissions units) to farmers for GHG

[21] For examples, see: Allen, J. and Wolfert, S. (2011). *Farming for the future: towards better information-based decision-making and communication. Phase I: Australasian stocktake of farm management tools used by farmers and rural professionals*. https://www.agfirst.co.nz/wp-content/uploads/2016/06/Farm-Management-Tools-report-v5.pdf

mitigating activities they undertake. Alternatively the point of obligation could be processors, in which case it is they who would be assigned the responsibility for buying and selling units. The Interim Climate Change Committee is undertaking a separate process to determine how agriculture could be brought into the ETS.[22]

Other policy options are possible. Alternatives to ETS-type policies include subjecting emissions to taxation, or implicitly pricing emissions via regulation or standards that put constraints on some GHG-emitting activities, or that require actions (or the use of technologies) that are recognised to deliver emissions reduction. This could involve the development and use of farm plans that specify mitigation actions that are viable for particular farms, and are auditable. I endorse consideration of this latter approach as being both practical and amenable to integrating multiple farm objectives for both environmental and economic sustainability.

Advisory mechanisms and farm plans

The problem arising from a lack of reliable GHG accounting tools that farmers themselves can use is compounded by the fact that there is no system-wide accredited advisory mechanism to assist them to make the best decisions (both for the environment and for the profitability of their farms) in a way that links their decisions to GHG emissions abatement. Many farm advisors at present will not have, and cannot be expected to have the knowledge base to be effective in this regard.

Farmers need to understand their farms on an individual basis in order to effectively adopt best-management practices that will work for them. They need clear information to understand costs and benefits. This may best be served by a cadre of specialist advisors developing whole-farm environment plans that can accommodate the variable and economic needs of individual farms while considering the need to minimise GHG production in the context of all other initiatives.

For farm plans to be useful for GHG reduction, they need to:

- identify priority emissions sources
- allow reporting of trends in emissions intensity as well as absolute emissions
- allow a wide range of potential mitigation actions to be captured
- link to other requirements farmers must meet

As discussed above, BERG modelling describes 'packages' of mitigations which, if developed, may be useful as a starting point from which to design whole farm plans based on the objectives and specific circumstances of each farm. Farm plans would need to be unique to a property and reflect the local climate and soils, the type of farming operation, and the goals and aspirations of the land user, while also incorporating sector-specific Good Management Practices (GMPs). Similar farm environment plans have long been used

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[22] Interim Climate Change Committee Terms of Reference: http://www.mfe.govt.nz/sites/default/files/media/Legislation/Cabinet%20paper/interim-climate-change-committee-tor.pdf

to manage environmental risks within the farm business, but many have had a specific focus, such as managing nutrient runoff and/or sediment loss. (e.g. Horizons Sustainable Land Use Initiative [SLUI] and others). If properly constructed and implemented, farm plans can help to improve farm efficiency through the strategies used to reduce such environmental losses.

As discussed above, farm plans may be informed, in part, by models such as OVERSEER® and other decision-support tools to help reduce GHG emissions in the context of the specific farm system. These plans could potentially be linked to incentives or regulations through an auditing system (e.g. rewarding 'climate-smart farms'). In some sectors this may occur through upstream points of obligation such as collectives (e.g. Fonterra for the dairy industry). For the plans to be auditable in regulation, the assessment methodologies need to be consistent and usable across the sector.

New Zealand is well positioned to capitalise on the growing market for sustainable products that can be verified as having a low carbon footprint. Accreditation through adhering to validated farm environment plans could be a means of achieving this (e.g. similar to certification of organic farms[23]). This would become very attractive in the event that foods were traceable directly back to the source, where a highly ranked farm would command a market premium for its products.

One possible model would involve a farmer agreeing to a farm plan encompassing GHG emissions mitigation, animal welfare, and other aspects of environmental management and land-use, and be held accountable to that plan over a number of years. Given the interest in farm plans for other objectives (e.g. water quality), this unified approach would simplify compliance, monitoring and effort from the farmer. Work on this is already underway in the dairy sector as part of the Dairy Tomorrow Strategy,[24] which aims to "achieve all farms implementing and reporting under certified farm sustainability plans" by 2025. Compliance with the farm plan should be incentivised through whatever mechanism the Government decides on for linking agriculture to GHG regulation.

A consideration here is recognition of the cost of training a suitable number of specialist farm advisors who can propose effective GHG mitigation strategies, such that the farming community respects and works with them. There will also be a need for Government to audit/regulate these advisors.

Looking to the future

Combining existing strategies into individualised farm plans should help to improve both environmental and economic efficiencies across the pastoral sector, and reduce emissions intensity of agricultural products, as well as being able to link with other objectives that will maximise total farm resilience. However, as discussed, the BERG's modelling suggests that the gains that are possible using existing strategies are likely to make only small (<10%)

[23] http://organicfoodchain.com.au/news/iso-17065-accreditation/
[24] Dairy tomorrow: the future of New Zealand dairying. The dairy industry strategy 2017-2025. http://www.dairytomorrow.co.nz/wp-content/uploads/2017/12/dairy-strategy-2017-A4-booklet-Part3.pdf

reductions in our total agricultural emission equation without significant afforestation, a reduction in stock numbers, or other changes in land use.

For larger reductions from the primary sector, technological innovations will be needed, and these will have to be acceptable to regulators, New Zealand farmers and the public (both domestically and in our export markets).

Innovations for the medium-term

There are technologies under development that could be available in New Zealand in the near future, with some effort on the part of researchers, regulators and investors.

There are several biological and chemical steps involved in nitrogen losses and N_2O emissions from soil, and a number of inhibitors exist that are designed to impede these processes in order to reduce emissions. For example, urease inhibitors function to block urease enzyme activity, which creates localised alkaline conditions in the soil and thereby reduces N_2O emissions. Nitrification inhibitors reduce nitrate leaching and improve nitrogen-use efficiency of fertilisers. The nitrification inhibitor di-cyandiamide (DCD) is effective in reducing N_2O emissions but is no longer used in New Zealand because of regulatory constraints relating to residues in milk. Similarly active new inhibitors are in development. For example, 3,4-dimethypyrazole phosphate (DMPP) is another nitrification inhibitor often claimed to be efficient in regulating soil N transformations and influencing plant productivity, with no observed adverse effects. Further work in this area will require careful consideration of the regulatory environment and early engagement with regulators in order to introduce such inhibitors in New Zealand.

Methane inhibitors such as 3-nitrooxypropanol (3NOP) have shown considerable promise internationally, but will require modification in New Zealand pastoral systems. 3NOP inhibits methanogenesis in the rumen when consumed in feed thereby reducing CH_4 emissions by blocking the last step in methane production by bacteria in the rumen. In grain-fed systems where 3NOP can be added to the feed supply and consumed continuously as the animal eats, CH_4 emissions reductions of over 30% have been observed without residues in milk or meat. For use with New Zealand's grazing animals, a long-acting or slow-release formulation would need to be developed and this is a technological challenge that likely could be overcome. In the case of dairy herds, this would allow the material could be ingested at milking and remain active in the rumen until the next feed. New Zealand has the skills to develop such a formulation, but there is also a need to be able to manufacture large amounts of the compound, which would require significant capital investment and would itself have a carbon footprint. Additionally, the New Zealand regulatory regime will determine the likely speed of development and adoption of this product.

Methane-inhibiting vaccines are theoretically promising but are further away from practical use than chemical inhibitors. The potential availability of vaccines to reduce methane production in the rumen would increase the sustainability of ruminant livestock farming generally. If an appropriate antigen can be identified, such vaccines might be effective in all ruminant livestock systems (dairy, beef, lamb). However, progress in this area has been somewhat disappointing and this approach remains theoretical.

Further on the horizon

Over the last 10 years there has been research which suggests novel and effective ways to reduce pastoral GHGs. While showing considerable but theoretical promise, many of these technologies would rely on gene editing (GE) or transgenic/genetic modification (GM) methods. This means that there are important regulatory and social licence issues that would need to be considered, as well as progress towards establishing context-specific proof of concept for reducing emissions.

The innovations of most theoretical potential are:

- Transgenic forages: This includes high-energy forages and those with tannin protection that reduce GHG emissions from livestock. Such forages have already been developed experimentally based on New Zealand science. For example, a high energy ryegrass is now in field trials in the USA, and anectodal reports have been positive; however, current regulation and the absence of social licence means that it has not been field tested in New Zealand. The theoretical estimated reduction in emissions that is possible at the individual animal level is considerable (> 20%), although the impact across the industry is likely to be lower since much of New Zealand's grasslands are permanent. The inability to assess these technologies in New Zealand conditions may be to our long-term disadvantage.
- Transgenic endophytes are potentially valuable as a delivery vehicles for a nitrogen inhibition mechanism in forage plants: Endophytes are fungi that exist in symbiotic relationship with grasses. The modification of grass endophytes may be used for the introduction of genes for desired traits such as nitrogen inhibition.
- GM or GE forestry to achieve faster growth of trees with desirable production characteristics, including enhanced carbon sequestration.

Each of these approaches would need broad social license before any context-specific research was possible, so these remain speculative approaches. It is noteworthy that many ruminants in Europe now routinely consume GM feeds. Clearly social license for these technologies does not exist in New Zealand. However, given the progression of science on one hand, and a broader understanding of the crisis of climate change on the other, not having a further discussion of these technologies at some point may limit our options.

Ultimately all uses or rejections of any technology requires acknowledgement of the trade-offs being made. While there are many other possible trade-offs to consider, the potential role of advanced biological technologies in reducing the burden of pastoral GHGs needs to be considered alongside other options (e.g. reducing animal numbers significantly, investing in offsets etc). Further issues are created by the complex and changing international trading environment for New Zealand food products.

The appropriate use of the precautionary principle in evaluating trade-offs, and in particular in considering new technologies, is to inform adaptive management rather than to be a fixed point for all time; that is, as additional information becomes available and the risk profile becomes clearer, the need for either less or more regulation becomes apparent.

Depending on the trajectory taken both in New Zealand and around the globe, future norms, attitudes, and possibly economic and environmental imperatives will further drive change in the structure of New Zealand farming. Acceptance of rapidly-developing innovations such as plant-based meat substitutes could steer farms away from pastoral agriculture towards more climate- and environment-friendly horticulture and cropping. These types of trends need to be considered in order to future-proof New Zealand's agricultural sector. Again new technologies, if acceptable to consumers, could change the economic potential of such approaches.

Knowledge diffusion and behaviour change

It is noted that research and innovation will not lead to emissions reduction without widespread behaviour change. Some farmers may see environmental concerns as threatening their economic viability, but farmer behavior is not based simply on rational economic decision making; indeed this is true of decision-making in most contexts by most people. Underlying any response are many diverse and complex factors, attitudes and values.

There is a need to address cultural, skill and economic barriers to extensive adoption of 'best practice'. This should include consideration of Māori views and land ownership issues. Because farmers are known to each other by reputation, farmer-to-farmer knowledge exchange within farming community networks is one of the most likely ways to encourage good environmental practices, cooperative action and compliance with group norms. The success (both economic and in terms of farm resilience) of 'early adopters' within the network is key to enhancing further uptake of innovations.

While the importance of farmer-to-farmer networks cannot be downplayed, effective large-scale mitigation will require communication and dissemination of best-practice knowledge widely across the sector. Designing a system of comprehensive farm plans or any other solution would require a system-wide farm advisory mechanism that is capable of integrating multiple objectives for each individual farm.

In the near term, with regard to GHG abatement, farming enterprises should be encouraged to utilise available best-practice packages of options and work to optimise their fit with current systems, while continuing to look to the future. There is an abiding need to be progressively ambitious about meeting targets. Any proposed strategies will need to consider adaptation to climate change alongside mitigation, and importantly, how the outcomes of these actions will be measured against the NZ GHG inventory. Regulatory and policy mechanisms will need to provide certainty and incentive to promote desired behaviours.

An overriding issue is the broad theme of acceptance of practice change, and the sector and others' ability to provide objective support, involving councils, farm consultants, environmental analysts, accountants, banks and investors, plus the various research and training institutions. Capacity building within farming networks could involve promoting the success of early adopters as mentors.

Summary

New Zealand, with the rest of the world, is aiming for long-term climate stabilisation at $<2^{\circ}C$ above pre-industrial levels in order to avoid the most severe consequences of climate change. This will require very intensive and more urgent effort to reduce CO_2 emissions to net zero or below in the atmosphere, while constraining the emissions of other GHGs. New Zealand's most important contribution to this effort will be in effectively reducing biological emissions from agriculture – an area where we are positioned to be world leading. Driving emissions mitigations from the agricultural sector is thus critical to the government's commitment to act domestically against climate change. But the equation is not simple – it will involve trade-offs between multiple imperatives affecting different stakeholders differently.

There are actions that farmers can take now, and they should be encouraged to do so. Many current approaches can be implemented to make small gains, but there is much to be done to determine the optimal combinations for specific farm situations. For some, the data can be both encouraging and sometimes contradictory. Farmers will require assistance in the form of a strong advisory mechanism that can help them achieve real gains without pollution swapping.

Farm plans that can demonstrate both environmental and economic gains are one possible route to encourage greater environmental stewardship. Farm plan schemes can begin as voluntary initiatives, but ultimately will require policy action and significant strengthening of the farm advisory mechanism so that consistent results can be achieved across the sector.

There are also compelling reasons to pursue some of the identified medium-term options. It is clear that apart from substantial land-use change and afforestation, the main opportunities to reduce emissions significantly will depend on technological innovation such as the use of inhibitors. A mission-led approach to research will continue to be needed. Social science research is also needed to see how to both encourage early adopters and to enhance uptake of effective strategies across the sector.

For larger and longer-term gains, unravelling the regulatory and social licence issues around the use of new and evolving technologies will be critical for continuing scientific advancement as part of the national effort to reduce New Zealand's largest sources of GHGs.

Despite the many scientific, economic and implementation challenges, failure to take action in the agricultural sector will not only be costly to those farmers who find themselves unprepared for change, it will also ultimately be costly to New Zealand.