

Climate change and agriculture: Understanding the biological greenhouse gases

October 2016



Parliamentary Commissioner
for the **Environment**
Te Kaitiaki Taiao a Te Whare Pāremata

Acknowledgements

The Parliamentary Commissioner for the Environment would like to express her gratitude to those who assisted with the research and preparation of this report, with special thanks to her staff who worked so tirelessly to bring it to completion.

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Overview

When I was a child, most New Zealand farmers lived 'off the sheep's back'. At one stage, the price of wool was a pound for a pound. Farmers' sons were reputed to buy motorbikes on the proceeds from picking tufts of wool off barbed wire fences.

In the last 25 years, hundreds of sheep farms have been converted to dairy farms. This is especially so in my home province of Canterbury where many of the familiar macrocarpa shelter belts have been felled to make way for travelling irrigators up to a kilometre long.

This rural landscape too will change. But New Zealand will almost certainly keep doing what it does so well – producing and exporting food. Today most of that food is meat and milk from pastoral farming. Unfortunately, the production of this valuable protein is accompanied by the emission of two potent greenhouse gases – methane and nitrous oxide.

Late last year, New Zealand along with many other countries, committed to a new climate change agreement in Paris. As I write this, the news has just come through that New Zealand has ratified the Paris agreement, and thus formally adopted the 2030 target for reducing greenhouse gases. This makes us one of 72 countries who have now ratified. And more will follow.

The Paris agreement recognises the fundamental importance of safeguarding food security and ending hunger, and that food production systems will be vulnerable to climate change.

Globally, carbon dioxide is the main driver of climate change, and it is accumulating in the atmosphere at an alarming rate. But in contrast to many other countries, the biological gases from agriculture form about half of New Zealand's greenhouse gas emissions.

The sheep, cattle, deer, and goats – the ruminants – on our farms burp out a huge amount of methane. And the origin of most of the nitrous oxide – an especially powerful greenhouse gas – is the urine of farm animals.

This report is about the science of these two biological gases – how they are formed, how they behave in the atmosphere, and what might be done about them.

Methane in the atmosphere is short-lived, in contrast with nitrous oxide and carbon dioxide. If the flow of methane into the atmosphere stopped rising, and there were no other greenhouse gas emissions, the temperature of the atmosphere would stabilise in a few decades.

Nevertheless, methane emissions are damaging. For instance, while methane molecules disappear relatively rapidly from the atmosphere, they do leave some damage behind. Most of the heat that they trap is absorbed into the ocean, contributing to sea level rise.

Much of this report is an evaluation of a range of ways of reducing methane and nitrous oxide – changes in the way animals are bred, changes in what they are fed, targeting the microbes that produce methane, and targeting the interaction between urea and soil that produces nitrous oxide.

Demonstrating that a mitigation option is effective in a laboratory or in a field trial is only the beginning. There is much else to consider before any option can be seen as holding real potential to make a sizeable dent in the nation's emissions of methane and/or nitrous oxide.

During this investigation it has become clear that there is no silver bullet on the horizon.

Methane is the greater challenge. It amounts to four-fifths of the biological gases under standard accounting rules, and current ways of reducing it are very marginal.

One potential mitigation option stands out as holding particular promise – a vaccine that could decrease the amount of enteric methane emitted from sheep and cattle by 20% or more.

Such a vaccine could be readily integrated into current farming systems and would be of great value way beyond New Zealand. However, research is still at an early stage, and there is no guarantee that an effective vaccine will be developed.

There are two environmental problems that result from microbes in soil breaking down animal urine. One is the greenhouse gas nitrous oxide. The other is the nitrate that leaches into rivers and streams. Some management practices that have been adopted in response to concern over water quality have the added benefit of reducing nitrous oxide. An example is the use of feed pads to take cows off pasture at the time of the year when their urine is most damaging.

There is a growing body of research and practice showing that farm profit can sometimes be maintained, or even increased, with fewer animals. It can also make farming less risky. Reducing the need for inputs like palm kernel reduces the exposure of the farmer to price fluctuations.

Lake View Farm near Hamilton reduced its stocking rate from 530 cows in 2009 to 350 cows in 2014 – reducing emissions of both biological gases, reducing nitrate leaching, and increasing profitability. On their beef-finishing farm in the Lake Taupo catchment, Mike and Sharon Barton have made many changes aimed at increasing the dollar value and the environmental value of their beef. Landcorp has a goal of being carbon-neutral within a decade and is already diversifying into sheep milk and more forestry.

This brings me to trees.

Farmers already plant trees for many purposes – for shelter, for timber, to control erosion, to protect waterways, and to provide habitat. Each tonne of carbon stored in a tree means that almost four tonnes of carbon dioxide has been sucked out of the air.

On hill country farms, higher altitude pasture provides little nourishment for livestock, and farmers battle to clear reinvading scrub. In some cases, fencing off the higher marginal land will lead to the slow steady regeneration of native forest – and the slow steady storage of carbon for the indefinite future.

A very different type of forest is a rapidly growing plantation of radiata pine where the carbon storage is only for a time before the trees are felled. This has the effect of pushing emissions into the future. But it is still valuable because it buys time to make a smoother transition to a low emissions future.

In the upper Whanganui, Dan Steele of Blue Duck Station has retired the steeper land, diversified into mānuka honey, and built a tourist lodge. In Taranaki, Neil Walker is earning many thousands of dollars from the carbon being stored in his eucalyptus forests. Ngāti Porou also has interests in the carbon farming and mānuka honey potential of their hill country land.

The forestry rules that will be renegotiated in the wake of ratification of the Paris agreement will be critical for New Zealand. There will also be an opportunity to change the rules governing the recognition of carbon storage in the ETS. Ngāi Tahu has drawn attention to the way in which the carbon stored by native tree species is often not recognised. Remote sensing technology, perhaps using drones, may also allow for the recognition of smaller 'carbon forests' by reducing the costs of monitoring and compliance.

This investigation has made me a greater advocate of planting trees, although we cannot rely on trees alone. Establishing forests does not rely on technological breakthroughs. Photosynthesis is simplicity itself beside the arcane mysteries of the rumen and the complexities of what happens after the urine hits the soil.

Over more than a decade, there have been a number of false starts in the very difficult area of dealing with the biological emissions from agriculture. The first initiative faltered in 2003 when the misnamed 'fart tax' tractor was driven up the steps of Parliament.

Making a smooth transition to producing lower emission food is very important. Continuing delay just makes an abrupt transition more likely. In the past, for this reason, I have recommended that the biological gases should be included in the Emissions Trading Scheme. But the ETS is not the only way forward – there are other options.

The Government has recently established a Biological Emissions Reference Group. It is critical that this time progress is made on reducing the methane and nitrous oxide that together form such a large part of our greenhouse gas emissions.

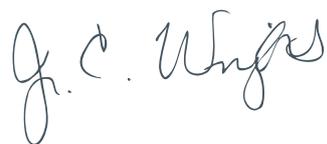
The transition must begin. If we ignore the biological gases from agriculture, other sectors of the economy – and the taxpayer – will become increasingly squeezed.

Diversifying land uses is not as simple as it sounds for a remote island country that exports most of the food it produces. But New Zealand farmers are nothing if not adaptable.

Moreover, the food of the future will be different in ways we can scarcely begin to imagine. A number of start-up companies in Silicon Valley are already developing synthetic milk and meat, growing it in laboratories from animal DNA.

Opportunities to develop and market new or different products that meet changing global demand, and emit little in the way of greenhouse gases, will be crucial to the future profitability of our agricultural sector.

When farmers look over their land fifty years from now, I hope that they see vibrant communities that not only feed New Zealanders – and others in the world – but do it in a way that contributes to the stability of our climate.



Dr Jan Wright

Parliamentary Commissioner for the Environment

Tirohanga Whānui

I a au e tamariki ana, i whai oranga te nuinga o ngā kaipāmu i ngā hua e makere mai ana i te tuarā hipi. I tētahi wā, he pauna moni ka utua mō te pauna wūru. E ai ki te kōrero, ka hoko motopaika ngā tama a ngā kaipāmu i te utu mō ngā wekuweku wūru i tangohia i ngā taiepa taratara.

I ngā 25 tau kua pahure ake nei, he rau ngā pāmu hipi kua whakahuriria hei pāmu kau. Ka tino kitea tēnei i taku takiwa, i Waitaha. Ko ngā pāhauhau makorokapa, i kitea whānuitia i reira i mua, kua topea kia mahea ai te huarahi mō ngā mīhini whakamākūkū nekeneke e tata ki te kotahi kiromita te roa.

Nā, ka rerekē haere te tuawhenua. Engari, kāore e kore ka mahi tonu a Aotearoa i tana e pai ai – ko te whakatipu me te hokohoko kai. I tēnei wā, ko te nuinga o taua kai he mīti, he miraka nō te pāmu tarutaru kararehe. Ko te mea whakarapa kē, mā te whakatipu i tēnei pūmua e puta ai ētahi haurehu kati mahana kaha – te mewaro me te hauota-rua ōkai.

I te mutunga o tērā tau, i whakaae a Aotearoa me te maha noa atu o ngā whenua o te ao ki te whakaaetanga panoni āhuarangi hou i Parihi. I a au e tuhi ana i tēnei, kua hau mai te rongu kua whakamana a Aotearoa i te whakaaetanga o Parihi, ā, kua whakaae ōkawa nei ki te taumata mō 2030 mō te whakaheke i ngā haurehu kati mahana. Ināianei ko Aotearoa tētahi o ngā whenua e 72 kua whakamana i te whakaaetanga. He whenua anō ka whai mai.

Kua kitea i roto i te whakaaetanga o Parihi he mea tino nui te tiaki i te ita kai me te whakamutu i te matekai, ā ka paraheahea ngā pūnaha whakatipu kai i te panoni āhuarangi.

Huri noa te ao, ko te hauhā te pūtake nui o te panoni āhuarangi, ā he mea whakaohorete te auau o te whakaemitanga ki te kohauhau. Heoi anō, ko te rerekētanga o Aotearoa ki whenua kē, ko ngā haurehu koiora nō te ahuhenua he haurua pea o ngā putanga haurehu kati mahana.

Ko te hipi, te kau, te tia, te nanekoti – ko taua momo – i runga i ō tātou pāmu e tokopūhā atu i te mewaro nui rawa atu. Ko te pūtake o te nuinga o te hauota-rua ōkai – he haurehu kati mahana kaha – ko te mimi o ngā kararehe pāmu.

Ko tēnei pūrongo mō te pūtaiao e pā ana ki ēnei haurehu koiora – he pēhea e auahatia ai, he pēhea te whanonga i te kohauhau, ā me pēhea e whakamahi.

Ka mutu wawe te mewaro i roto i te kohauhau, he rerekē ki te hauota-rua ōkai me te hauhā. Ki te oti te rere ake o te mewaro ki te kohauhau, ā, ki te kore e whakaputaina ētahi atu haurehu kati mahana, ka taurite te pāmahana o te kohauhau kia pahure ake ngā tekau tau ruarua noa iho.

Heoi anō, he mahi whakakino tō ngā putanga mewaro. Hei tauira, ahakoa ka mutu wawe ngā rāpoi ngota mewaro i te kohauhau, ka mahi whakakino tonu. Ko te nuinga o te wera i hopukia e ēnei rāpoi ngota ka tāuteutetia ki te moana, ā ka whakapiki i te pae moana.

He wāhanga nui nō te pūrongo nei e aromātai i ngā huarahi e whakaheke ai i te mewaro me te hauota-rua ōkai – te whakarerekē o te whakatipu kararehe, o ngā kai mā ngā kararehe, o ngā moroiti e whakaputa ai i te mewaro, me te tiroiro i te pāhekohekotanga o te tiomimi me te oneone e whakaputa nei i te hauota-rua ōkai.

Mehemea he whakaaweawe pai tō te kōwhiringa whakaiti i roto i te taiwhanga, i te whakamātau o waho rānei, he tīmatanga noa iho. He nui rawa ngā mea hei whakaarotanga i mua i te whakataunga e tika ai tētahi kōwhiringa hei whakaiti rawa i ngā putanga ā-motu o te mewaro, o te hauota-rua ōkai hoki/rānei.

I roto i tēnei rangahautanga kua kitea kāore he whakautu kotahi kei te taepaepatanga o te rangi.

Kei te mewaro te tino wero. E whā haurima o ngā haurehu koiora te nui o taua haurehu i raro i ngā tikanga kaute o nāianei, ā ko ngā huarahi e whāia ana kia whakaitia ināianei he iti te whakaaweawe.

Tērā tētahi kōwhiringa hei whakaiti e pai ai ā tōna wā pea – he rongoā āraimate e whakaiti pea i te 20 ōrau, nui ake rānei, te mewaro kōpiro e puta ai i ngā hipi me ngā kau.

Ko te rongoā āraimate pēnei ka ngāwari te whakauru ki ngā pūnaha pāmu o nāianei, ā ka whai hua i waho atu o Aotearoa. Heoi anō, kātahi anō ka tīmata tēnei rangahau, ā, kāore i te mōhiotia mehemea ka puta he rongoā āraimate pai.

E rua ngā raru taiao e puta ai i ngā moroiti i roto i te oneone e pākarukaru ai i te mimi kararehe. Ko tētahi ko te haurehu kati mahana e kīia nei ko te hauota-rua ōkai. Ko tētahi atu ko te pākawa ota e whakapākeka nei ki ngā awa me ngā manga. Tērā tētahi atu painga o ētahi tikanga whakahaere kua mahia hei whakautu i ngā āwangawanga e pā ana ki te hauora o te wai. Arā, ko te whakaiti i te hauota-rua ōkai. Hei tauira ko te whakamahi i ngā papa whāngai kia nekehia ngā kau i te tarutaru kararehe i te peka o te tau e kikino rawa te mimi.

E whanake ana te rangahau me te mahi e whakaatu ana ko te huamoni pāmu e pupuritia ana, e pikitia ana pea, ahakoa ka heke te nama o ngā kararehe. Ka heke iho hoki ngā tūraru pāmu. Ko te whakamutu i te hiahia ki ngā urunga pēnei i te kākano pāma ka ārai atu i te piki me te heke o ngā utu e utua ai e te kaipāmu.

Ko Lake View Farm, e tata ana ki Kirikiriroa, kua whakaiti i te nui o ngā kau mai i te 530 i 2009 ki 350 i 2014 – kua whakaiti i ngā putanga o ngā haurehu koiora e rua, kua whakaiti i te whakapākeka pākawa ota hoki, ā kua whakapiki i te huamoni. I runga i te pāmu whakaputa mīti kau i te rohe o te roto o Taupō, kua nui ngā mahi whakarerekē a Mike rāua ko Sharon Barton kia nui ake te uara moni me te uara taiao o te mīti kau. E whai ana a Kaporeihana Whenua kia waro ngū i roto i te tekau tau e whai ake nei, ā kua whakuru ki te miraka hipi me te whakanui ake i ngā mahi ngahere.

I konei ka kōrerotia ngā rākau.

He maha ngā take e whakatō rākau ai ngā kaipāmu – mō te pāhauhau, mō te rākau, kia whakaiti i te ngahorohoro, kia haumarua i ngā arawai, ā kia whakaritea he nohanga. Mō te tana waro e whakaputua ki te rākau, e tata ki te whā tana hauhā kua unuhia i te hau takiwā.

I runga i ngā pāmu pukepuke, ko te tarutaru kararehe i te wāhi tiketike kāore e whaipanga mā ngā kararehe, ā, he uaua mā ngā kaipāmu te whakapara i ngā mōheuheu e hokihoki mai ana. I ētahi wā, ki te hanga tāepa hei aukati i ngā whenua ngoikore nei, ka timata te whanake mai o te ngahere ake o Aotearoa – me te āta whakaputu pōturi nei i te waro mō te wā tītoki.

Ko tētahi ngahere rerekē ko te uru paina e tere tipu ake ai, ā ka whakaputua te waro mō te wā poto i mua i te wā ka topea ngā rākau. I runga i te mahi nei ka kawea atu ngā putanga ki anamata. Engari, ko te painga o tēnei ka whai wā tātou kia ngāwari ai te huri ki anamata e iti ai ngā putanga.

I te raki o Whanganui, ko Dan Steele o te Blue Duck Station kua whakamutu i te whakamahi o te whenua teitei, kua whakauru ki te miere mānuka, ā kua hanga te whare tāpoi. I Taranaki, he mano tāra e utua ana ki a Neil Walker mō te waro e whakaputua ana ki ana ngahere purukamu. E whai pānga ana a Ngāti Porou ki te pāmu i te waro me te whakatipu miere mānuka i tōna whenua pukepuke.

Hei kaupapa nunui rawa mā Aotearoa ngā ture ngaherehere e whakaritea anōtia i muri i te whakamanatanga o te whakaaetanga Parihi. Tērā te wā e taea ai te whakarerekē i ngā ture e whakahaeretia ai te whakaputu waro i raro i te ETS. Kua whakaatuhia e Ngāi Tahu ko te whakaputu waro ki ngā rākau ake o Aotearoa kāore i tino kitea. Mā te hangarau kite tawhiti, mā te whakamahi pea i ngā matatopa, e taea ai te kite i ngā ngahere waro iti i runga i te hekenga o te utu mō te tirohanga me te whakaū.

Mā tēnei rangahautanga kua kaha taku tautoko i te whakatō rākau – engari kāore e taea e ngā rākau anake. Ka taea te whakatipu ngahere, ahakoa kāore e hua mai he hangarau hou. He māmā te ahotakakame kāore e pērā ki ngā āhuatanga kore e mōhiotia o te wāhanga tutahi o te puku o ngā momo kararehe kua kōrerotia i runga ake nei me ngā mahi e whai muri mai i te pānga o te mimi ki te oneone.

Neke atu i te tekau tau, kua kore e whai hua ētahi tīmatanga i te mahi uaua e pā ana ki ngā putanga koiora i te ahuhenua. Ko te kaupapa tuatahi i tikokikoki ai i 2003 i te tarakihana i tapaina i runga i te hē, ‘tāke patero’ i taraiwatia ake i ngā arawhata o te Pāremata.

He mea nui kia mōhianihani ai te whakawhitinga ki te whakatipu kai e iti ai ngā putanga. Ki te whakaroaroa, he ohore te whakawhitinga. I mua, mō te take i kōrerohia ake nei, kua tūtohu au me uru ngā haurehu koiora ki te Whakangārahu Hoko Putanga (ETS). Engari ehara te ETS i te kaupapa kotahi e ahu whakamua ai – tērā ētahi atu kōwhiringa.

Kua whakatūria e te Kāwanatanga te Biological Emissions Reference Group. Ināianei, me timata te whakaiti rawa i te mewaro me te hauota-rua ōkai, nā te mea, nā ēnei mea e rua te wāhi nui o ō tātou putanga haurehu kati mahana.

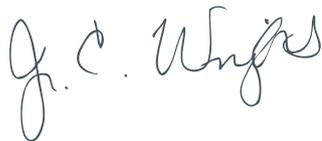
Me timata te whakawhitinga. Ki te kore tātou e aro atu ki ngā haurehu nō te ahuhenua, ko ētahi atu wāhanga o te ohaoha – me ngā kaiutu tāke – ka tino pēhia.

Kia noho kanorau te whakamahi whenua he uaua mō te whenua tawhiti rawa e hokohoko ai i te nuinga o ngā kai e whakatipuria ana. Heoi anō, ko te mea mōhiotia mō ngā kaipāmu o Aotearoa, ka taea e rātou te urutau.

Waihoki, kāore i te mōhiotia he pēhea te rerekē o ngā kai o anamata. Kua timata ētahi kamupene hou i Silicon Valley te whakatipu i te miraka me te mīti horihori. Ka whakatipuria i roto i ngā taiwhanga ki te Pītau Ira kararehe.

He mea nui kia whai huamoni te wāhanga ahuhenua o anamata. Nā reira me whai huarahi ki te whakatipu me te hoko i ngā rawa hou, i ngā rawa rerekē rānei, e tutuki ai i ngā hiahia o te ao, me te whakaputa iti i ngā haurehu kati mahana.

Ina tirotiro ngā kaipāmu i ō rātou whenua i paunga o te rima tekau tau e whai ake nei, ko te hiahia ka kitea he hāpori ngangahau e whāngai i ngā tāngata o Aotearoa me te ao hoki – ā, ka mahia kia tautoko i te noho taurite o tō tātou āhuarangi.



Dr Jan Wright

Te Kaitiaki Taiao a Te Whare Pāremata



1

Introduction

Greenhouse gases are gases that trap heat in the atmosphere. Without such gases in the atmosphere, life on Earth would not be possible. Indeed, as John Tyndall, the discoverer of the greenhouse effect, wrote:

“The warmth of our fields and gardens would pour itself unrequited into space, and the Sun would rise upon an island held fast in the iron grip of frost”.¹

But being held fast in the iron grip of frost is not the problem we face. For 150 years or so, the concentrations of greenhouse gases in the atmosphere have risen steadily, trapping more and more heat. Fifteen of the sixteen hottest years on record have occurred since 2000.²

The main greenhouse gas is carbon dioxide. It's steeply increasing concentration in the atmosphere is due to the burning of fossil fuels and deforestation. Of the remaining greenhouse gases, methane and nitrous oxide are the most important.

In New Zealand, most of the methane and virtually all of the nitrous oxide is biogenic – it is of biological origin.

- Most of the methane is emitted when sheep and cattle burp.
- Most of the nitrous oxide is emitted when animal urine interacts with microbes in soil.

Sheep, cattle and other ruminants have the valuable ability to convert grass into protein. With its temperate climate, much of New Zealand is well-suited to growing grass, and pastoral farms cover about a third of the country. This results in methane and nitrous oxide together forming about half of the country's greenhouse gas emissions.

This high proportion of emissions coming from agriculture is a major challenge. The science is complex and the policy debate is polarised.

The main policy 'instrument' in New Zealand for reducing greenhouse gas emissions is the Emissions Trading Scheme (ETS). The biological gases from agriculture have not yet been included in the ETS. Some argue they should be; others make the opposite case.

This particular dispute, however, lies within a bigger question – what, if anything, should we do about the methane and nitrous oxide from agriculture? Our efforts to answer this question will be more efficient and constructive if we have a common understanding of the basic science. It is hoped that this report will help develop that understanding.

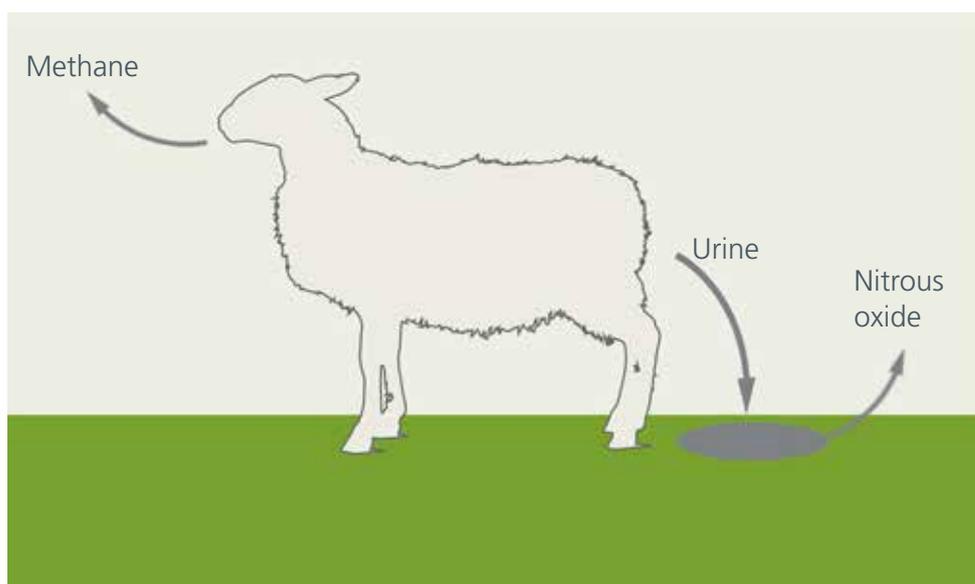


Figure 1.1 In New Zealand, most of the emissions of methane and nitrous oxide are by-products of pastoral farming. Contrary to popular belief, almost all of the methane comes out of the front end, not the back end, of ruminant animals.

1.1 Purpose of this report

The Parliamentary Commissioner for the Environment is an independent Officer of Parliament, with functions and powers granted by the Environment Act 1986. She provides Members of Parliament with independent advice in their consideration of matters that may have impacts on the quality of the environment.

Climate change is the most important environmental issue the world faces. Late last year at the Paris conference, almost all the countries in the world (including China and the United States) committed to taking action to limit the warming of the atmosphere to well below two degrees Centigrade.

The target for 2030 that New Zealand committed to at Paris is important, but it is more important to keep our eyes on the long-term goal – to map out a pathway toward a low-carbon economy. Indeed, the Government recognised the need to look decades ahead when it set the '50 by 50' target in 2011 – a 50% reduction in the country's greenhouse gas emissions by 2050.

Most other nations are currently focused on carbon dioxide emitted from burning gas and coal in electricity generation, in heavy industry, and in transport. However, relatively little of New Zealand's electricity comes from burning fossil fuels and the country has little heavy industry, although transport emissions are high.

Nevertheless, greenhouse gas emissions per capita in New Zealand are one of the highest in the world – largely because the country produces so much food. So while there are big challenges in dealing with the biological greenhouse gases from agriculture, deciding what to do about them cannot be delayed indefinitely.

Thus, the purpose of this report is to tease out various issues in the fraught area of the biological emissions. It is focused on explaining the complexities and exploring a number of key questions to provide a basis for discussion and policy-making that is as objective and accessible as possible.

1.2 What are the biological greenhouse gases?

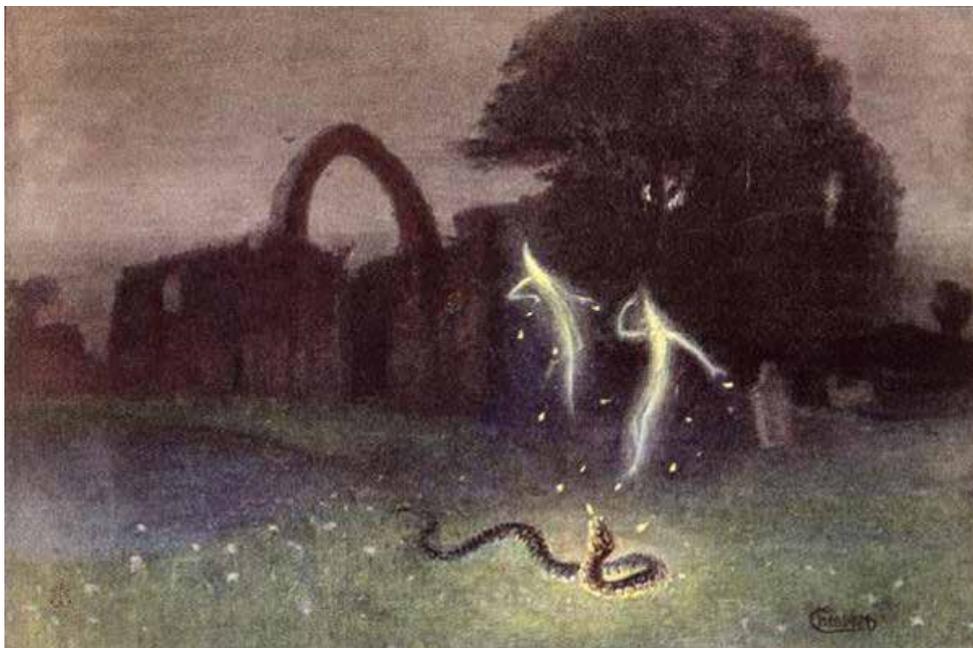
Methane

Methane is an odourless, colourless gas that burns with a blue flame. Each molecule of methane consists of one carbon atom and four hydrogen atoms, and its chemical formula is CH₄.

Methane is formed when bacteria break down organic matter in the absence of oxygen (anaerobic decomposition). It is the main component of marsh gas – the gas produced from decaying vegetation in wetlands.

Sheep, cattle and other ruminants also produce biogenic methane. They are called ruminants because the plants they eat are fermented in the rumen – the main chamber of their stomachs. Some of the microbes in the rumen produce methane.

Confusingly, as well as being a greenhouse gas, methane is also a fossil fuel. This thermogenic methane – methane of thermal origin – has been formed under high temperatures and pressures deep in the earth, and is the main component of natural gas.



The Will o' the Wisp and the Snake by Hermann Hendrich (1854-1931)
Source: Wikicommons

Figure 1.2 A painting by Hermann Hendrich of will-o-the-wisps – the ghost lights thought to be created by methane emitted from marshes and ignited. Will-o-the-wisps were feared because they were thought to lure travellers into dangerous swamps.

Nitrous oxide

Nitrous oxide is a non-flammable gas that smells and tastes slightly sweet. Each molecule consists of two nitrogen atoms and one oxygen atom, and its chemical formula is N_2O . It should not be confused with the other oxides of nitrogen.³

Nitrous oxide acquired the name 'laughing gas' when Humphry Davy (the inventor of the safety lamp) discovered the exhilarating effects of inhaling it. For a long time, it was only used to liven up private parties and public shows. Later it was used as an anaesthetic by dentists and today is still sometimes used to relieve pain.

Like methane, most of the nitrous oxide emitted in New Zealand originates from pastoral agriculture. Most of it comes from urine on soil, with the remainder from fertiliser and from dung. When animals urinate, microbes in the soil act on the nitrogen in the urea. Some of the nitrogen ends up fertilising grass, some is formed into soluble nitrate that leaches into waterways, and some is lost to the atmosphere as nitrous oxide.



Doctor and Mrs Syntax, with a party of friends, experimenting with laughing gas. Coloured aquatint by T. Rowlandson after W. Combe

Source: Wellcome Images, Wikicommons, CC BY 4.0

Figure 1.3 A laughing gas party in the eighteenth century.

1.3 What this report does not cover

This report does not include any detailed discussion or analysis of the following.

- Targets or scenarios for reduction of greenhouse gas emissions
- The functioning of the Emissions Trading Scheme, except where pertinent to the agricultural greenhouse gases
- The impacts of climate change on agriculture

Box 1 Adding up different greenhouse gases

Molecule for molecule, methane is a far more potent greenhouse gas than carbon dioxide, and nitrous oxide is much more potent than methane.

The warming effects of methane and of nitrous oxide are calculated using the concept of carbon dioxide equivalence.

Using the standard conversion factors currently used in greenhouse gas inventories:

One tonne of methane is equivalent to 25 tonnes of carbon dioxide.

One tonne of nitrous oxide is equivalent to 298 tonnes of carbon dioxide.⁴

Chapter 3 discusses this in more detail.

1.4 What comes next?

Chapter 2 begins by showing how unusual New Zealand's greenhouse gas profile is compared with other developed countries. The biological processes that lead to the emission of methane and nitrous oxide from agriculture are then described. A fourth section with New Zealand's total greenhouse gas emissions and the concept of emissions intensity – the amount of greenhouse gas emitted per unit of product. The chapter ends with a discussion of how changes in farm management can reduce emissions.

Chapter 3 is focused on the characteristics and climate impacts of the three main gases, and discusses how they can be compared.

Chapter 4 introduces the chapters of the report that deal with mitigation options – different ways of reducing the biological emissions from agriculture. It outlines five questions that need to be considered when assessing the potential of a mitigation option.

In the next five chapters, these five questions are used to guide thinking about the potential of a number of mitigation technologies and management practices that are the subject of research in New Zealand. Some are in the early stages of research, others are being tested in field trials, and others are being used to some extent on farms. There is still much to be learned, so the assessments are tentative. But they do give a sense of the potential of a range of different options, including identifying some of the barriers that stand in the way of their widespread adoption.

Chapter 5 is about the selective breeding of 'low emission' sheep and cattle.

Chapter 6 is about reducing biological emissions by changing animal feed.

Chapter 7 is about biotechnologies that directly target the microbes in the rumen that produce methane.

Chapter 8 is about ways of reducing the nitrous oxide that is produced when microbes in soil interact with animal urine and nitrogen fertiliser.

Chapter 9 examines a different approach to mitigating methane and nitrous oxide emissions.

As trees grow, they take carbon dioxide out of the atmosphere. Thus, trees can be used to offset the biological emissions.

Chapter 10 contains the conclusions reached during the investigation.

Two reports were commissioned from Motu Economic and Public Policy Research to provide background information for this investigation. One report is focused on the science of biological emissions from agriculture, and was jointly authored by a scientific working group. The second report discusses the treatment of agriculture as part of New Zealand's climate policy. These reports are available at www.pce.parliament.nz.



Source: Fairfax NZ

Figure 1.4 Climate change will result in more extreme weather like droughts and floods. Areas like North Canterbury (pictured) have endured prolonged drought conditions in recent years, exposing farmers to higher supplementary feed costs.



2

Pastoral farming and the biological gases

This chapter provides further information on the biological gases from agriculture in New Zealand.

It is divided into five sections.

New Zealand's unusual greenhouse gas profile – currently, 44% carbon dioxide, 43% methane, and 11% nitrous oxide – is the subject of the first section.⁵ The large proportions of methane and nitrous oxide make this a very different profile from that of many other countries.

The production of methane from pastoral agriculture is described in the second section. Sheep, cattle, and other ruminants have been domesticated by humans because they can digest tough plants like grass and turn it into meat, milk and wool. But some of the microbes that live in the rumen produce methane.

Most of the nitrous oxide from pastoral agriculture is produced when microbes in the soil break down nitrogen in animal urine. Much less comes from fertiliser and a tiny amount from dung. How this occurs is described in the third section. Some of the nitrogen fertilises plants, some ends up as nitrate polluting waterways, and some is emitted into the air as nitrous oxide.

Discussions about the methane and nitrous oxide from agriculture sometimes veer between two different measures of emissions – total emissions and emissions intensity. This is the subject of the fourth section.

There are changes that can be made now to the way some farms are managed that reduce emissions of methane and nitrous oxide while maintaining or increasing profitability. This emerging area of interest is discussed in the fifth section.

2.1 New Zealand's unusual greenhouse gas profile

New Zealand's greenhouse gas profile sets it apart from many other countries. Figure 2.1 shows methane and nitrous oxide as a percentage of the total greenhouse gas emissions of all the countries in the OECD. The percentage for New Zealand – about 54% – is the highest by a considerable margin.⁶

Globally, *carbon dioxide* is the main greenhouse gas. Most of it is emitted when coal, oil, and gas are burned, but about 15% is the result of deforestation and other changes in the way land is used.⁷ However, carbon dioxide forms less than half of New Zealand's greenhouse gas emissions.

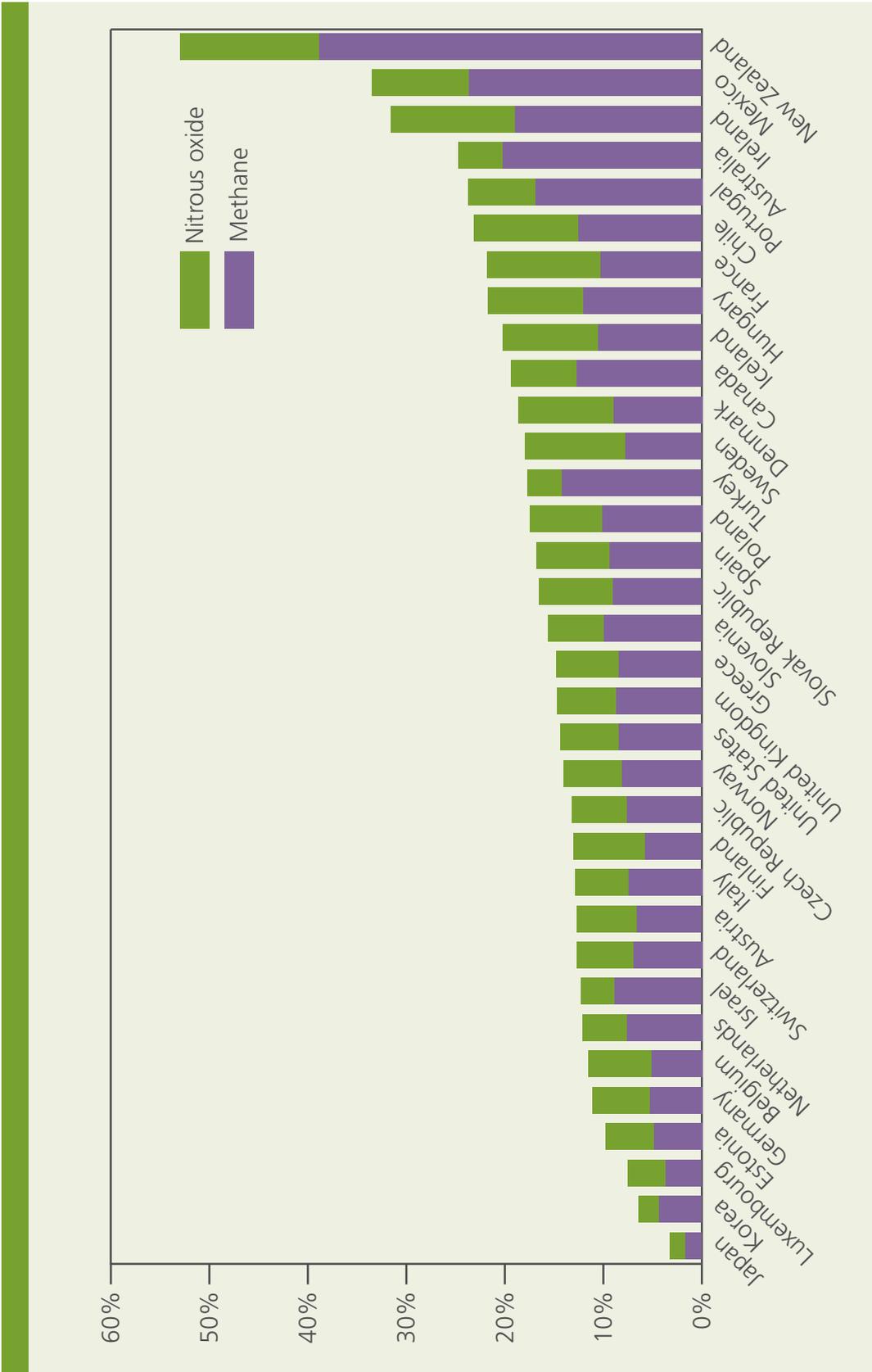
In contrast, emissions of methane and nitrous oxide in New Zealand are relatively high because pastoral agriculture makes up a large part of the economy.

While sheep and cattle are the main source of *methane* in New Zealand, this is not the case in many other countries. The flooding of rice paddies leads to anaerobic decomposition of plants and thus the release of methane. In some industrialised countries, the main source of methane is the 'fugitive emissions' that leak into the atmosphere when natural gas and oil are extracted and when coal is mined.⁸

Agriculture is the main source of *nitrous oxide*. It is emitted when microbes in soil break down animal urine and nitrogen fertiliser. In New Zealand, about 17% comes from fertiliser, but it is much higher in countries where most of the agricultural land is used for growing crops. Nitrous oxide is also emitted in diesel exhaust and during the manufacture of plastics and fertiliser, though these are minor sources in New Zealand.

Measuring the carbon dioxide emitted from burning fossil fuels is relatively straightforward because it can be derived directly from sales of coal, gas, and oil. But estimating methane and nitrous oxide emissions is much more difficult because there is so much variation within biological systems.⁹

Along with most other countries, New Zealand has a greenhouse gas inventory that keeps track of the emissions of the different greenhouse gases. This inventory is based on internationally accepted methodologies, but some changes have been made that better reflect the reality in New Zealand.¹⁰



Data: OECD statistics

Figure 2.1 Methane and nitrous oxide as a percentage of the total greenhouse gas emissions of OECD countries in 2010. Both gases are expressed in carbon dioxide equivalents. Methane and nitrous oxide from all sources in each country are included, not just from agriculture.

2.2 How methane is produced

Methane currently accounts for 43% of New Zealand's greenhouse gas emissions. Over 80% of it is produced by ruminant animals – cattle, sheep, deer, and goats.¹¹

Ruminants are mammals that have four-chambered stomachs – the rumen, the reticulum, the omasum, and the abomasum. This complex digestive system enables them to readily break down and extract energy and nutrients from fibrous plants like grass.

Part of this digestive process involves repeatedly regurgitating and re-chewing the tough plant material. As Aristotle noted in the earliest known description of the four chambered stomachs of ruminants in 350 BC: *“These animals, by the way, are those that are said to chew the cud...”*¹²

Within the rumen, billions of microbes break down complex carbohydrates into simpler molecules – a process known as enteric fermentation. The rumen is essentially a big fermentation vat that continuously produces nutrients for the animal (Figure 2.2).

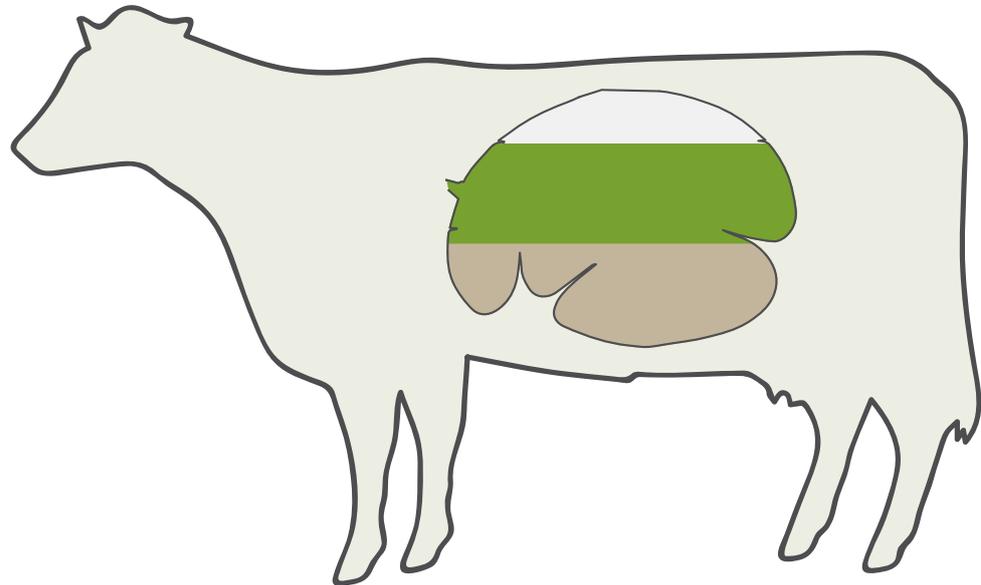
Some of these microbes – methanogens – produce methane. This methane does not appear to play any useful role in the digestion process, and is effectively a loss of energy that the animal could have used.

A layer of gas – mostly carbon dioxide and methane – forms and sits on top of the feed in the rumen. About 10% of the methane is absorbed into the blood and is breathed out by the animal. Regular contractions of the rumen push the gas bubble forward and out of the oesophagus, resulting in the rest of the methane being burped out by the animal.¹³

A much smaller amount of methane is emitted from decomposing effluent.

Table 2.1 Methane from farm animals in New Zealand in 2014. This includes both enteric methane and methane from effluent.

	Sheep	Beef	Dairy
Kilograms of CH ₄ from one animal in one year	12	59	88
Tonnes of CO ₂ -eq from one animal in one year	0.31	1.47	2.19



□ Layer of gas ■ Raft of fibrous plant material ■ Microbial 'soup'

Figure 2.2 A schematic diagram of the rumen. The rumen is the first, and by far the largest, chamber of the four-chambered stomach in a ruminant. Its capacity is typically 100 litres in a cattle beast and 30 litres in a sheep.

2.3 How nitrous oxide is produced

Nitrous oxide currently accounts for 11% of New Zealand's greenhouse gas emissions. Most of it originates from the urine and the dung of farm animals. Over the last 25 years, the nitrous oxide originating from synthetic fertiliser has increased rapidly, though it remains relatively small.¹⁴

Much more nitrous oxide comes from urine than from dung. The nitrogen in urine is readily available, whereas dung takes time to break down and release nitrogen. Thus, a lot more of the nitrogen in the dung ends up fertilising the plants.

Urea from urine or fertiliser deposited on pasture is broken down by microbes in the soil (Figure 2.3).

- Some of the nitrogen is absorbed by plants. Nitrogen is an essential element for plant growth.
- Some of the nitrogen is converted to nitrate. Because nitrate is highly soluble, it can be washed off into waterways or leach down through soil into groundwater.
- A small amount of the nitrogen – about 1% – is converted into nitrous oxide and emitted into the atmosphere.

The quantity of nitrous oxide that is emitted in a particular situation depends on many factors.¹⁵ One factor is the moisture in the soil – the microbes that produce nitrous oxide thrive in water-logged soil. Another factor is soil compaction – heavily compacted soil can slow plant uptake of nitrogen, and so lead to the release of more nitrous oxide.¹⁶

Table 2.2 Nitrous oxide from farm animals in New Zealand in 2014¹⁷

	Sheep	Beef	Dairy
Kilograms of N ₂ O from one animal in one year	0.2	1.1	1.8
Tonnes of CO ₂ -eq from one animal in one year	0.07	0.32	0.54

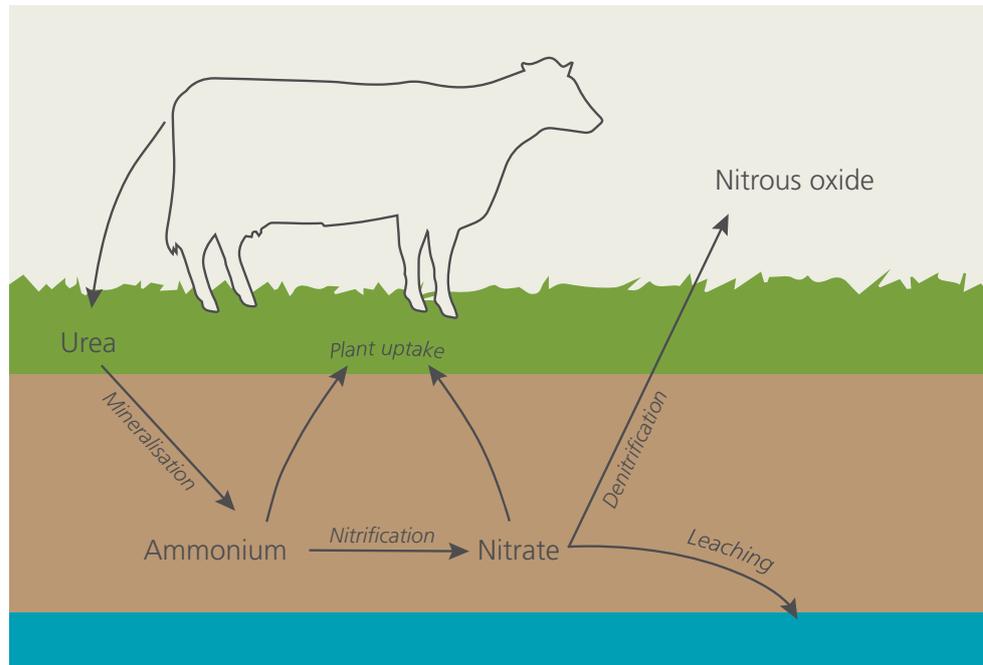


Figure 2.3 The nitrogen in urine deposited on pasture ends up in three main places. Some fertilises the growth of grass and other pasture plants. Some ends up in the atmosphere as nitrous oxide. Some is leached into water where it can help fertilise unwanted plant growth such as periphyton (slime) and algal blooms. Nitrogen from the application of fertiliser follows the same cycle. (Some of the urea is converted to ammonia gas. Most of the ammonia is deposited back on the ground, where it enters the soil nitrogen cycle. This is not shown in the figure.)

2.4 Total emissions and emission intensity

Discussions about the biological emissions from agriculture sometimes veer between two different measures of emissions – *total emissions* and *emissions intensity*.

Total emissions of greenhouse gases are the cause of climate change.

The total biological emissions from agriculture over the last 25 years in New Zealand have increased by about 15% (Figure 2.4). In contrast, over the same period the carbon dioxide emissions from road transport increased by 71%, from industrial processing by 45%, and from electricity and heat by 21%.

Emissions intensity is the amount of greenhouse gas (in carbon dioxide equivalent) emitted per unit of product. So for pastoral agriculture, emissions intensity is measured in terms of tonnes CO₂-eq per kilogram of meat or milk.

While total biological emissions have risen by 15% over the last 25 years, the emissions intensity of pastoral agriculture has declined by 20% due to large improvements in productivity. This is shown in Figure 2.5.

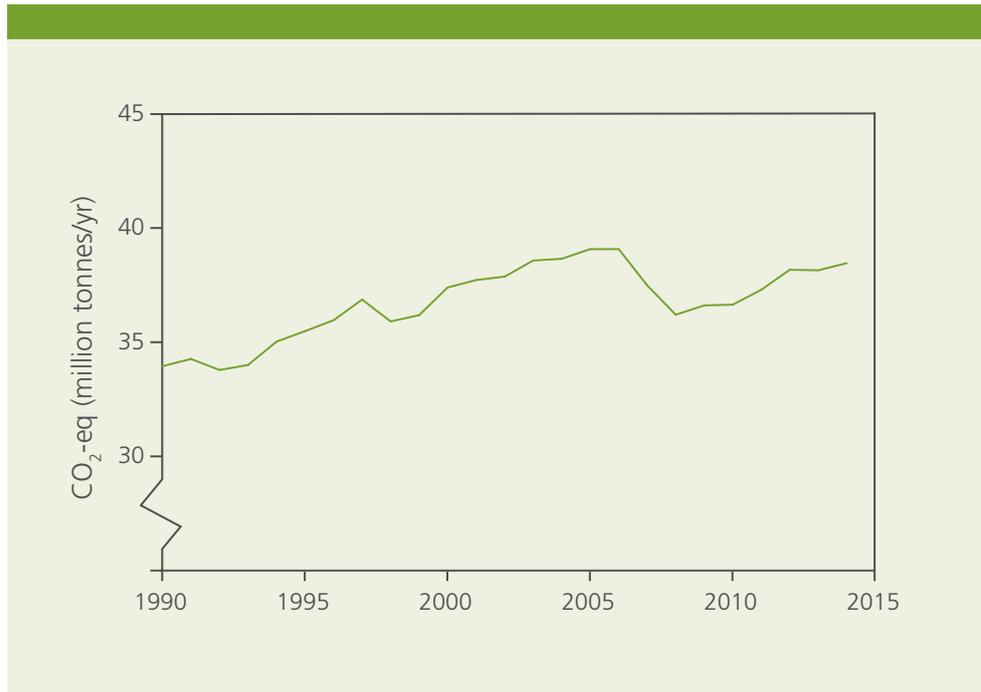
The number of dairy cows in New Zealand has almost doubled over the last 25 years, but each cow is producing 35% more milk. The number of sheep has almost halved, but on average lamb production per sheep is 60% higher.¹⁸

Without the gains in productivity that have been achieved since 1990, emissions of methane and nitrous oxide from agriculture would now be about 40% higher than they currently are.¹⁹ These improvements have been achieved through breeding more efficient animals and improving farm management. Such improvements in emissions intensity are expected to continue but at a declining rate.²⁰

Despite the decline in biological emissions intensity over the last 25 years, total emissions from agriculture increased over the same period because so much more food has been produced.

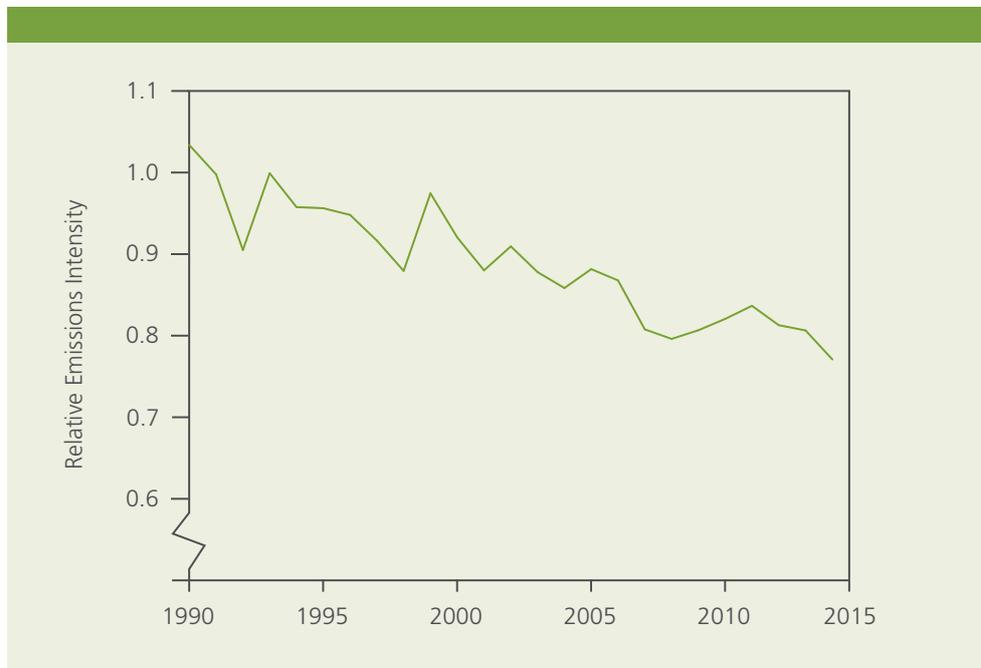
It is sometimes claimed that New Zealand is the most greenhouse gas efficient producer of milk in the world – that the emissions intensity of the milk produced here is lower than in any other country.

But comparing the emissions intensity of dairy farming across countries and production systems is extremely difficult, and can never be precise.²¹ Calculations of emissions intensity are very sensitive to different methodologies, assumptions, and data quality.²² However, it is fair to say New Zealand is one of the most efficient producers of milk and meat.²³



Data: New Zealand Greenhouse Gas Inventory

Figure 2.4 The total biological emissions from agriculture in New Zealand have increased by about 15% over the last 25 years. The impacts of the 1997/98 El Niño drought and the more widespread 2006/07 drought can be seen – reducing stock numbers reduces emissions of the biological greenhouse gases.



Data: Reisinger and Clarke, 2016.

Figure 2.5 The emissions intensity of pastoral agriculture in New Zealand has declined by about 20% since 1990 due to improvements in productivity.

2.5 Changing farm management can reduce emissions

New Zealand farms vary widely in their biological emissions – the highest emitting farms can produce around twice as much methane per hectare, and three times as much nitrous oxide, as the lowest emitting farms. Biological emissions intensity can also vary by a factor of two or more.²⁴ This reflects the variety of soils, climate, farm size, and farm type, and importantly, the way in which a farm is managed.

Many farmers are already reducing their emissions of greenhouse gases. For some, this is a conscious decision, while for others, reductions are occurring as a co-benefit of other actions, such efforts to reduce impacts on water quality.

There is an increasing body of research showing that it is possible on some farms to reduce stock numbers and thus reduce greenhouse gas emissions, while maintaining or improving profitability.²⁵

In one case study of a Waikato dairy farm, the number of cows was reduced from 530 to 350 over a five-year period. A range of improvements to farm management led to lower input costs. Each cow became more productive, the milk produced by the farm remained the same. The outcome was increased profitability, a small reduction in methane, a reduction in nitrous oxide of 20-30%, and a reduction of nitrate leaching of 50%.²⁶

A major project is underway aimed at improving productivity and simultaneously reducing greenhouse gas emissions on 29 Māori farms. Four of these were chosen as Focus Farms – two dairy farms and two sheep and beef farms. A range of changes to the farm systems were modelled using FARMAX and OVERSEER.²⁷ These included changes to feeds, fertiliser application, stocking rates, and the stock mix. The use of feed pads, and planting trees – manuka, pines, and cypresses – were also modelled.²⁸

Figure 2.6 shows a field day on Oromahoe, one of the Focus farms in the study.²⁹

The modelling of changes to the management of the farms has generally shown the potential for relatively modest reductions in greenhouse gas emissions (5–10%). However, in some cases, the modelling has shown potential for greater reductions in both biological gases, along with increased profitability.



Source: Oromahoe Trust

Figure 2.6 A field day on Oromahoe, a large sheep and beef finishing farm held in a trust for a number of Ngāpuhi hapū. The Trustees have a strong focus on improving the performance and sustainability of the farm, and are considering ways of increasing the profitability of the farm while also reducing greenhouse gas emissions.



3

Greenhouse gases differ in important ways

The impact of any greenhouse gas depends on many things. How much heat each molecule traps is just the beginning. There are many other factors that affect the impact that different greenhouse gases have.

There are three sections in this chapter.

The first section is a brief description of the fate of the three main greenhouse gases in the atmosphere. What happens to methane is different from what happens to carbon dioxide. What happens to nitrous oxide is different again.

The second section is about metrics – the ways in which different greenhouse gases can be added together. This is of particular interest in New Zealand because of the high proportion of short-lived methane in the country's greenhouse gas profile.

How much then do the different gases matter? The third section begins to explore this question.

3.1 Three very different gases

The three main greenhouse gases – carbon dioxide, methane, and nitrous oxide – have very different characteristics.

Carbon dioxide

Molecule for molecule, carbon dioxide is the weakest of the three greenhouse gases. It is a stable molecule and does not break down in the atmosphere.

Carbon dioxide is a long-lived greenhouse gas. However, different molecules spend very different periods of time in the atmosphere. This is because of the way carbon dioxide cycles between land, sea, and air. One molecule might be absorbed into a tree through photosynthesis, another might dissolve in the sea making it more acidic, and another might stay in the atmosphere trapping heat for thousands of years.³⁰

Methane

Methane is a more powerful greenhouse gas than carbon dioxide – each molecule of methane traps about 26 times more heat than each molecule of carbon dioxide.³¹

Methane is a short-lived greenhouse gas. Molecules emitted into the atmosphere last on average about 12 years before being broken down into other gases – but a small proportion will remain for decades.

About a third of the warming impact of methane is not caused by methane itself. Under the influence of sunlight, most of the methane emitted into the atmosphere breaks down into carbon dioxide, ozone, and water vapour. The ozone and the water vapour contribute to the warming of the atmosphere.³²

However, somewhat counter-intuitively, the carbon dioxide does not contribute to warming – *if* the methane has come from agriculture. This is because the methane has its origin in the grass eaten by the animal – grass that grew by taking carbon dioxide out of the atmosphere. This carbon dioxide has simply been recycled.³³

Nitrous oxide

Nitrous oxide is more powerful still – each molecule of nitrous oxide traps 219 times more heat than each molecule of carbon dioxide.

Nitrous oxide is a long-lived greenhouse gas. Its average lifetime in the atmosphere is 121 years – ten times longer than the average lifetime of methane.

Most nitrous oxide breaks down eventually into nitrogen and oxygen – but these two gases do not contribute to the warming of the atmosphere.³⁴

3.2 The problem of metrics

Because different greenhouse gases differ in so many ways, adding up the impact of each on the climate is far from straightforward. Yet this is done for many reasons, including setting overall targets for greenhouse gas reductions and measuring progress towards them.

Emissions of different greenhouse gases are commonly added together in units of equivalent carbon dioxide – CO₂-eq.

The standard metric used in international agreements is the **Global Warming Potential 100** (GWP₁₀₀). Under this metric:

- 1 tonne of methane = 25 tonnes of CO₂-eq
- 1 tonne of nitrous oxide = 298 tonnes of CO₂-eq

The GWP₁₀₀ of a greenhouse gas is the total heating that a tonne of the gas released now causes over the course of the next century relative to carbon dioxide. Thus, a tonne of methane emitted this year causes 25 times as much heating over the next hundred years as a tonne of carbon dioxide.³⁵

One tonne of nitrous oxide emitted this year causes 298 times as much heating over the next hundred years as a tonne of carbon dioxide.³⁶

Another metric for adding up the effect of different greenhouse gases that is sometimes proposed is **Global Temperature Potential 100** (GTP₁₀₀).

The GTP₁₀₀ of a greenhouse gas is the temperature change that a tonne of the gas released now will cause one hundred years in the future relative to carbon dioxide. Unlike GWP₁₀₀, it is not concerned with effects in the interim, only with the temperature change 100 years in the future.³⁷

The GTP₁₀₀ of methane is about 4, which is much smaller than the GWP₁₀₀ of 25. This is a consequence of the short lifetime of methane in the atmosphere. A hundred years from now, there will be very little of the methane released this year still in the atmosphere.

In contrast, the GTP₁₀₀ of nitrous oxide is similar to its GWP₁₀₀. This is because it has a long atmospheric lifetime. A hundred years from now, much of the nitrous oxide released this year will still be in the atmosphere.

Another metric that has been mooted is a time-varying GTP. This GTP rises steeply as a target – for example, a temperature increase, such as 2°C, or a year, such as 2100 – is approached.³⁸

There are other metrics that have been suggested by various experts. But there will never be a ‘right’ one, because constructing a metric involves more than science.³⁹ It involves judgements about the relative importance of different effects, and when they occur – in the short, medium, or long term.

To quote Professor Myles Allen:

*“... any metric that is suitable for longterm impacts would be misleading for shortterm impacts and vice versa. Using a metric that changes over time would help, but introduces greater complexity and uncertainty.”*⁴⁰

3.3 So how much do the different gases matter?

Radiative forcing is the term used by climate scientists to describe the difference between the energy in sunlight being absorbed by the Earth and the energy being radiated back to space.

If it is positive, the Earth is warming; if it is negative, the Earth is cooling.

Greenhouse gases trap heat in the atmosphere. Figure 3.1 shows the radiative forcing from the three main greenhouse gases as they have accumulated in the atmosphere over the last century and a half. Carbon dioxide has become more and more dominant.

A tonne of methane creates a strong pulse of warming in the atmosphere, but is a lesser force overall than carbon dioxide – there is much less of it and it only persists for a short time in the atmosphere.

Most of the methane released this year will be gone in twenty years. But each strong pulse of warming is being replaced by another slightly bigger pulse.

Nitrous oxide is a relatively small force because its concentration is relatively low, but it stays in the atmosphere for a long time.

It is important to distinguish between the presence of these gases in the atmosphere and the damage they do.

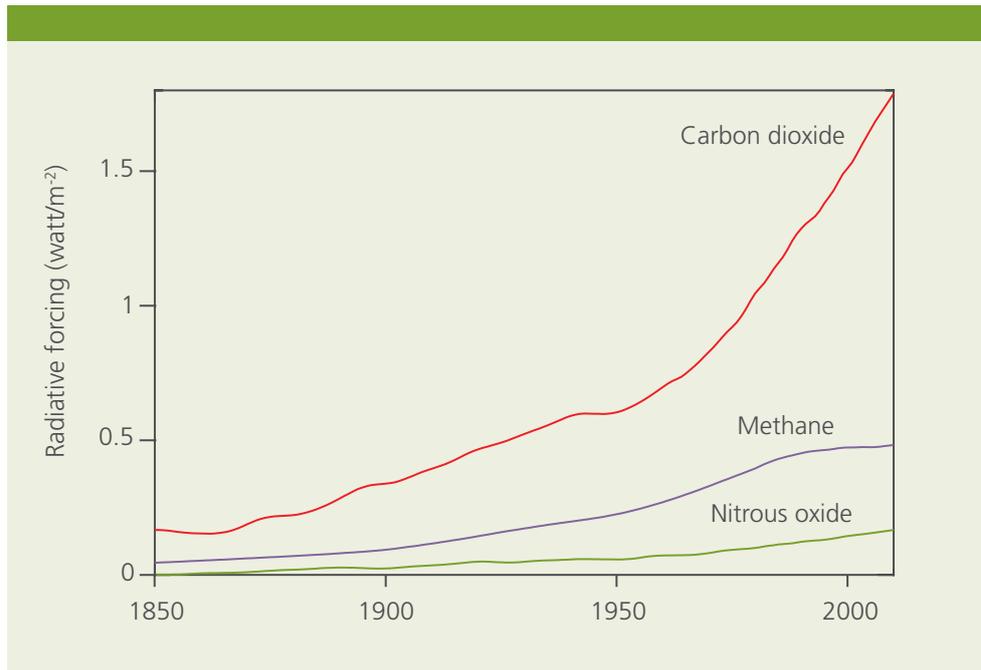
Most of the heat trapped by these gases while they are in the atmosphere is absorbed into the ocean. Like any other liquid, the warmer the sea becomes, the more it expands. And the more it expands, the higher the level of the sea will rise. In this way, current emissions of all three gases will affect the Earth for thousands of years.

In contrast, the increasing acidification of the ocean is caused by carbon dioxide leaving the atmosphere and dissolving in the sea. Methane and nitrous oxide have no impact on this.⁴¹

The rate of temperature rise is also important. The more quickly the temperature rises, the less time the world has to adapt to the changing climate. All the greenhouse gases are affecting the rate at which the Earth is warming.⁴²

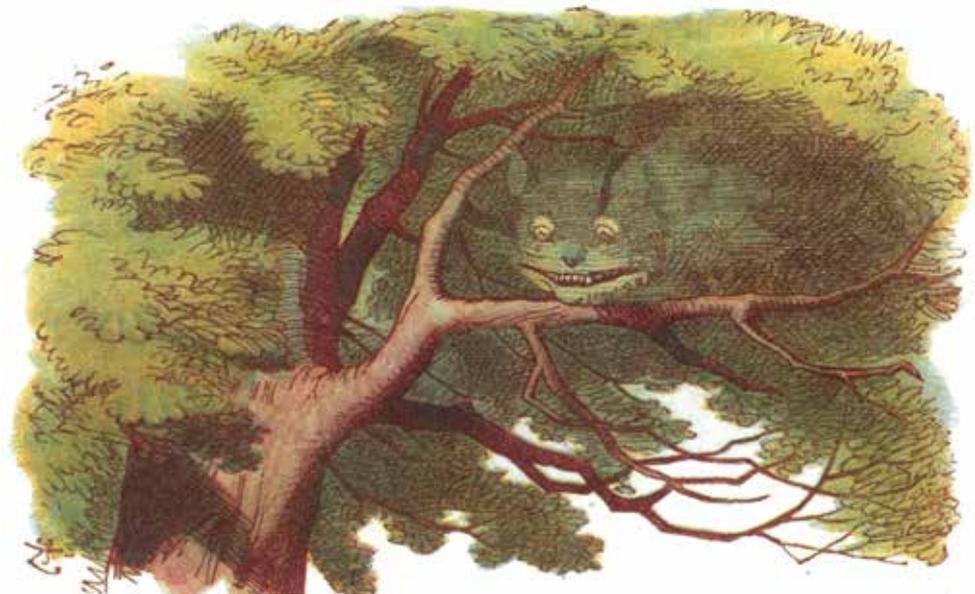
Because long-lived gases accumulate in the atmosphere, they keep driving the temperature upwards.

Methane is different. If the flow of methane into the atmosphere became constant, and there were no other greenhouse gas emissions, the temperature of the atmosphere would stabilise over a few decades.⁴³ But the higher the level of methane, the higher the temperature would be when it stabilised.



Source: IPCC, 2013.

Figure 3.1 The radiative forcing from the three main greenhouse gases as they have accumulated in the atmosphere over the last 150 years. The indirect effects from the decomposition of methane are not included, and would increase the radiative forcing of methane by about a third.



Source: alice-in-wonderland.net

Figure 3.2 In *Alice's Adventures in Wonderland*, the Cheshire Cat disappears but leaves its grin behind. While methane molecules disappear relatively rapidly from the atmosphere, they do leave some damage behind.

3.4 In conclusion

The three major greenhouse gases – carbon dioxide, methane, and nitrous oxide – all behave very differently in the atmosphere.

Currently, the standard way in which emissions of different greenhouse gases are added together is by using the metric GWP100. Some have contended that this metric places too much weight on methane and not enough on carbon dioxide.

There is particular interest in this debate in New Zealand because the methane emissions from pastoral agriculture form such a large proportion of the country's greenhouse gas profile.

All metrics are problematic in some way. This is because they are mixes of scientific facts and value judgements. The more weight given to the impacts of climate change over the next few decades, the more we should be concerned about methane. The more weight given to the long-term impacts of climate change, the less we should be concerned about today's methane.

There is no debate about the importance of nitrous oxide. It is a very powerful greenhouse gas that persists in the atmosphere for a long time.

Regardless of the stance different analysts take on the urgency of reducing methane, all agree on the overriding need to reduce emissions of carbon dioxide. It will not be possible to stop temperatures from continuing to rise without stopping net carbon dioxide emissions.

Carbon dioxide is the main problem, but methane is doing damage and cannot be ignored.



4

Evaluating ways of reducing biological emissions

New Zealand has a strong record of research into ways to reduce greenhouse gas emissions from pastoral farming, and has taken a leadership role internationally.⁴⁴ A way of reducing methane or nitrous oxide that is found to be effective in this country could potentially help other countries reduce their biological emissions.

Mitigation options – ways of reducing biological emissions – can take many forms. One option might involve the use of new biotechnology, another might involve changing a management practice, and yet another might involve reducing stock numbers or changing land use.

A number of different mitigation options are being investigated and developed by New Zealand scientists. In this chapter, a set of questions for exploring the potential of such options is presented.

Suppose a silver bullet solution were to be found for reducing methane emissions, and another found for nitrous oxide emissions. What characteristics would such a silver bullet have?

It would be very effective at reducing emissions at a farm level. It might produce other benefits such as increased productivity, but would not produce major undesirable effects. It would be cost-effective, and able to be readily integrated into existing farming systems. And importantly, farm-level effectiveness would scale up across the country to make sizeable dents in New Zealand's total greenhouse gas emissions.

There are no silver bullets for reducing methane and nitrous oxide emissions currently on the horizon. But the mitigation options that are the subject of research can be assessed (to some extent) against the characteristics of a silver bullet solution.

In the next four chapters, the potential of various mitigation options is considered – the selective breeding of 'low emission' animals, changes in animal feed, targeting the microbes that produce methane in the rumen, and targeting the interaction between urine and soil that produces nitrous oxide. All of these have been the subject of active research for some time.

The potential of these options is assessed by exploring the answers to the five questions posed in this chapter.

4.1 Is the mitigation option effective?

Does the mitigation option really reduce emissions of methane or nitrous oxide?

A biotechnology might look promising in a laboratory. Another might have demonstrated its effectiveness in field trials, but be less reliable on farms because of the expertise required to implement it.

In some situations, effectiveness may fade over time. This may happen, for example, with options that alter the physiology of the animal – the tendency to revert to a normal state is called homeostasis.

Importantly, the effectiveness of options that target the same biological process are unlikely to be additive. If one option reduces the methane emitted by an animal by 30% and another reduces it by 20%, using both will not necessarily reduce it by 50%.

4.2 Does the mitigation option have other impacts?

Mitigation options that reduce emissions of methane or nitrous oxide will almost inevitably cause other changes. Some changes may be desirable and others not.

For instance, a mitigation option may reduce emissions of one greenhouse gas while increasing emissions of another.

Some mitigation options may have other effects on the environment. For instance, the major source of both nitrous oxide and the nitrate that leaches into waterways is animal urine. Thus, actions taken to reduce nitrous oxide emissions may help improve water quality.

Because both methane and nitrous oxide emissions are waste products, reducing them could potentially increase animal productivity.

A gain in productivity accompanied by a reduction in emissions will lower the emissions intensity of production. But it will not necessarily lower the total emissions on a farm, especially if the productivity gain enables a higher stocking rate.

4.3 Is the mitigation option likely to be cost-effective?

There are four ways in which a mitigation option that reduces methane or nitrous oxide emissions could be cost-effective.

The first is if the cost is so low that it is seen as insignificant.

The second is if using the option has the additional effect of increasing productivity and the value of this exceeds the cost of the option.

The third way depends on the existence of a cost to emitting methane or nitrous oxide. Including biological emissions in the Emissions Trading Scheme would create such a cost. The mitigation option would be cost-effective if emitting is more expensive than mitigating.

The fourth is if consumers are willing to pay a higher price for the use of the mitigation option.

4.4 Can the mitigation option be integrated into existing systems?

A way of reducing methane and/or nitrous oxide needs to be practicable if it is to be widely adopted. One that fits readily into existing pastoral farming systems would be much easier to adopt than one that requires complex new techniques and processes.

Some mitigation options might have impacts that breach regulations. Even if regulations are complied with, concerns about animal welfare or residues in food might be barriers to adoption.

4.5 Does the mitigation option make sense from a national perspective?

A mitigation option may be very effective on a particular type of farm, but there may be relatively few farms for which it is suited, so the impact at a national level would be insignificant.

Another might have a high national potential, but it would take many years before it can be fully implemented.

Finally, reductions in methane or nitrous oxide emissions must be able to be accounted for in the Greenhouse Gas Inventory if they are to be recognised as progress towards any climate change target, including the current 2030 target.



Source: Parliamentary Commissioner for the Environment archives

Figure 4.1 One of the mitigation options covered in this report is the use of chemical compounds that inhibit the production of methane in the rumen. The photograph shows the testing of potential methane inhibitors in rumen fluid at AgResearch in Palmerston North.



5

Breeding low emission sheep and cattle

For centuries, the breeding of sheep and cattle has been done to select the animals that are the hardiest and the most productive.

In this chapter, the potential for selectively breeding animals that are low emitters of methane and nitrous oxide is discussed.

The first section is focused on the potential for the targeted breeding of 'low methane' animals. The amount of methane emitted by ruminants of the same species typically varies significantly. 'Low methane' sheep have been successfully bred in trials in New Zealand, but the equivalent research on cattle has only recently begun.

The second section is focused on the potential for the targeted breeding of 'low nitrous oxide' animals. There is some work being done on the potential for breeding cattle that are efficient converters of feed into protein. Such cattle would excrete less nitrogen, and this would very likely result in lower emissions of nitrous oxide.

The third section is a summary of the potential of selective breeding as a way of reducing the biological emissions from pastoral agriculture, based on the questions in Chapter 4.

5.1 Breeding ‘low methane’ emitters

The targeted breeding of animals that are low emitters of methane is an active area of research in New Zealand.

One study measuring methane from sheep showed that the highest emitters produced 50% more methane than the lowest emitters although both had eaten the same amount of feed.⁴⁵ Another study showed that low emitting sheep have smaller rumens and that food being digested spends less time in the rumen.⁴⁶

The equivalent research on cattle has only just begun in New Zealand, although overseas studies have established that cattle also vary significantly in their methane yield.⁴⁷

It is estimated that selective breeding of low emitters (cattle and sheep) could produce an average 10 to 20% reduction in methane emissions with no change to the amount of feed.⁴⁸ This trait has been shown to persist over several generations in sheep.⁴⁹

It is possible that the chromosomes that carry the genes that lead to low methane emissions could also carry genes that lead to other desirable or undesirable traits.

The breeding of cattle and sheep is aimed at increasing their economic value. Figure 5.1 shows the weighting put on different genetic traits in the dairy industry in New Zealand. Each year these weightings are combined with economic values to create the Breeding Worth index.⁵⁰ A similar breeding index is used for sheep.

Low methane emission does not feature in these indices. It has no economic value because farmers do not face any cost for the methane emitted by sheep and cattle.

Breeding could also help reduce emissions by focusing on selecting animals that are the most efficient converters of feed into products. Animals that need to eat less to produce the same amount of meat or milk would digest less food and therefore would be expected to produce less methane.

Dairy New Zealand is working on developing a breeding value for feed conversion efficiency because it would reduce feed costs.⁵¹ Breeding for feed conversion efficiency could therefore indirectly produce ‘low methane’ cattle. It is likely that such cattle would also be ‘low nitrous oxide’ emitters, and this is discussed in the next section.

The great majority of dairy cattle in New Zealand are bred using artificial insemination. A small number of bulls sire almost all the calves born each year. This means that breeding ‘low methane’ (or feed conversion efficiency) into the country’s beef and dairy herds could be achieved relatively quickly. This is not the case with sheep, where this process may take decades or more.

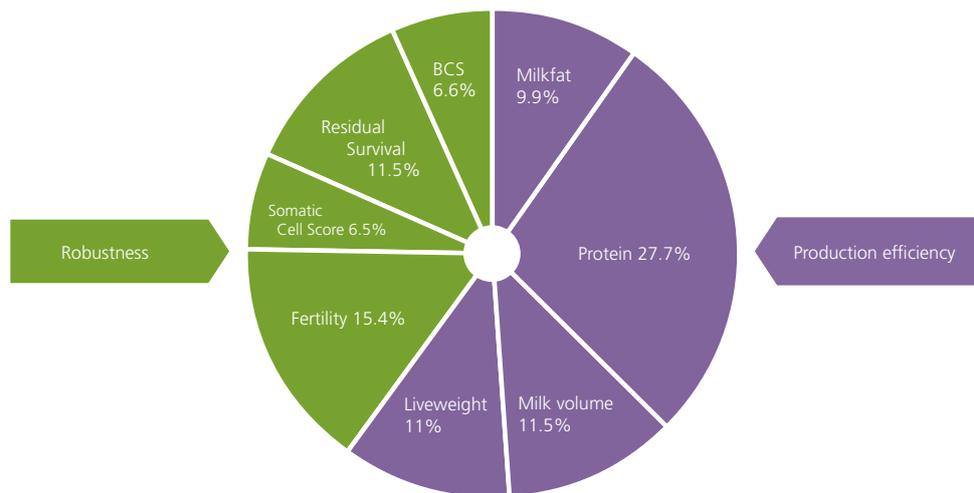
5.2 Breeding ‘low nitrous oxide’ emitters

There are at least two possible avenues for research on breeding cattle and sheep that are low emitters of nitrous oxide.

The first would involve changing the way in which cattle and sheep urinate, or more accurately, the way cows and ewes urinate. The overloading of nitrogen in urine patches created by the females of both species is the main origin of the nitrous oxide and the nitrate leached into waterways. This is particularly so on dairy farms where a urinating cow deposits about two litres of urine on about a fifth of a square metre of pasture.⁵²

Another approach would involve selecting for feed conversion efficiency, as discussed in the previous section. Cattle that use nitrogen efficiently excrete less nitrogen, which should lead to lower nitrous oxide emissions. However, this has not yet been established through measurement.

Feed conversion efficiency in cattle appears to be moderately heritable.⁵³ It is already captured to some extent in the production efficiency traits in the Breeding Worth index.⁵⁴



Source: DairyNZ

Figure 5.1 The Breeding Worth index for dairy cattle in New Zealand.

5.3 In conclusion

Returning to the questions posed in Chapter 4, what is the potential of selective breeding?

Selecting for low methane emitters could be an effective mitigation option. Some sheep and cattle are low emitters of methane, and it has been shown that this trait is heritable in sheep. It is thought that selective breeding could eventually reduce methane emissions from individual animals by an average of 10 to 20% without lowering production.

If it were possible to make every sheep a low emitter of methane, total biological methane could be up to 5% lower than it is now.

Although it is theoretical at this stage, if it were possible to make every cattle beast a low emitter of methane, total biological methane could be up to 10% lower than it is now.⁵⁵

This option could be integrated into current farming systems, but it would take decades to fully implement – although it could be done more quickly for cattle than for sheep.

Work is being done on the possibility of adding ‘feed conversion efficiency’ to the Breeding Worth index. Cattle that eat less to produce the same amount of product emit less methane, and are also likely to excrete less nitrogen leading to lower nitrous oxide emissions.

With respect to other impacts, there are a number of issues. For instance, undesirable traits could be inherited along with the low emission trait.

The research being done on selective breeding is important and holds promise. But it would take a long time before it would have a significant effect at the national level.



6

Low emission animal feed

There is a considerable body of research focused on the potential for reducing methane and nitrous oxide emissions by changing animal feed.

There are three sections in this chapter.

The first section is about the types of animal feed that have been shown to reduce methane emissions – feed that is low in cellulose or high in fat.

The second section is about the types of animal feed that have been shown to reduce nitrous oxide emissions – feed that is low in protein and/or high in carbohydrate.

In New Zealand, most sheep and cattle graze on pasture throughout the year. Most pasture is a mix of ryegrass and clover. The third section is about ryegrasses that could potentially reduce both methane and nitrous oxide emissions.

The fourth section is a summary of the potential of animal feeds for reducing the biological emissions from pastoral agriculture, based on the questions in Chapter 4.

6.1 'Low methane' animal feed

The amount of methane that is burped and breathed out by cattle and sheep is affected by what they eat.

Reducing the amount of *fibres* in animal feed leads to lower methane emissions. This is because less fermentation is needed to break it down in the rumen.

Increasing the amount of fat in animal feed can lead to lower methane emissions. This is because fat is readily digested, and again less fermentation is needed.

Grains are low in *fibres*. Feeding grains to ruminants can reduce methane emissions provided the cereal is at least 30 to 60% of the animal's diet.⁵⁶ But cattle and sheep in New Zealand do not eat this much grain.

Brassicas are also low in *fibres*, and in some parts of New Zealand, are an important feed crop – both as leafy forage and as bulbs.⁵⁷

The effect of feeding forage rape to sheep has been extensively studied. Sheep fed exclusively on forage rape in winter have been found to emit 38% less methane on average, but only 13% less in summer.⁵⁸ Only one study of the effect of feeding brassicas to cattle appears to have been done in New Zealand – it showed heifers fed exclusively on forage rape in winter emitted 43% less methane.⁵⁹ While these reductions in methane are significant, stock are only fed on brassicas in some parts of the country and only for a portion of the year. Thus, reductions at a national level are likely to be very small.

But while feeding forage brassicas to sheep and cattle reduces methane emissions, the standard way in which it is done – break feeding – can lead to increased nitrous oxide emissions and increased nitrate leaching. Break-feeding involves rationing pasture using a moveable electric fence (Figure 6.1).

Break-feeding results in high nitrogen losses particularly when the soil is wet and compacted. In winter, the nitrogen losses from grazing on brassicas can be five to ten times higher than from grazing on pasture – much more of the nitrogen in the urine ends up outgassing as nitrous oxide and leaching off as nitrate.⁶⁰ Thus, encouraging the feeding of brassicas to reduce methane could be counter-productive from an environmental perspective.

Many overseas studies have shown that adding fat to animal feed significantly decreases the methane emitted from cattle.⁶¹ In the feedlot systems used in some other countries, a variety of fats and oils are sometimes added to animal feed. But this is not suited to New Zealand's pasture system.



Source: Parliamentary Commissioner for the Environment archives

Figure 6.1 Break-feeding a winter forage crop. Lower methane emissions from the cattle may come at a cost of higher nitrous oxide emissions and more nitrate leaching into groundwater and streams.

6.2 'Low nitrous oxide' animal feed

What sheep and cattle eat affects the amount of nitrous oxide that is emitted from urine-soaked soil.

Reducing the amount of protein in animal feed helps lead to lower nitrous oxide emissions. Cattle and sheep eat far more protein than they need, and nitrogen is a key element in protein. The less protein they eat, the less nitrogen they excrete, and this leads to less nitrous oxide outgassing from the soil.

Increasing the amount of carbohydrate in animal feed may also help lower nitrous oxide emissions. Carbohydrate promotes the growth of certain species of microbe in the rumen making the feed easier to digest. The animal is able to extract more nutrition and energy out of the food. There is less 'wasted' nitrogen and therefore less nitrogen excreted. In theory, this has the effect of lowering the amount of nitrous oxide emitted.

Maize silage is an animal feed that is low in protein and high in carbohydrate (Figure 6.2). Over recent years it has been increasingly used on dairy farms to supplement ryegrass because it increases milk yield. However, nitrogen fertiliser is used to grow the maize, and this is also a source of nitrous oxide (and leached nitrate). A New Zealand 'whole farm' trial of the use of maize silage as a supplement showed a decrease in nitrous oxide per kilogram of milk, an increase in total milk production, and a small increase in the amount of nitrous oxide emitted from the farm.⁶²

The environmental impacts of feeding maize silage as a supplement depend on how the farm is managed.⁶³

Other plants such as plantain, lucerne, and chicory that are grown as forage crops or mixed in with pasture may also reduce nitrous oxide. One New Zealand trial has shown that dairy cattle grazing on plantain excreted about 50% less nitrogen in their urine compared to those grazed on traditional ryegrass and clover pasture.⁶⁴ Again, all else being equal, less nitrogen excreted should result in less nitrous oxide emitted and less nitrate leached.⁶⁵



Source: Rasbak, Wikicommons, CC BY-SA 3.0

Figure 6.2 The urine of cattle and sheep fed on maize silage contains less nitrogen and may result in less nitrous oxide being emitted. Maize silage is a feed supplement that is produced by harvesting, shredding, and packing maize into covered silage pits. In the absence of air, the maize ferments into a palatable animal feed.

6.3 Ryegrasses that may reduce emissions of both gases

Most livestock up and down New Zealand graze outside, year-round, on pasture. Most of the improved pastures are a mix of ryegrass and clover. Thus, 'low emission' ryegrasses that significantly reduce emissions of methane and/or nitrous oxide, could be relatively effective at the national level.

The rate of uptake of any low-emission grass would depend on how often pasture is re-sown. This is done more often on dairy farms than on sheep/beef farms. Also the effectiveness would decline over time as weeds and other grasses invade the pasture.

High-sugar ryegrasses

High-sugar ryegrasses were originally developed overseas. They have been promoted as increasing the productivity of livestock and decreasing both methane and nitrous oxide emissions. High-sugar ryegrasses are now being sold in New Zealand.

There is relatively little research into how these grasses actually perform in New Zealand. Two studies have looked at the effect on animal productivity. In one study, lambs grazing on high sugar grass gained weight faster than those fed on standard ryegrass.⁶⁶ However, an earlier two-year study of dairy cows gave no conclusive result.⁶⁷

Evidence of reduction in greenhouse gas emissions is even more limited. One study has looked at methane reductions in sheep fed high-sugar grass in respiration chambers. The results were inconclusive – methane emitted from sheep fed high-sugar ryegrass was 9% lower than standard grass in one trial, but no different in the other two trials.⁶⁸

Evidence of reduction in greenhouse gas emissions is even more limited. One study has compared methane emissions from captive sheep fed three different types of ryegrass – a conventional ryegrass and two 'high-sugar' cultivars.⁶⁹

Overall, the methane emissions for sheep fed the 'high-sugar' grasses were lower than for sheep fed the conventional ryegrass. However, the results for the individual grasses were inconsistent across the trials.⁷⁰

Another indoor feeding study found that feeding high-sugar grass to sheep instead of standard ryegrass made no difference to the nitrogen they excreted.⁷¹

Reductions in methane or nitrous oxide emissions from sheep or cattle grazing on high-sugar ryegrass pasture have not been shown, and indeed it may be difficult to do so.⁷²

A high-fat ryegrass

In New Zealand, a new form of ryegrass is under development by AgResearch using genetic modification. This ryegrass is expected to increase productivity, and to decrease both methane and nitrous oxide emissions.⁷³ Figure 6.3 shows the difference in growth between conventional ryegrass and the genetically modified ryegrass under the controlled conditions of a laboratory.

The key feature of the genetically modified ryegrass is that it contains about twice as much fat as non-modified ryegrasses. The scientists who are developing this ryegrass have reported that fermentation of the grass in bottles containing rumen fluid showed a 15% decrease in methane emissions per unit of feed. However, this work is yet to be published.

Increasing the amount of *fat* in animal feed can also lead to lower methane emissions. This is because fat is readily digestible by the animal, so less fermentation is needed.

Importantly, the fat in the ryegrass is stored permanently. This is a key difference between the genetically modified ryegrass and the high sugar ryegrasses. In the latter, the sugar level varies over the day and over the year.

The nutritional composition of the genetically modified ryegrass is expected to result in less nitrogen in the urine. Modelling has shown the potential for a 17% decrease in nitrous oxide emissions per unit of feed, although this has yet to be published.

To date all results have come from controlled glasshouse experiments and models. Indeed the genetically modified ryegrass has not yet been eaten by any animals.

Current New Zealand law places tight restrictions on the field-testing of genetically modified organisms.⁷⁴ Field trials are expected to begin in the United States in 2018.⁷⁵



Source: Parliamentary Commissioner for the Environment archives

Figure 6.3 The high-fat genetically modified ryegrass has been grown under controlled conditions in a laboratory. Both plants in the photograph are the same age. The genetically modified ryegrass on the right has produced more biomass in its leaves and roots than the standard ryegrass on the left. However, the higher productivity of the modified ryegrass could allow for increased stocking rates. While the emissions intensity might fall, adding more livestock could push up the total emissions of the farm.

6.4 In conclusion

Changes to animal feed do not look very promising in the light of the questions posed in Chapter 4. Altering what livestock eat does reduce emissions on some farms for some of the time, but there are important tradeoffs to consider. The impact at a national level would also be likely to be small.

Both methane and nitrous oxide emissions are affected by what sheep and cattle eat. There are a number of different kinds of feed that could reduce methane and/or nitrous oxide, but there are complications with all of them.

In general, the less fermentation in the rumen that is required, the lower the methane emissions will be.

Some low-emission feeds would not fit readily into a pastoral system. Feeding grains, fats, and oils to sheep and cattle reduces methane emissions. But these are not fed in the amounts needed to make a difference in New Zealand.

Forage brassicas are also a 'low methane' animal feed, and are used in parts of New Zealand mainly in winter. But the way in which brassicas are fed – break feeding – can increase both nitrous oxide and nitrate leaching.

Feeds that better meet an animal's nutritional and energy requirements will result in less excretion of nitrogen. This leads to lower emissions of nitrous oxide.

Using maize silage as a supplementary feed can reduce the emissions intensity of meat and milk, but may not reduce total emissions if the maize is then used to increase stock numbers.

Most livestock in New Zealand graze outside year-round on pasture that is a mix of ryegrass and clover. A 'low emission' ryegrass could thus be much more significant than feeds used as supplements. However, the impact would depend on how much and how often pasture is re-sown. Hill country pasture is seldom if ever re-sown. Also over time, weeds and other grass species would invade the pasture, decreasing the effectiveness of the 'low emission' ryegrass.

High-sugar ryegrasses are now being sold in New Zealand. Overseas, they are promoted as leading to higher productivity and lower methane and nitrous oxide emissions, though this has not been substantiated in New Zealand.

Another possibility is the high-fat ryegrass being developed using genetic modification. This ryegrass is expected to increase productivity and it is hoped that it will reduce emissions of both methane and nitrous oxide. At a national level, if the hoped-for benefits eventuate, then the reduction in agricultural methane could be up to 7% and the reduction in nitrous oxide up to 6%.⁷⁶

However, this ryegrass has so far only been grown in a laboratory, and it is yet to be tested in field trials. Also, its higher productivity would likely allow for increasing the number of animals grazing on each hectare – the emissions intensity might be lower, but the total emissions could end up higher.



7

Targeting the methanogens

The microbes in the rumen of sheep and cattle that produce methane are called methanogens.

Directly targeting these methanogens is an active area of research in New Zealand and in some other countries.⁷⁷

Only a proportion of all the microbes in the rumen are methanogens. They do not appear to be necessary for the digestive process in ruminants. In principle, it should be possible to selectively suppress methanogens while maintaining healthy and productive animals.

Two approaches to targeting these methanogens are being developed – methane inhibitors and methane vaccines.

The first section is focused on methane inhibitors. These are chemical compounds that suppress the production of methane when they are fed to sheep and cattle.

The second section is focused on methane vaccines. These too suppress the production of methane, but do it by triggering the immune system of the animal.

The third section is a summary of the potential of inhibitors and vaccines to reduce enteric methane emitted by livestock, based on the questions in Chapter 4.

There are many different types of microbes producing methane in the rumen, but most of the methane is produced by only a few.⁷⁸ In order to be effective, an inhibitor or a vaccine would need to target these dominant methanogens. Because these same few types of methanogens are dominant in the rumens of livestock across the world, the potential effectiveness of a methane inhibitor or vaccine could go well beyond New Zealand.

7.1 Inhibiting the production of methane

A methane inhibitor is a chemical compound that must be fed to the animal so that it can directly target the methanogens in the rumen. It must not affect the health of the animal or leave residues in meat or milk.

There are different ways in which an inhibitor might reduce the amount of methane produced. One inhibitor may kill methanogens. Another may deprive them of the hydrogen they need to produce the methane.

In New Zealand, scientists have screened thousands of compounds as potential methane inhibitors, but have now focused on animal trials of the five that look particularly promising.⁷⁹

One methane inhibitor that has been developed overseas is called 3-nitrooxypropanol (3NOP). When mixed through processed feed and fed to dairy cattle in a feedlot, 3NOP has been shown to reduce methane emissions by about 30%, with no change to the amount of feed consumed and with no change to the amount of milk produced.⁸⁰ The same trial showed no decline in effectiveness over a 12 week period.

However, this inhibitor is unlikely to offer a solution for New Zealand, because administering a methane inhibitor in a pasture-based system is much more difficult. The most likely way it could be done is by putting it in a bolus – a large slow-release tablet that would slowly dissolve in the rumen, thus providing a continuous dose of the inhibitor. An inhibitor administered in this way would have to be effective at very low concentrations in the rumen, otherwise boluses would have to be administered very frequently.

Boluses are commonly used in New Zealand to prevent facial eczema, but the time, labour, and skill involved is considerable (Figure 7.1). A methane inhibitor could be dusted on to pasture or added to drinking water, but the dose received by each animal would vary.

Thus the cost of using methane inhibitors on New Zealand would depend on how often a bolus would need to be administered – the greater the frequency, the greater the cost.

Another critical factor would be the establishment of long-term effectiveness. The effectiveness of an inhibitor would decline if the methanogens become resistant to it.

In theory, a methane inhibitor could be administered to all the cattle and sheep in New Zealand. However, it would be most practicable on lowland farms where stock are brought into yards more frequently.



Source: Fairfax NZ

Figure 7.1 Administering a bolus to prevent facial eczema.

7.2 Methane vaccine

The other approach to suppressing the production of methane is a vaccine. Such a vaccine would trigger the animal's immune system to produce antibodies that 'fight' the methanogens. The antibodies then need to be delivered to the rumen.

One place where these antibodies need to appear is in saliva. Ruminants secrete huge quantities of saliva – every day, cattle produce more than 100 litres each. The saliva is continually transported to and from the rumen as the animal chews, regurgitates, and re-chews its cud. Thus, antibodies in the saliva are delivered directly into the rumen.

To be effective, a vaccine must target the dominant methanogens – the few types of microbes that produce most of the methane. The antibodies that are produced in response to the vaccine must last long enough in the rumen to bind on to these microbes.⁸¹

New Zealand researchers have produced prototype vaccines which generate antibodies that have an impact on methanogens extracted from the rumen of sheep and cultivated in the laboratory. Trials of these vaccines on live sheep are underway to test whether this translates into an impact on methane emissions.⁸²

The aim is to produce a vaccine that would reduce methane emissions by at least 20%, without reducing productivity. It is considered that a vaccine that was less effective than this would not be worth developing.

Once developed into a commercial product, such a vaccine could be 'rolled out' quickly across the country because vaccines are routinely given to livestock in New Zealand. For instance, campylobacter is a common cause of abortion in sheep and it is recommended that all breeding ewes be vaccinated against this bacterial infection (Figure 7.2).

A vaccine would be unlikely to meet consumer resistance because it is not an antibiotic or a food additive.

Once developed, vaccines are cheap to produce. Nonetheless, an effective vaccine could have very high commercial value because it could be sold around the world.



Source: Fairfax NZ

Figure 7.2 Injecting two-tooth ewes with a campylobacter vaccine after shearing on a Hawke's Bay hill farm.

7.3 In conclusion

Two approaches to directly targeting the production of methane in the rumen are being pursued – inhibitors and vaccines.

But when assessed against the questions outlined in Chapter 4, a methane vaccine would clearly be superior to a methane inhibitor – provided it can be developed.

Overseas, a methane inhibitor has been shown to reduce enteric methane by 30%.

There are no successful trials of a methane vaccine as yet. A reduction of at least 20% in enteric methane has been set as a target by the scientists working in this area.

A 25% reduction in the enteric methane emitted by all sheep and cattle would lead to about a 24% reduction in the biological methane from agriculture – assuming, of course, no increase in livestock numbers.⁸³

Because only a few types of methanogens are dominant in ruminants everywhere in the world, the potential of biotechnologies that target methanogens goes way beyond New Zealand. This is particularly true for a vaccine, which could be readily integrated into any system of livestock farming.

Indeed a methane vaccine would have a number of other advantages over a methane inhibitor. It is much easier and cheaper to inject a vaccine into an animal than to deliver a bolus. Once developed, a vaccine would almost certainly be much cheaper than an inhibitor. A vaccine would also be much less likely than an inhibitor to leave residues in milk or meat.

However, developing a vaccine is challenging and likely to take a long time because the way in which it would work in the animal is complex. Antibodies have been generated in sheep with prototype vaccines, but this is only a first step toward the goal of suppressing the production of methane.

Even a very optimistic scenario would not see inhibitors tailored for New Zealand becoming available before the 2020s. The development of a vaccine would take longer, if it can be done at all.



8

Targeting urine patches and fertiliser

The major source of nitrous oxide in New Zealand is the urine of cattle and sheep. The minor source (about 17%) is nitrogen fertiliser.

Microbes in the soil break down the urea in the urine and in the fertiliser. Some of the nitrogen in the urea fertilises plants, some outgasses as nitrous oxide or ammonia, and some leaches into water as nitrate.

Two approaches to reducing nitrous oxide from urine and fertiliser are described in the first two sections of this chapter.

The first involves using inhibitors – compounds that slow the rate at which microbes in the soil convert urea into nitrous oxide. This gives plants more opportunity to take up the nitrogen and use it to fertilise their growth.

The second involves keeping animals off pasture at the times when their urine would be most environmentally damaging.

The third section is a summary of the potential of inhibitors and of taking animals off pasture to reduce nitrous oxide outgassing from soil, based on the questions in Chapter 4.

The environmental impact from animal urine is two-fold – while nitrous oxide is a greenhouse gas, nitrate is a water pollutant. When nitrate leaches from soil into groundwater and streams, it can end up fertilising the growth of unwanted plants – invasive water weeds, algal blooms, and slimy periphyton.

Some actions taken to reduce nitrous oxide will also reduce nitrate leaching, and *vice versa*. But this is not always so. For instance, the creation of wetlands is an effective way to reduce nitrate leaching into waterways, but wetlands can be sources of nitrous oxide and methane.

8.1 Inhibiting the production of nitrous oxide

An inhibitor is a compound that can be applied to pasture to reduce the amount of nitrous oxide that outgasses from the soil. There is some experience on dairy farms in New Zealand with two inhibitors – a nitrification inhibitor commonly known as DCD (dicyandiamide), and a urease inhibitor.

DCD

DCD suppresses the activity of microbes in the soil in the nitrification stage of the nitrogen cycle (see Figure 2.3). It can be sprayed or spread on to crop or pasture soils, and reduces emissions of nitrous oxide and nitrate leaching (Figure 8.1).

The widespread sale of DCD in New Zealand began in 2007, and it was marketed as an environmentally beneficial way to increase grass growth under the brand names of 'eco-n' and 'DCn'. In 2009, an adjustment was incorporated into the Greenhouse Gas Inventory to account for the lower nitrous oxide emissions of the several hundred dairy farms using DCD.

The sale of DCD in New Zealand was stopped by the fertiliser companies after Fonterra found traces of it in milk powder in 2012. In 2008, the Chinese melamine scandal had broken out when it was discovered that milk adulterated with melamine had caused kidney damage in thousands of babies. DCD is not melamine, but both share the same basic chemical building-block – cyanamide. DCD and melamine were linked together in media reports in the United States and China.⁸⁴

Small amounts of DCD are considered harmless, but there are no international standards for levels in food, and DCD is still unavailable in New Zealand. However, this may change in the future. The Ministry for Primary Industries is pursuing a fast track mechanism for the Codex Alimentarius Commission to set approved levels of residues in food of DCD and other compounds of low public health concern. Some progress has been made.^{85,86}

Although DCD is currently 'off the table', other nitrous oxide inhibitors may become available, so it is still useful to look at how effective DCD was on New Zealand dairy farms.

Much of the nitrous oxide from urine is emitted during autumn and winter.⁸⁷ This is because the microbes that drive the nitrogen cycle in the soil are most active when the soil is cold and wet and compacted. The recommended use of DCD was for two to three applications between May and September.⁸⁸

Studies of nitrous oxide reduction by DCD on dairy farms show great variation in its effectiveness. Four studies published in 2014 using the same methodology in different parts of the country reported reductions in emissions ranging from 18% to 82%, with an average of 56%. This translates into an annual effectiveness of about 40%.^{89,90}

The causes of the variability in effectiveness include temperature, soil moisture, urine rate, and the timing of fertiliser application, but are not well understood.

Although it was expected that DCD would increase grass growth, there is limited evidence of this from field trials.⁹¹

Urease inhibitors

The urea that ends up on farmland comes in two forms – as a solid in nitrogen fertilisers and as a liquid dissolved in urine.

Urease inhibitors are compounds that are mixed with some nitrogen fertilisers to reduce nitrogen lost as ammonia gas.⁹² Ammonia gas is an indirect source of nitrous oxide.⁹³

In New Zealand, the fertilisers marketed as SustaiN and N-protect comprise urea granules coated with urease inhibitors.⁹⁴ About a fifth of all urea fertiliser applied in 2014 contained urease inhibitor. The impact of this on total nitrous oxide emissions is captured in the Greenhouse Gas Inventory.⁹⁵

It has been suggested that urease inhibitors could also be applied to urine-soaked soil to reduce nitrous oxide emissions and this has been the subject of some research.

While applying urease inhibitors can be expected to reduce the amount of ammonia gas that is produced from urine, this will have little effect on overall nitrous oxide emissions.

Few studies in New Zealand have looked at the potential for these inhibitors to reduce the direct production of nitrous oxide from urine.

A glasshouse experiment in which a urease inhibitor was applied directly to urine patches reduced nitrous oxide emissions by 62%.⁹⁶ However a review of field-based trials found inconsistent effects of urease inhibitors on direct nitrous oxide emissions.⁹⁷

Whether or not any benefit can be seen in the field remains to be seen.^{98,99}

As with DCD, there are no international standards for approved levels of urease inhibitors. There is a possibility that residues could be detected in meat or milk. In New Zealand's proposal to the Codex Alimentarius Commission for managing residues in food that are of very low public health concern, urease inhibitors are specifically mentioned.¹⁰⁰



Source: Ravensdown

Figure 8.1 Applying the nitrification inhibitor DCD.

8.2 Urine off soil

Another approach to reducing nitrous oxide emissions is to move livestock off pasture at times when their urine is most environmentally damaging. This is increasingly being done on dairy farms partly in response to concerns about nitrate leaching into waterways.

The amount of nitrous oxide emitted and the amount of nitrate leached into waterways is greatest in autumn and winter when grass is growing slowly, if at all. It is the time of the year also when waterlogged soil is most likely to become compacted by hooves, leading to the microbes in the soil that produce nitrous oxide becoming more active.

Cattle taken off pasture can be put into different kinds of dairy barns or on stand-off pads.

A dairy barn might be a permanent building with feed alleys and freestalls where cattle can lie down and ruminate. Or it might be a simple open structure with a plastic roof.

A stand-off pad is a drained area where cattle can be held, with space for them to lie down.

It should be covered with free-draining material such as wood chips (see Figure 8.2). Cattle are not given hay and other supplementary feed on a stand-off pad – that can be done on a separate concrete feed pad.

There are many advantages from using dairy barns and stand-off pads. For instance:

- both provide the opportunity for urine and dung to be collected and used as fertiliser at optimal times
- cattle that can be put into dairy barns will be more productive because they can keep warmer in winter and cooler in summer
- the material covering stand-off pads must be periodically scraped off and replenished – the mixture of wood chips and dung scraped off can be used to make compost that will improve soil structure as well as fertility.

Two field trials of the effectiveness of keeping cattle off pasture to reduce nitrous oxide emissions yielded very similar results.

In the first trial, cattle were kept off pasture for 21 hours a day from March to May in Southland. The reduction of nitrous oxide from the pasture over this time was 57%. The annual reduction in nitrous oxide for the whole farm was at least 7% and may have been as high as 11%.¹⁰¹

In the second trial, cattle were kept off pasture for 18 hours a day from May to August in Waikato. The reduction of nitrous oxide from the pasture over this time was about 60%. The annual reduction in nitrous oxide for the whole farm was about 9%.¹⁰²

If the potential environmental benefits of dairy barns and stand-off pads are to be realised, good effluent management is critical. Urine and dung should be kept separate as much as possible, since urine and dung combined in a slurry will generate both methane and nitrous oxide – indeed in some cases these emissions could outweigh the reductions made from keeping the livestock off-pasture. In some countries, effluent ponds are a significant source of biological emissions.¹⁰³



Source: animalbedding.kiwi.nz

Figure 8.2 Cattle on a stand-off pad with a bedding surface of post-peelings (a by-product from making fence posts).

8.3 In conclusion

There are some effective ways to reduce nitrous oxide emissions from soil. However, there are significant challenges when it comes to integrating these into existing farming systems, and cost is also likely to be a barrier.

There are two approaches to reducing nitrous oxide emissions by targeting the interaction of urine with microbes in the soil.

The first approach involves using compounds that slow the rate at which nitrous oxide is formed from the urea in the urine.

DCD was such an inhibitor used for several years on several hundred dairy farms in New Zealand. If all dairy farms were to use it, it could reduce total nitrous oxide from agriculture by up to 13%.¹⁰⁴

However, DCD has been voluntarily withdrawn from the market following traces of it being found in milk powder.

Urease inhibitors are compounds that are already used to reduce nitrous oxide lost from fertiliser. If all nitrogen fertiliser sold contained urease inhibitors, the total nitrous oxide from agriculture could be reduced by up to 3%.¹⁰⁵

Urease inhibitors may also prove effective in reducing nitrous oxide emissions from urine-soaked soil. However, after the DCD experience, the use of any compound that could leave residues in meat or milk – however small and safe – would be likely to meet consumer resistance offshore. So it seems that no nitrous oxide inhibitors will be able to be used unless New Zealand's proposal to the Codex Alimentarius Commission is successful. But even if it is successful, it will still take a number of years.

The second approach is to keep livestock off pasture at the times when their urine would be most environmentally damaging.

Cattle spend a relatively small proportion of the day grazing and taking them off pasture on to stand-off pads or into barns is being done on an increasing number of dairy farms.

If the cows on every dairy farm were taken off pasture at vulnerable times of the year, it could reduce total nitrous oxide from agriculture by up to 5%.¹⁰⁶ The manure collected while cattle are off-pasture would need to be managed well in order not to increase emissions from this source.

The use of inhibitors also reduces nitrate leaching into waterways. So does taking cattle off pasture, although it is important that effluent be managed well.



9

How can trees help us?

Chapters 5 through 8 have looked at the potential for reducing the methane and nitrous oxide emissions from agriculture directly using a variety of technologies. Using trees to offset emissions is another approach that can be considered. It seems particularly appropriate as a way of addressing biological emissions since forestry and farming are different uses of land.

Farmers already plant trees for many purposes – for shelter, for timber, to control erosion, and to protect waterways. But can more trees help offset the biological emissions from agriculture? This question is explored in this chapter.

As trees grow, they take carbon dioxide out of the atmosphere. The carbon is stored in the trees and oxygen is released into the atmosphere through the process of photosynthesis.

About half the dry weight of a tree is carbon. Each tonne of carbon stored in a tree means that almost four tonnes of carbon dioxide has been taken out of the air.¹⁰⁷ By storing carbon, trees effectively store carbon dioxide.

In the first section, the possibility of allowing native forests to regenerate on marginal land is considered. The areas of native forest that would offset the biological emissions from sheep, beef, and dairy farms are estimated. Such forests accumulate carbon slowly but steadily for a long time.

The second section is focused on a very different kind of forest – a plantation of radiata pine. These trees are periodically harvested and must be replanted if the forest is to continue storing carbon. The areas of plantation forest that would need to be planted every twenty years to offset the biological emissions from sheep, beef, and dairy farms are estimated.

The third section looks at some of the practicalities that would be involved.

Finally, carbon can be stored in soil as well as in trees, although this is not yet well understood. This is the subject of the fourth section.

9.1 Regenerating native forests

The mature podocarp and beech forests of New Zealand have an enormous amount of carbon stored within their wood. If all these forests were to burn down, the carbon dioxide released into the atmosphere would be about 75 times as much as the country's total annual greenhouse gas emissions.¹⁰⁸

These mature forests are, on average, neither losing nor gaining carbon. However, regenerating native forests are slowly accumulating and storing carbon dioxide.

The reestablishment of a native forest commonly begins with the 'pioneer' shrubs of mānuka and kānuka because they thrive in cleared land. These shelter tree seedlings. The mānuka starts to die after about 40 years, opening up space for trees such as tawa and kāmahī. Later the giant podocarps – rimu, totara, and kahikatea – emerge through the canopy.

Large areas of New Zealand were once covered in podocarp forest. Many trees were felled for timber, and much of the remaining forest was cleared and burned to make way for agriculture. Some of the cleared land has become 'marginal' for agriculture, and if fenced off, could slowly begin to regenerate into podocarp forest.¹⁰⁹



Source: Parliamentary Commissioner for the Environment archives

Figure 9.1 Regenerating mānuka invading pasture on a North Island hill country sheep farm. The scrub seen in the background of the picture has reverted from pasture land over the last two decades.

How large would a regenerating podocarp forest need to be to offset the biological emissions from sheep, beef, and dairy farms?

Figure 9.2 shows the rate of carbon dioxide accumulation in a regenerating podocarp forest over a hundred years.¹¹⁰

The accumulation rate shown over the first fifty years is much faster than over the second fifty years. As the mānuka, and later the kānuka, die off, the accumulation rate slows because the other species coming through the canopy grow very slowly at first.

After fifty years of growth, one hectare of native trees will have accumulated about 320 tonnes of carbon dioxide.

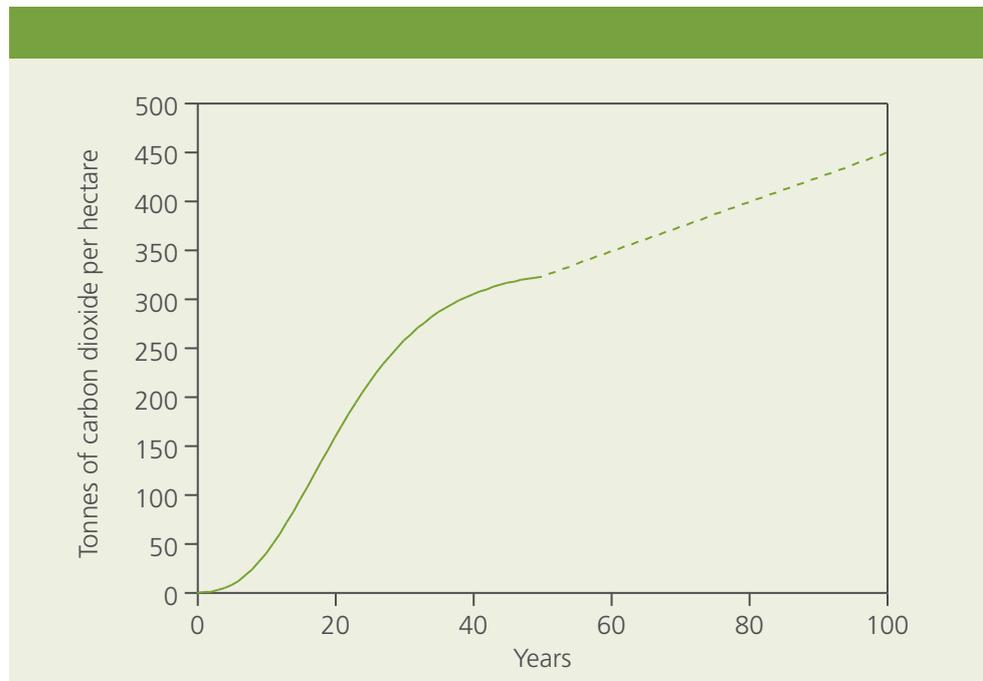


Figure 9.2 Carbon dioxide accumulation in a regenerating podocarp forest.

Table 9.1 shows the areas of regenerating podocarp forest that would offset the biological emissions from sheep, beef, and dairy farms.

The first column shows the methane and nitrous oxide emitted annually by livestock – 100 sheep, 100 beef cattle, and 100 dairy cattle – expressed in the equivalent amount of carbon dioxide.

The second column shows the area of regenerating native forest that would be needed to offset these emissions every year for fifty years.¹¹¹

Table 9.1 Offsetting biological emissions from livestock using regenerating native forest.

	Tonnes of CO ₂ -eq per year from 100 animals	Hectares of forest needed to offset biological emissions
Sheep	38	6
Beef	179	28
Dairy	273	42



Source: Virtual Oceania

Figure 9.3 Mānuka trees die off at about 40 years old, the canopy opens, and other native tree species take over.

9.2 Pine plantations

Towards the end of the nineteenth century, concern about the depletion of native forests led to a growing interest in planting introduced species for timber. In 1909, the five thousand hectares of plantation forest that had been established contained more than sixty tree species, with larch the most common. But the very rapid growth rate, and thus the appeal, of one of the minor species – *Pinus insignis* – was becoming evident.¹¹²

Today we know *Pinus insignis* as the *Pinus radiata* that makes up about 90% of all the plantation trees in New Zealand – although there is growing interest in other plantation species.¹¹³ Radiata pine grows much faster in New Zealand than in its native California, and fastest in Northland and Gisborne.¹¹⁴

This rapid growth rate makes radiata pine very efficient at taking carbon dioxide out of the air.

Unlike the regenerating native forest discussed in the first section, pine trees are typically harvested when they are about 28 years old. The discarded branches (slash) and roots left behind begin to decay, releasing carbon dioxide back into the air. The harvested logs are turned into various products, including paper, particleboard, and timber for construction. The longer-lived the product is, the longer it stores carbon before it is discarded and begins to decay.

Figure 9.4 shows the rate at which carbon dioxide is accumulated in each hectare of a stand of radiata pine, and the rate of carbon dioxide loss after the trees are all harvested 28 years after planting.¹¹⁵

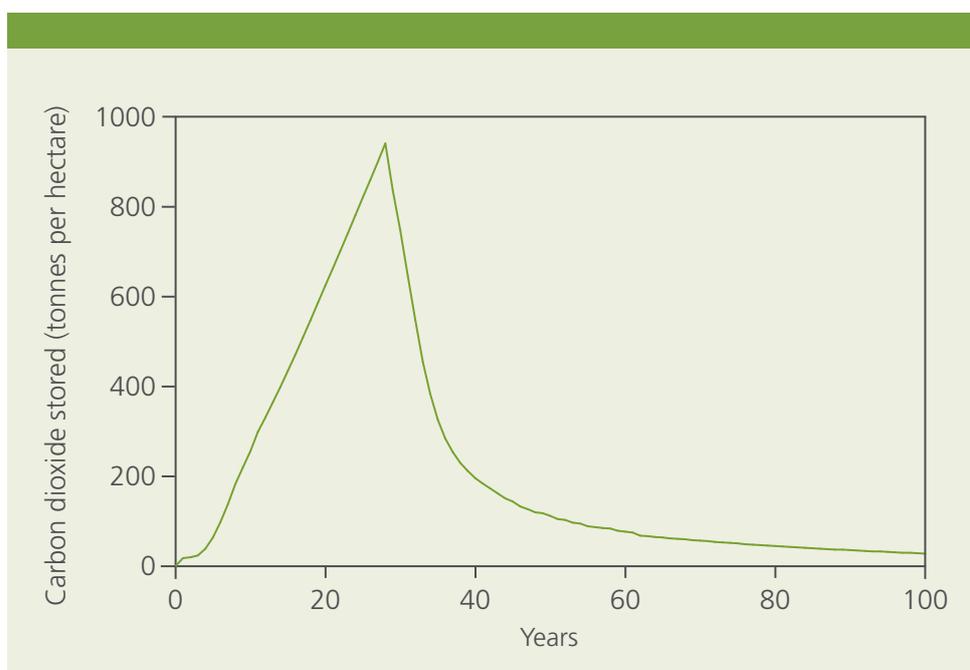


Figure 9.4 The carbon dioxide accumulated by radiata pine increases until the trees are felled. Then the loss of carbon dioxide back to the atmosphere begins.

The accumulation of carbon in the stand of radiata pine in Figure 9.4 is only temporary. But if trees are replanted, the cycle can begin again, as shown in Figure 9.5. Each stand may be temporary but the whole forest can be thought of as permanent, at least for the foreseeable future.

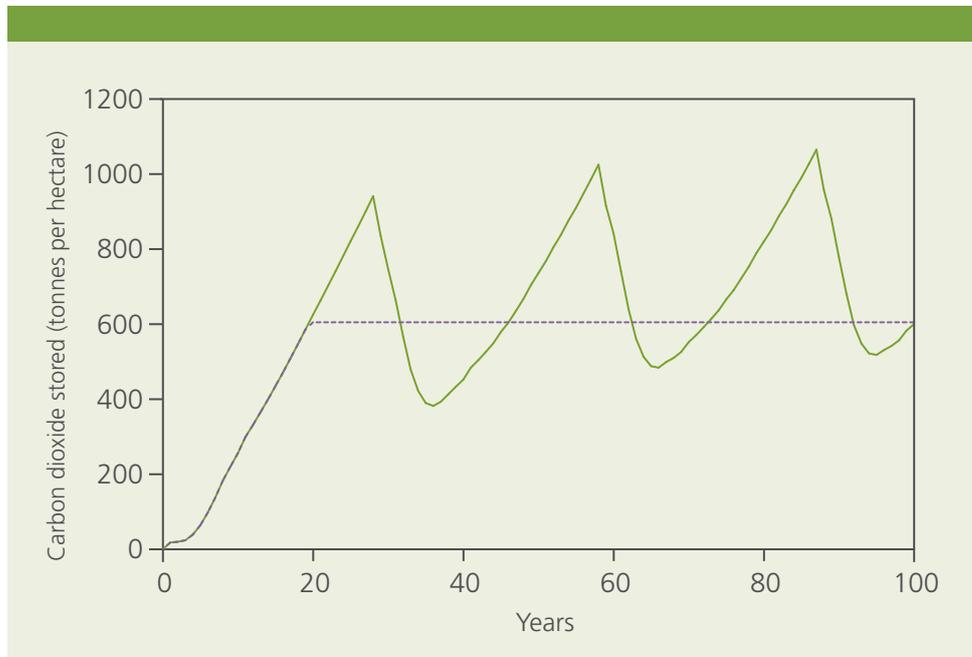


Figure 9.5 The amount of carbon dioxide accumulated by establishing a hectare of radiata pine forest and replanting it after each harvest.

How large would a pine plantation forest need to be to offset the biological emissions of sheep, beef, and dairy farms?

In Figure 9.5, the flat segment of the dotted line shows the average amount of carbon stored in a forest over a hundred years – 31 tonnes per hectare per year for the first 20 years, and then no more. To retain the storage of 600 tonnes of carbon dioxide in each hectare of pines, the rotations would have to continue indefinitely, or an equivalent new area would need to be planted with pines.

But if a pine forest is not replanted, it will have, in effect, pushed the biological emissions it offsets into the future. This is valuable because it buys time for new technologies to be developed.

If a pine forest is to continue offsetting biological emissions, the planted area would need to periodically increase. This is shown in Table 9.2.

In this table, the second column shows the new areas that would have to be planted with pines, and added every twenty years to the offsetting plantation.

Table 9.2 Offsetting biological emissions from livestock using a radiata pine plantation.

	Tonnes of CO ₂ -eq per year from 100 animals	Hectares of new plantation added every 20 years to offset biological emissions
Sheep	38	1.2
Beef	179	5.7
Dairy	273	8.7



Source: Shutterstock

Figure 9.6 A radiata pine plantation. Although radiata pine remains by far the main plantation species in New Zealand, there is growing interest in planting other species such as Douglas fir and redwood, and natives such as totara. These slower growing species would be harvested on much longer rotations, so would store carbon for a longer period of time.

9.3 How much can trees help us?

Regenerating native forest

There are large areas of low productivity grassland mostly in the North Island that contain seeds of native shrubs and trees. These can potentially revert to podocarp and broadleaf forest. In many places, the land would initially be covered with gorse, but this spiny invasive legume can act as a nursery for native shrubs and trees, sheltering them from the wind and supplying them with nitrogen.¹¹⁶

Enabling native forest to regenerate through fencing off marginal farmland does much more than just sucking carbon dioxide out of the air. Enormous amounts of topsoil have been lost as erosion has followed the clearing of forest on unstable hill country. This has led to layers of sediment building up on the beds of streams and rivers. The result has been a loss of biodiversity on both land and in freshwater, along with falling agricultural productivity. Regenerating forest can arrest and begin to reverse this decline.

Building and maintaining fences would be a significant cost. There would also be a loss of grazing but, on the other hand, there would be a reduction in the time-consuming work of keeping pasture free of scrub. Then there is the potential for beekeeping – the price of mānuka honey has grown rapidly over recent years.

The cost of establishing a native forest will be much greater if seedlings must be planted and pests controlled. It is not just possums that are a problem. Deer and goats browse on seedlings and saplings, and also alter the composition of the forest and thus the amount of carbon stored.¹¹⁷

How much marginal agricultural land has the potential to revert to shrubland and native forest? Various analyses have suggested that at least a million hectares of land would fall into this category.¹¹⁸

Allowing a million hectares of marginal hill country to revert to scrub could capture the equivalent of about 17% of all the biological methane and nitrous oxide currently emitted each year for 50 years. This carbon store would continue to grow for hundreds of years.¹¹⁹

Pine plantations

A pine plantation is very different from a regenerating native forest. It costs much more to establish, but the processed logs have many uses. But it is preferable to not plant pine on steep land prone to erosion, because of the potential for sediment to wash into waterways between harvest and the establishment of new trees.

However, as shown in the previous section, radiata pine accumulates carbon extremely quickly. Current pine plantations cover about 1.6 million hectares. Planting a further million hectares in pines could capture the equivalent of about 81% of all the biological methane and nitrous oxide currently emitted each year.

But, in contrast to the regenerating native forest, this offsetting would only last for twenty years. To keep the carbon sequestered, the trees would have to be replanted, and for the offsetting to continue, new plantations would be needed.

What is a 'carbon forest'?

There are already many trees on farms that are accumulating carbon as they grow – riparian strips, shelter belts, and so on. On some farms, forestry has become an integral part of the farm. Figure 9.7 shows a Waikato farm where cows graze between rows of paulownia trees.

The carbon accumulated by such trees will be unable to be counted as progress towards New Zealand's current greenhouse gas target unless the trees form a 'carbon forest'. Currently, a carbon forest must be a minimum of 30 metres wide and cover one hectare, with the crowns of the trees covering more than 30% of each hectare, and the trees must have the potential to grow to a height of at least five metres.¹²⁰

One challenging aspect of carbon forestry is the issue of wilding pines. These trees – self-sown and unwanted – can rapidly colonise native or pastoral grassland growing into dense thickets, reducing grazing land, and changing the ecology and landscape. Lodgepole pine (*Pinus contorta*) is the worst offender. Other wilding species include Douglas fir, radiata pine, and larch, although almost all conifers species are prone to spreading.

A case could be made for 'letting wildings go' and using them to accumulate carbon dioxide.¹²¹ However, the economic and environmental impacts of wilding tree spread have generally been considered to outweigh this.



Source: Graham Smith

Figure 9.7 Rows of paulownia trees planted on a dairy farm near Te Awamutu. Paulownia is a rapidly growing hardwood tree native to China. The cattle are eating the tree prunings.



Courtesy of Poutama Trust / Tai Tokerau Honey / Cinzia Jonathan Photography

Figure 9.8 In the far North at Ahipara, Tai Tokerau Honey Ltd, a Māori owned and operated beekeeping company, specialises in the production of mānuka honey. With the help of the Poutama Trust, companies like Tai Tokerau have formed relationships with local hapū and iwi around the North Island in order to gain access to privately owned marginal land for their hives.



Source: Sophie Walker

Figure 9.9 Pines are not the only trees that grow rapidly in New Zealand. This forest of eucalypts planted on hill country in South Taranaki earned farmer Neil Walker more than \$100,000 in carbon credits in 2016.

9.4 Can soil help?

When plants and animals decompose, some of the carbon they contain enters the soil. Then as microbes in the soil respire, some of the carbon in the soil is released into the atmosphere as carbon dioxide.

Globally, soils store a massive amount of carbon – several times more than all the trees and plants.¹²² In many parts of the world, soil carbon has been depleted as forest has been converted into agriculture, and land has been repeatedly tilled.¹²³

During the climate change conference at Paris last year, an initiative was launched promoting increasing soil carbon as a way of stopping the annual increase of carbon dioxide in the atmosphere. The initiative has the goal of increasing the amount of carbon stored in soil by 0.4% each year.¹²⁴

However, soil carbon levels in many parts of New Zealand are already comparatively high.¹²⁵

The actual amount of carbon stored can vary under different kinds of farming. For instance, there is evidence that soil carbon is increasing on some hill country farms.¹²⁶

Some farming practices, such as no-tillage, can help maintain, reduce carbon losses, or even further accumulate carbon. Another way to raise the soil carbon content of soil is to add biochar – a highly porous charcoal that can be created from harvesting waste from plantation forests.¹²⁷

Such practices are not accounted for in New Zealand's Greenhouse Gas Inventory. The inventory does, however, assume that the carbon content of soil changes when the land use changes.¹²⁸

It is not clear how soil carbon could be integrated into international reporting. One concern is that changes in soil carbon can be very hard to monitor and measure. Another is that while it generally takes a long time to build up soil carbon, it can be lost very rapidly through, for example, poor pasture or crop management, or a drought.



10

Bringing it all together

Late last year at the climate change conference in Paris, almost all the countries in the world committed to taking action to limit the warming of the atmosphere to well below two degrees Centigrade. To achieve this goal, the world must make dramatic reductions in greenhouse gas emissions in the coming decades.

Biological emissions from agriculture – methane and nitrous oxide – form a large proportion of New Zealand's greenhouse gases. The world will continue to need food. But the way in which food is grown and the types of food grown will have to change if biological emissions are to be reduced.

There will need to be reductions in methane from rice paddies in Asia, and from burping sheep in New Zealand. There will need to be reductions in nitrous oxide from the heavily fertilised Corn Belt in the United States, and from urinating cattle in New Zealand.

This chapter summarises the major findings of the investigation into the biological gases from agriculture. It includes some comments relevant to policy development.

10.1 Biological emissions are a major challenge for New Zealand

Most countries came to Paris with targets that included the biological gases from agriculture. New Zealand faces the challenge of dealing with these gases ahead of other developed countries with its unusual greenhouse gas profile of about 45% carbon dioxide, 45% methane, and 10% nitrous oxide.

This is a consequence of the major role that pastoral farming plays in the economy. Most of the methane is produced by grass fermenting in the rumens of sheep and cattle. Most of the nitrous oxide is produced by soil microbes breaking down animal urine.

Emissions intensity and carbon leakage

It is important to distinguish between total emissions and the emissions intensity of production. The emissions intensity of milk and meat production in New Zealand is low compared with other countries, and has become steadily lower over the last 25 years. But although relatively low emissions accompany the production of every kilogram of meat and milk, the total emissions from pastoral farming have risen.

The argument is sometimes made that if New Zealand produced less, production would shift to other countries with higher emissions intensity, and overall emissions would rise. But although New Zealand produces a lot of meat and milk, it is still tiny on a global scale, so any 'carbon leakage' would be very small. But some production shifting offshore could have an effect on farmers' competitiveness, although agriculture is not the only industry in this situation.

The metrics debate

Another issue sometimes raised is over the weightings put on different greenhouse gases when they are expressed in the equivalent amount of carbon dioxide. To change the weightings used in international targets would require global consensus.

This 'metrics' issue is of particular interest in New Zealand with its high proportion of methane. Methane in the atmosphere is short-lived, in contrast with carbon dioxide and nitrous oxide. But while methane molecules disappear relatively rapidly from the atmosphere, they do leave some damage behind, in the form of heat added to the ocean.

The concern is that the standard international weighting put on methane takes the focus away from carbon dioxide. The overriding need to reduce emissions of carbon dioxide is uncontroversial – it is emitted globally in very large quantities, it accumulates in the atmosphere, and its warming effect is accelerating rapidly.

But the focus in New Zealand policy thus far has been almost exclusively on carbon dioxide. Biological methane is not included in the Emissions Trading Scheme, effectively giving it a weighting of zero. The same applies to the other biological gas – the long-lived and very powerful nitrous oxide.

Biological methane and other short-lived greenhouse gases are different. If the flow of these gases into the atmosphere levelled off, and there were no other greenhouse gas emissions, the temperature of the atmosphere would stabilise in a few decades. But the higher the level, the higher the temperature would be. Methane does matter.

10.2 Reducing biological emissions

Changing management practices

Already some farms are considerably more 'greenhouse gas efficient' than others. This is partly due to different soils, climates, and topography, and partly due to managing farms in different ways.

It is becoming clear that changing management practices can lead to significant reductions in biological emissions by at least 10% on some farms without necessarily affecting profitability. There is a growing body of research and practice supporting this approach.

Over recent years, dairy farming, in particular, has become increasingly intensive. With this has come the need for more fertiliser and more feed – more variables, more complexity, and more risk. In some cases, lowering the stocking rate could lead to increased farm profit by decreasing the need for costly inputs.

It is axiomatic that the fewer sheep and cattle there are on a farm, the lower the biological emissions will generally be.

The water quality connection

Concern about water quality has become widespread in New Zealand, and regional councils have begun the process of setting nitrogen limits in catchments. Some actions taken to reduce nitrate leaching into waterways will have the spin-off effect of reducing nitrous oxide outgassing from urine-soaked pasture. An example is the practice taking cattle off pasture at times of the year when their urine is most damaging.

But this cannot be taken for granted. Riparian planting can help reduce nitrate leaching into waterways, but has no impact on nitrous oxide. And wetlands reduce nitrate leaching, but can be sources of methane and nitrous oxide.

Searching for silver bullets

Over recent years, options for reducing the biological gases from agriculture has been a major focus of research in New Zealand. But there are no silver bullets on the horizon yet.

Demonstrating that a mitigation option is effective in a laboratory or in a field trial is only the beginning. Other impacts the option may have, its cost-effectiveness, and the practicalities of integrating it into existing farming systems are also critical. And to qualify as a silver bullet, a mitigation technology or management practice should make a sizeable dent in the country's biological emissions.

Some potential mitigation options hold the promise of providing two benefits – an increase in productivity and a decrease in methane and/or nitrous oxide. Increases in productivity are welcome to farmers. But an increase in productivity may lead to an increase in the number of livestock on a farm. Thus, while emissions intensity would fall, the farm's total emissions may rise.

10.3 Mitigation and offsetting

A variety of mitigation options have been traversed in this report.

- Selective breeding of low emission ruminants.
- Changes in animal feeds.
- Suppressing the production of methane in the rumen.
- Reducing the production of nitrous oxide from urine on soil.

These are not a complete set of all the possibilities but they have all been the subject of research by many scientists in New Zealand over recent years.

A very different approach is to use trees to offset biological emissions. As trees grow they take carbon dioxide out of the atmosphere.

Of course, carbon forests can be used to offset the emissions from any sector, but the connection is particularly direct with agriculture since farmers already plant trees for many purposes.

Mitigation options

Breeding low emission sheep and cattle would have an effect, but it would be many years before it became significant at a national level.

Emissions of both biological gases are affected by what livestock eat. In general, high quality feed results in lower emissions intensity. But in New Zealand, high quality feed is generally only used as a supplement to ryegrass and clover. The genetically modified ryegrass under development might eventually lead to lower biological emissions, but has yet to leave the laboratory.

A methane vaccine that could decrease the amount of methane emitted from sheep and cattle by 20 to 30% would be especially valuable. A 25% reduction in the enteric methane emitted by every ruminant would lead to about a 24% reduction in the biological methane from agriculture – assuming, of course, no increase in livestock numbers.

The potential of a methane vaccine goes way beyond New Zealand because it could be readily integrated into any livestock system. Once developed, a vaccine would be cheap, and would not leave residues in meat or milk. But research is still at an early stage, and it is not certain that such a vaccine will ever become a reality.

Research on methane inhibitors is more advanced but such inhibitors are unlikely to integrate easily into New Zealand's pastoral farming system.

The way in which soil microbes break down urine and form nitrous oxide is complex, and changing it is a challenge.

The nitrification inhibitor DCD was used for some years to reduce nitrate leaching into waterways. It has also been shown to reduce the amount of nitrous oxide outgassing from urine-soaked pasture. But its use came to an end with the discovery of residue in milk powder. The success of New Zealand's proposal for changing the international standards in the Codex Alimentarius is crucial, if any such inhibitor is to be used again.

Taking dairy cows off-pasture at sensitive times is becoming increasingly common, and does not necessarily require expensive dairy barns. More broadly, good management of stock and feed can improve environmental outcomes. It is, for instance, far better to break-feed a forage crop downhill than uphill, and better still to harvest the feed and provide it to the stock on a feed pad.

Offsetting with carbon forests

A very different approach to dealing with biological emissions is to use trees to soak up and store carbon dioxide. Forests can be used for offsetting – taking carbon dioxide out of the atmosphere to compensate for the biological emissions entering the atmosphere.

Establishing carbon forests does not rely on technological breakthroughs. Carbon forests are already included in New Zealand's Emissions Trading Scheme, but much more can be done.

For instance, a hill country sheep farmer might fence off higher altitude land and leave the mānuka scrub to begin the slow steady recovery into mature podocarp forest, with all the accompanying benefits of slowing erosion, keeping sediment out of waterways, ameliorating flooding, and providing habitat for native birds and other creatures.

During this investigation, it was found that the biological emissions of 100 sheep could be offset indefinitely by about 6 hectares of marginal land left to regenerate into native forest. For 100 beef cattle, about 28 hectares would be required, and for 100 dairy cows, about 42 hectares.

It has been estimated that at least a million hectares of marginal land could be left to regenerate back into native forest. This would offset about 17% of all the biological methane and nitrous oxide currently emitted each year from agriculture for the indefinite future.

But there are many other options.

Some farmers might invest in plantations of rapidly growing pine or eucalypts. The carbon stored in trees that are harvested or left to rot eventually returns to the atmosphere as carbon dioxide. But even trees that are harvested do have a role to play – they buy some time.

10.4 So what should New Zealand do?

It is 24 years since the Rio de Janeiro Earth Summit where New Zealand joined many other countries in committing to tackling climate change. Since then, there have been various attempts in New Zealand to deal with the challenge of what to do about the biological emissions from agriculture.

Currently, the New Zealand Government invests about \$20 million each year and is playing an international role in research to reduce biological methane. Industry groups, including Fonterra, Dairy NZ, Beef and Lamb, Deer Research, and the Fertiliser Association, are also supporting much of this scientific work.

Further, a great deal of effort continues to go into refining the country's Greenhouse Gas Inventory, and the Government has established a new reference group to look at what can be done about the biological gases from agriculture, and another reference group to look at the role forestry can play.

The Emissions Trading Scheme

Currently New Zealand's main mechanism for reducing emissions is the Emissions Trading Scheme. Methane and nitrous oxide from agriculture have so far been excluded from the ETS.

Proponents for including biological emissions in the Emissions Trading Scheme focus on fairness to other industries and consumers, and on the distortion of the economy that follows from the exclusion of such a major industry.

The Government has decided not to include biological emissions until:

*“there are economically viable and practical technologies available to reduce emissions” and “our trading partners make more progress on tackling their emissions in general”.*¹²⁹

But some other sectors that are included in the ETS also have limited mitigation options and inclusion in the ETS helps to make mitigation economically viable.¹³⁰ As has been done in the past, carbon credits could be purchased from other countries, provided New Zealand gains access to international carbon markets.

Other sectors (and taxpayers) will become increasingly 'squeezed' if the agriculture sector does not begin to take some responsibility for methane and nitrous oxide.

However, there are some characteristics associated with the biological gases that set them apart from carbon dioxide. Foremost are the practical difficulties and compliance costs of measuring emissions on individual farms.

But just because there are difficulties does not mean that nothing can be, or should be, done.

The Biological Emissions Reference Group must find a way ahead, and the ETS is not the only mechanism that can be used.

Some ideas for consideration

A methane vaccine would be so valuable that the research aimed at developing it should be ramped up as much as possible. Methane inhibitors are presented as an equivalent biotechnology, and the research is more advanced, but a vaccine would be superior in many ways.

There are many different ways in which the planting of trees can be encouraged. It is critical that the forestry rules that are negotiated in the wake of ratification of the Paris agreement cover a wide range of options for carbon forests. Further, in its submission on the ETS, Ngāi Tahu have drawn attention to the way in which afforestation using native species is often prevented from earning carbon credits under the current rules.¹³¹

Farmers are besieged with advice from different sources, including some with vested interests. Advice to farmers on management practices and diversification options that would really help reduce biological emissions should be provided by independent experts. In many cases, much can be done without cutting edge biotechnology.

Such advice needs to be backed up with research. There is a clear need for research not just on management practices, but also on alternative lower emission uses of land. What might be low emission but still profitable ways to use land in Northland? In Manawatu? In Southland? One priority area of research should be improving the software programme OVERSEER so that it better models emissions of the biological gases.

The most practical way to drive change may sometimes be through regulation. For instance, farms could be required to monitor and report on their biological emissions right now. And the addition of a urease inhibitor to all nitrogen fertiliser could be made mandatory.

A major sticking point in considering the inclusion of the biological gases in the ETS is the location of the so-called 'point of obligation'. If it is put at the processor level, the farmer who produces a kilogram of meat or milk with relatively low biological emissions would not be rewarded. If it is put at the farm level, the compliance cost would be very large indeed because there are thousands of pastoral farms.

However, there may be ways for a partial inclusion of the biological gases into the Emissions Trading Scheme relatively quickly.

For instance, nitrogen fertiliser could be brought into the ETS. The amount of nitrous oxide originating from synthetic nitrogen fertiliser has increased four-fold over the last 25 years, although the interaction of urine with soil microbes remains by far the main source.

Another suggestion worth exploring is to bring farms above a certain size threshold into the ETS because compliance costs would be relatively low. A similar approach has been used in the Taupo catchment to manage nitrate leaching.¹³²

Continuing delay is not our friend. Neither are abrupt transitions. Yet prolonged delay will make an abrupt transition inevitable. Such an abrupt transition occurred in New Zealand in the late 1980s when most of the government support for agriculture was removed and many farming families suffered.

Farming in New Zealand now is very different to what it was fifty years ago. Many of the mixed sheep/cropping farms in Canterbury have become dairy farms, while many of the dairy farms in the Bay of Plenty now grow kiwifruit and avocados.

New Zealand farmers have proved themselves to be nothing if not adaptable. Doubtless, farming in the future will be very different to what it is now, and climate change will be an increasingly major influence.

Notes

¹ Tyndall, 1872, p.424.

² <https://www.climate.gov/>

³ There are three oxides of nitrogen. Nitrous oxide is N₂O. Nitric oxide is NO. Nitrogen dioxide is NO₂.

⁴ These are the 'equivalency' values in the 2007 Intergovernmental Panel on Climate Change (IPCC) Assessment Report. The 'equivalency' values in the 2013 IPCC Assessment Report are 28 for methane, and 265 for nitrous oxide. The 2007 numbers are used in this report because these are the values used in New Zealand's greenhouse gas reporting.

⁵ The other 2% includes hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF₆). All figures used in this chapter are taken from New Zealand's 2016 Greenhouse Gas Inventory (MfE, 2016) unless otherwise stated.

⁶ Methane and nitrous oxide have been converted to their global warming carbon dioxide equivalent (CO₂-eq) using the standard method described in Chapter 1. Carbon dioxide and minor greenhouse gases (about 2% on average) account for the remaining emissions. The figure is based on gross greenhouse gas emissions. Net greenhouse gas emissions also include the carbon dioxide stored in trees or released when they are harvested.

⁷ IPCC, 2014, WGIII, Summary for Policymakers, p.7.

⁸ The tragic explosion at Pike River on the West Coast in 2010 was caused by a build-up of methane in the mine. About 2% of the methane emitted from human activities in New Zealand leaks into the atmosphere during the extraction of natural gas and oil, and the mining of coal. These 'fugitive' emissions are included in the Emissions Trading Scheme (ETS), whereas biogenic methane from agriculture is not.

⁹ The same is true for estimating sources and sinks of carbon dioxide in forestry. It is even more so for changes in soil carbon because of the greater uncertainty.

¹⁰ The simplest option for countries when reporting on emissions in their inventories is to use default models and emission factors that have been developed by the IPCC. Countries are encouraged to refine their estimates to better reflect reality. New Zealand has put considerable effort into such refinement. For instance, the IPCC default emission factor for methane from dairy cattle is 90 kilograms per animal per year. By taking into account specific information such as the diet of dairy cattle, New Zealand now uses an average emission factor of 82 kilograms of methane per cow per year.

¹¹ Of the 'enteric methane' in 2014, dairy cows produced 48%, beef cattle produced 19%, sheep produced 31%, and deer produced 2%. Ministry for the Environment, 2016, p.xi and CRF summary table 1.A).

¹² Aristotle, 350BC, Book 2, Part 17.

¹³ Broucek, 2014, p.1484.

¹⁴ The nitrous oxide originating from synthetic fertiliser was more than four times greater in 2014 than in 1990.

¹⁵ Currently, there is only a single emissions factor of 1% in New Zealand's Greenhouse Gas Inventory for urine, and another for dung. Work is currently being undertaken at AgResearch that may lead to the development of emission factors that discriminate between different situations. For instance, a lower emissions factor for hill country farms may be justified.

¹⁶ Bhandral et al., 2007, pp.482-483.

¹⁷ Data provided by Ministry for Primary Industries.

¹⁸ Sources: Statistics New Zealand, Agricultural Production Statistics, and FAOSTATS 2014. Based on data for the period 1990 to 2013 because later production data is not yet available.

¹⁹ Royal Society of New Zealand, 2016, p.136.

²⁰ Reisinger and Clark, 2016, p.4.

²¹ "... comparisons between individual countries are fraught with methodological difficulties. There are insufficient studies that directly compare New Zealand with other countries to support claims that New Zealand is the lowest emissions intensity producer" (Royal Society of New Zealand, 2016, p.134).

²² For instance, Gerber et al. (2011) compares the emissions intensity of milk production across 155 countries and shows that the only countries with lower emissions intensities than New Zealand are Malta and Jordan. But this study covers such a range of farming systems and environments that small differences between developed countries are meaningless. The focus of this study is on the difference between developed countries and developing countries.

²³ A recent study of the emissions intensity of the livestock sector in various European countries is was comprehensive and transparent enough to enable comparison with the New Zealand estimates. This European study found that the emissions intensity of European milk ranged from around 0.9 to 1.8 kilograms of CO₂-eq per kilogram of milk, while other recent studies have estimated the emissions intensity of New Zealand milk as between 0.80 and 1.0 kilograms of CO₂-eq per kilogram of milk (Flysjö et al., 2011; Ledgard et al., 2016). In another study, European beef ranged from around 12 to 27 kilograms of CO₂-eq per kilogram of meat (Weiss and Leip, 2012), while New Zealand beef is 19.9 kilograms of CO₂-eq per kilogram of meat (Lieffering et al., 2012). All these studies only consider emissions 'to the farm gate' and do not include the emissions associated with processing and transporting the produce to market. The greenhouse gas intensity of pastoral farming in New Zealand is clearly low, but proving it is the lowest will always remain elusive. Note that the emissions intensity of meat should not be compared with that of milk.

²⁴ Kingi et al., 2015.

²⁵ A number of studies have modelled the effects of changing farm management practices on greenhouse gas emissions. For example, Anderson and Ridler (2010) estimated that lowering the stocking rate and increasing the milk production per cow could increase profits while reducing total greenhouse gas emissions by up to 15% in a model farm. Another study estimated that it was possible to reduce total greenhouse gas emissions on Waikato dairy farms by at least 25% while increasing profits through a combination of lower stocking rate, and improved cow genetics and pasture management (Beukes et al., 2010).

²⁶ Other research has also shown that similar results are possible (Dewes, 2015).

²⁷ FARMAX is a software package designed to help farmers make management decisions. OVERSEER® (Overseer), was originally designed for managing nitrogen fertiliser, but it can also be used to estimate emissions of methane and nitrous oxide by combining greenhouse gas emission factors used in the national inventory with farm data. However, because of the complexities of farm biological and management systems, Overseer's accuracy will always be limited. Current research is looking at improving it to enable more accurate measurement of emissions from individual farms and thus better estimation of the impacts of different farm management practices on greenhouse gas emissions.

²⁸ Journeaux et al., 2016. This study looked at a range of mitigation options and modelled the potential changes in production, total emissions, and emissions intensity per unit of milk or meat produced, along with the resulting profit.

²⁹ See 2015 Trustees' report: <http://oromahoetrust.jimdo.com/>.

³⁰ Carbon that is stored in a leaf may be quickly released back into the atmosphere once it decays, whereas another molecule may be stored in the wood of a tree for 100 years before it is released. However, carbon is permanently removed from the atmosphere very slowly – the lifetime of carbon dioxide in the atmosphere is centuries to millennia. The burning of fossil fuels effectively moves carbon that has been stored underground for millions of years into a new 'store' in the atmosphere.

³¹ The heat trapped by a molecule of a greenhouse gas is called its radiative efficiency. As the concentration of a greenhouse gas rises, its radiative efficiency increases. The radiative efficiencies in this section are taken from IPCC (2013, Working Group 1, Chapter 8, Table 8.A.1., p.731).

³² The ozone is formed in the troposphere and the water vapour in the stratosphere. Ozone in the troposphere is 'bad' ozone – not only is it a potent greenhouse gas, it damages health and hinders plant growth. Ozone in the stratosphere is 'good' ozone because it stops most of the ultraviolet light at the top of the atmosphere from reaching the surface of the earth (see IPCC, 2013, Working Group 1, Technical Summary, Table TS.7, p.57).

³³ When methane of fossil origin – known as thermogenic methane – breaks down, the resulting carbon dioxide does contribute to warming. It is new to the atmosphere.

³⁴ About 10% of the nitrous oxide is converted into nitric oxide in the stratosphere. This, in turn, can contribute to the depletion of 'good' ozone in the stratosphere (Portmann et al., 2012).

³⁵ The GWP100 for methane of fossil origin is slightly higher – 30 (IPCC, 2013, AR5, WG1, Chapter 8, p.731).

³⁶ These are the GWP100 conversion factors used in the IPCC's 2007 report, and are the factors currently used in New Zealand and other countries. The conversion factors for methane and nitrous oxide have changed in successive IPCC reports. There are various reasons for this, including the increasing temperature of the atmosphere and the increasing concentration of the greenhouse gases themselves.

IPCC report year	GWP ₁₀₀ for methane	GWP ₁₀₀ for nitrous oxide
1995	21	310
2001	23	296
2007	25	298
2013	28	265

These conversion factors do not include the indirect effects that methane and nitrous oxide have on carbon-cycle feedbacks, such as the impact the warming they cause will have on how much carbon the world's oceans and forests will be able to store in the future. These effects are thought to be large – their inclusion would increase the 2013 conversion factor for methane from 28 to 34, and the conversion factor for nitrous oxide from 265 to 298 (IPCC, 2013, AR5, WG1, Chapter 8, p.714).

³⁷ Neither GWP100 nor GTP100 take into account the warming effect of a gas after the 100-year time period.

³⁸ IPCC, 2013, Chapter 8, p.715. See also Persson et al., 2015.

³⁹ Reisinger et al., 2011.

⁴⁰ Allen, 2015, p.6.

⁴¹ This is true for biogenic methane where the carbon dioxide that is a product of the breakdown of methane is 'recycled' from the atmosphere. It is not true for thermogenic methane.

⁴² See the objective of Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC). This convention is the basis of all international agreements on climate change.

⁴³ Hollis et al., 2015, p.22.

⁴⁴ New Zealand helped to found the Global Research Alliance on Agricultural Greenhouse Gases. The Alliance now has 46 member countries and four research groups – Paddy Rice, Livestock, Croplands, and Integrative. Dr Harry Clark, Director of the New Zealand Agricultural Greenhouse Gas Research Centre, is the co-chair of the Livestock group.

⁴⁵ Shi et al., 2016. This difference is based on measurements of methane yield, that is, grams of methane per kilogram of dry matter intake.

⁴⁶ Goopy et al., 2014. Other factors include the nature of the microflora in the rumen and the type of feed. See, for instance, Rowe et al. (2015).

⁴⁷ See, for instance, Bird-Gardiner et al. (2015).

⁴⁸ Waghorn et al., 2006, p.117. See also Eckard et al., 2010.

⁴⁹ McEwan, 2015.

⁵⁰ <http://www.dairyNZ.co.nz/animal/animal-evaluation/interpreting-the-info/all-about-bw/>

⁵¹ <http://www.dairynz.co.nz/news/latest-news/can-we-select-for-feed-conversion-efficiency/>

⁵² Moir et al., 2010.

⁵³ Pryce et al., 2012. See also MacDonald et al., 2014.

⁵⁴ Woodward et al., 2011.

⁵⁵ This 'back-of-the-envelope' calculation is based on enteric methane from sheep making up about 30% of all biological methane. Therefore, a 15% reduction of enteric methane from sheep would result in a reduction in total agricultural methane of 5%. Similarly, enteric methane from cattle makes up about 64% of all biological methane – a 15% reduction of enteric methane from cattle would result in a reduction in total agricultural methane of 10%.

⁵⁶ AgResearch and PGgRc, 2015, p.12

⁵⁷ The area of land planted in forage brassicas has doubled in the last 13 years to about half a million hectares (Sun et al., 2016, p.451).

⁵⁸ In a trial where sheep were fed different brassicas, forage rape was more effective at reducing methane emissions than swedes, kale, and turnips (Sun et al., 2012). Swedes were almost as effective, but are only grown in Southland.

⁵⁹ Sun et al., 2016, p.454.

⁶⁰ See, for example, Chrystal et al. (2012) and Shepherd and Smeaton (2009). The high nitrogen losses are primarily because the urine and dung from the animals feeding on the crop is deposited back onto soil that will remain bare for a long time before a new crop is sown. As a result, there are no plants growing to take up any of the nitrogen that is deposited. Winter is also generally the wettest time of the year, meaning there is more chance of excess nitrate leaching into waterways over this time.

⁶¹ Grainger and Beauchemin, 2011.

⁶² Luo et al., 2008.

⁶³ Williams et al., 2007.

⁶⁴ Box et al., 2016.

⁶⁵ Another New Zealand trial has shown that cattle fed a mix of ryegrass, clover, chicory, plantain, and lucerne excreted less nitrogen in their urine compared to those grazed on traditional ryegrass and clover pasture. In this trial, dairy cows were fed a mix of these plants in individual stalls for 10 days (Woodward et al., 2012).

⁶⁶ Proctor et al., 2015.

⁶⁷ Cosgrove et al., 2007. In this trial, no difference was found in the production of milk solids in spring 2004, or in spring 2005, or in autumn 2006. In autumn 2007, milk production was 10% higher in the cows fed high-sugar ryegrass than in cows fed standard ryegrass.

⁶⁸ Jonker et al., 2016.

⁶⁹ One of the 'high-sugar' grasses was a diploid strain bred from the high-sugar cultivars developed overseas, while the other grass was a tetraploid cultivar developed in New Zealand.

⁷⁰ The diploid high-sugar cultivar was better than the conventional grass in one trial, while the tetraploid grass was better than conventional in the other two trials (Jonker et al., 2016).

⁷¹ Jonker et al., 2016. See also Pacheco et al., 2009.

⁷² As a general rule, demonstrating greenhouse gas emission reductions under field conditions is not an easy task. Reductions in emissions may only be in the order of a few percent, and variations between individual animals, pasture and feed composition, and climatic conditions all make it difficult to detect whether new grasses are better than standard grasses (Parsons et al., 2011).

⁷³ Information on the genetically modified ryegrass has been provided by scientists at AgResearch. Manuscripts for submission to journals are in preparation.

⁷⁴ At the end of a field test of any genetically modified organism in New Zealand, *“the organism, or any heritable material arising from it”* must be able to be retrieved or destroyed (Hazardous Substances and New Organisms Act 1996, s2(1)).

⁷⁵ The requirements for releasing a genetically modified organism in New Zealand include, *“there is sufficient information available to assess the adverse effects of the organism”* and *“the positive effects of the organism outweigh the adverse effects of the organism”* (Hazardous Substances and New Organisms Act 1996, s38C (1)(b) and (c)). It is hard to see how these requirements could be met for an organism that has not been field-tested in New Zealand.

⁷⁶ Every year, about 7% of dairy pasture is resown – this pasture is typically 73% ryegrass (Thomas et al., 2014, p.6). The ‘back-of-the-envelope’ calculation used here is based on the assumption that all dairy pasture has been resown with the high-fat ryegrass. A similar calculation for resowing sheep and beef pasture has not been attempted, as much of this is never resown.

⁷⁷ Sometimes the question is raised as to whether reducing the emissions of methane might cause the cow to explode. This may not be as crazy as it sounds. The stomachs of ruminants can explode under certain circumstances – such as when rapid changes in diet cause bloat. The consequences of reducing the production of methane in the rumen on animal health and production is a significant concern for researchers in this field. In one recent trial of a methane inhibitor, hydrogen increased dramatically in the rumen, although this did not appear to harm the animals or reduce production (Hristov et al., 2015).

⁷⁸ Henderson et al., 2015.

⁷⁹ AgResearch, 2015.

⁸⁰ Hristov et al., 2015. This trial did not include testing for residue in the milk.

⁸¹ Wedlock et al., 2013.

⁸² New Zealand Agricultural Greenhouse Gas Research Consortium, 2015b.

⁸³ Assuming all sheep and cattle were successfully treated. The drop from 25% to 24% is due to the fact that enteric methane makes up 96% of biological methane. The remainder comes from landfills.

⁸⁴ Melamine is used in making plastics. Like proteins, it is rich in nitrogen. Simple testing of the protein content in milk measures nitrogen content, so testing of the adulterated milk did not distinguish between protein and melamine (see Xiu and Klein, 2010; Assimon et al., 2015, p.1402).

⁸⁵ The CODEX Alimentarius is an international food code established in 1963 by the Food and Agriculture Organisation of the United Nations (FAO) and the World Health Organisation. 188 countries are members of the Codex Alimentarius Commission. Members of the Commission work to set international food standards, guidelines, and codes of practice, which are then published in the CODEX Alimentarius. The standards are actually recommendations that countries implement on a voluntary basis. However, in practice, they serve as the basis for national legislation and regulations around food safety and trade.

⁸⁶ FAO/WHO, 2016.

⁸⁷ de Klein et al. (2011, p.485) assume that 60 to 80% of nitrous oxide emissions occur between early autumn and late winter.

⁸⁸ de Klein et al., 2011, p. 485.

⁸⁹ Assuming 70% of the nitrous oxide is emitted over autumn and winter ($0.7 * 56\% = 39.2\%$).

⁹⁰ The reductions in nitrous oxide in the four studies are: 41–82% in Canterbury (Cameron et al., 2014), 18–71% in Waikato (Ledgard et al., 2014), 54–78% in Manawatu (Kim et al., 2014), and 33–72% in South Otago (de Klein et al., 2014). A 2011 summary of earlier studies of nitrous oxide reduction by DCD showed similar variation, with reductions that ranged from 0% to 86% with an average of 57% over autumn and winter (de Klein et al., 2011, p.485). The DCD adjustment in the Greenhouse Gas Inventory was based on a reduction of 67% for the part of the year when the compound was applied (based on results from Clough et al., 2011). The inventory assumes that nitrous oxide emissions are uniform throughout the year – so this translated to an annual reduction of 28%. If we were to assume 70% of the nitrous oxide is emitted over autumn and winter, the reduction would have been higher (47%). Including seasonal variation in nitrous oxide emissions is currently being investigated as a potential improvement to the inventory.

⁹¹ In the four studies referred to in the previous note, Cameron et al. (2014) found the increase in pasture growth varying between 0 and 17%, but the other three found no effect.

⁹² Urease is an enzyme produced by microbes in the soil that converts urea into ammonium – the first stage of the nitrogen cycle. Urease inhibitors slow this process down, providing opportunity for plants to take up more of the nitrogen in the fertiliser.

⁹³ Ammonia gas is only a very small and indirect source of nitrous oxide – only 1% of the nitrogen in the ammonia gas ends up as nitrous oxide.

⁹⁴ As with DCD, the effect of urease inhibitors on grass growth in New Zealand is unclear. There is clear evidence for improved productivity from using urease inhibitors in overseas cropping systems where fertiliser application is high. One study found an 11% increase in productivity (Zaman et al., 2013). But another found no increase (Singh et al., 2013).

⁹⁵ The reduction in nitrous oxide emission due to the use of urease inhibitor in fertiliser is included in New Zealand's 2016 Inventory (MfE, 2016, p.180).

⁹⁶ Singh et al., 2013.

⁹⁷ Saggart et al., 2013.

⁹⁸ Since urease inhibitors lead to more of the nitrogen being retained in the soil, they could potentially lead to more nitrous oxide emissions and nitrogen leaching into waterways.

⁹⁹ In addition, there are challenges to be overcome as to how and when to directly apply a urease inhibitor to urine patches. A New Zealand company is working on developing a device that can detect fresh urine patches and apply a urease inhibitor directly on to the urine-soaked soil. It has been trademarked Spikey® after its appearance. The aim is to only spread the inhibitor where it is needed, and thus make it cheaper to use (Bates et al., 2015).

¹⁰⁰ New Zealand Government, 2016, Emerging Issues, para.9.

¹⁰¹ De Klein et al., 2006. The trial was conducted in 2001, 2002, and 2003, so the results are three-year averages. The nitrate leaching from the pasture over the three months was reduced by 41%.

¹⁰² Luo, 2008. The trial was conducted in 2004 and 2005, so the results are two-year averages. The annual average nitrate leaching from the pasture was reduced by 25%.

¹⁰³ In the United States, managed livestock waste is about 12% of biological emissions from agriculture. In New Zealand, it is about 3% (MfE, 2016; USDA, 2013, p.1.4).

¹⁰⁴ This calculation assumes inhibitors could achieve an annual reduction of 40% in nitrous oxide from urine and dung on all dairy farms. Emissions from dairy cattle urine and dung makes up about 33% of all agricultural nitrous oxide.

¹⁰⁵ Urease inhibitors were added to one-fifth of fertiliser sold in 2014, and this was estimated to reduce emissions of agricultural nitrous oxide by 0.8%. If this effectiveness is extrapolated to all fertiliser sold, emissions of nitrous oxide would reduce by about a further 3%.

¹⁰⁶ Keeping cows off pasture at key times was assumed to reduce annual nitrous oxide emissions from farms by an average of 9%. Around half of the agricultural nitrous oxide emissions come from dairy farms, so a 9% reduction scales up to just under a 5% reduction in total emissions. However, some farms are already using such practices, so actual reductions in nitrous oxide emissions would be lower.

¹⁰⁷ This is because a molecule of carbon dioxide is 3.7 times heavier than a molecule of carbon. Note that what is often referred to as a carbon price is actually a price on a tonne of carbon dioxide.

¹⁰⁸ The amount of carbon stored in tall native forest is about 258 tonnes of carbon per hectare (Holdaway et al., 2014, p.20). This is equivalent to 955 tonnes of carbon dioxide per hectare. The total area of tall native forest is about 6.5 million hectares. $955 * 6.5 \text{ million} = 6.2 \text{ billion tonnes of CO}_2\text{-eq}$. New Zealand's total annual greenhouse emissions are about 80 million tonnes of CO₂-eq.

¹⁰⁹ In contrast, most beech forest is on colder, more mountainous land that was less attractive for agriculture.

¹¹⁰ For the first fifty years, the carbon storage is based on the Emissions Trading Scheme lookup table for native forests. Climate Change (Forestry Sector) Regulations 2008 – Schedule 6, Table 2. The growth rate over the second fifty years is indicative only – based on assuming that a regenerating podocarp forest accumulates carbon dioxide at a constant rate until it has accumulated 955 tonnes per hectare at 300 years. The figure does not include any losses in soil carbon that may occur when land use changes. Note also the albedo effect from changing grassland to forest – the darker colour of the forest means that it absorbs more energy than grassland.

¹¹¹ For the 100 sheep, 38 tonnes of CO₂-eq per year divided by 6.5 CO₂-eq per hectare per year equals 6 hectares.

Carbon accumulation is likely to be slower in the second fifty years.

¹¹² Department of Lands, 1909, pp.110-111, 113.

¹¹³ Of the remaining 10%, 6% is Douglas fir, and most of the rest is larch, redwood, and eucalypts.

¹¹⁴ Climate Change (Forestry Sector) Regulations 2008. Schedule 6.

¹¹⁵ Figure 9.4 is based on information provided by the Ministry for the Environment and the Ministry for Primary Industries. It includes the average carbon accumulation rate of a growing pine forest, the amount of carbon removed in roundwood when the forest is harvested, the decay rate of the carbon left behind in roots and slash, the proportions of roundwood used domestically and exported, the amount of roundwood turned into products, and the rates at which these products decay and release carbon dioxide back into the atmosphere.

¹¹⁶ Gorse that is 30 years old and about four metres high contains about 460 tonnes of CO₂-eq per hectare. This includes the CO₂-eq sequestered in the native trees growing alongside the gorse (Carswell and Belliss, 2014).

¹¹⁷ Holdaway et al., 2012.

¹¹⁸ For example, Shepherd et al. (2008) found that 1.55 million hectares of land is potentially available for indigenous reversion.

¹¹⁹ The emissions from all livestock in 2014 totalled about 38.5 million tonnes of CO₂-eq.

¹²⁰ MfE, 2005, Annex 1, Background on forestry rules. There is a further requirement for carbon forests to earn credits in New Zealand's ETS – the tree crown cover must be wider than 30 metres (Climate Change Response Act, Section 4, forest land).

¹²¹ See, for instance, Destruction of beneficial tree species a waste of resources, Wanaka Sun, 12 May 2016. One study estimated that wilding conifer infestations currently accumulate about 2.7 million tonnes of CO₂-eq each year (Velarde et al., 2015).

¹²² Lal, 2008, p.816.

¹²³ Global pattern of soil carbon losses due to the conversion of forests to agricultural land. (Wei et al., 2014).

¹²⁴ See <http://4p1000.org/understand>.

¹²⁵ NZAGRC and PGgRc, 2015a, p.8.

¹²⁶ See Parfitt et al., 2014; Schipper et al., 2014.

¹²⁷ Sequestering carbon in this way is an active area of research both in New Zealand and internationally.

¹²⁸ For example, the 2016 Greenhouse Gas Inventory assumes that when one hectare of low-producing grassland is converted to a forest, the soil loses about 50 tonnes of CO₂-eq over 20 years (Table 6.3.2). Under current international rules, the inventory must report on changes in soil carbon when land use changes. But changes in soil carbon are not included in New Zealand's Emission Trading Scheme.

¹²⁹ New Zealand Government, 2015, p.5.

¹³⁰ New Zealand Treasury, 2012.

¹³¹ Te Rūnanga o Ngāi Tahu, 2016.

¹³² Motu, Agricultural emissions mitigation in New Zealand: Answers to questions from the PCE, pp.47-48. Large farms will already be using OVERSEER.

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