Chapter 4c:

Reducing emissions – opportunities and challenges across sectors

Agriculture

Agriculture contributes significantly to the Aotearoa economy, communities and culture. Farming livestock makes up the majority of agricultural emissions, with smaller contributions from horticulture and cropping. Agriculture emits the majority of biogenic methane emissions in Aotearoa and also makes a significant contribution to long-lived gas emissions.

This chapter explores the sources of livestock emissions and opportunities for reducing emissions, including farm management and new technologies, along with the opportunities and challenges for each option. Emissions from farm vehicles and machinery are covered in the transport and heat, industry and power chapters.

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4c.1 Agricultural emissions

Agriculture makes a significant contribution to the Aotearoa economy, and has helped to shape our landscapes, communities and culture for generations. The ways land is used also impacts greenhouse gas emissions. Agricultural emissions in Aotearoa come from livestock farms, horticulture operations and arable cropping (Figure 4c.1). Farming of ruminant livestock makes up the majority of agricultural emissions and leads to the release of methane (CH_4) and nitrous oxide (N_2O). Aotearoa farms have changed significantly over time, as has their overall contribution to climate change.

Aotearoa has a total land area of 26.8 million hectares. Almost 40%, about ten million hectares, is used for pastoral agriculture – predominantly dairy, sheep and beef farms. A relatively small area of land is used for horticulture and arable cropping – about 270,000 hectares or 1%. In Aotearoa, most emissions (90%) from the agriculture sector come from livestock farming, and the methane and nitrous oxide emitted are the result of complex biological processes. Agriculture emits 88% of biogenic methane and 18% of gross emissions of long-lived greenhouse gases.[1] Emissions from removing trees and changing to a different land use (deforestation) is covered in C*hapter 5: Removing carbon from our atmosphere*.

[1] Ministry for the Environment (2020)

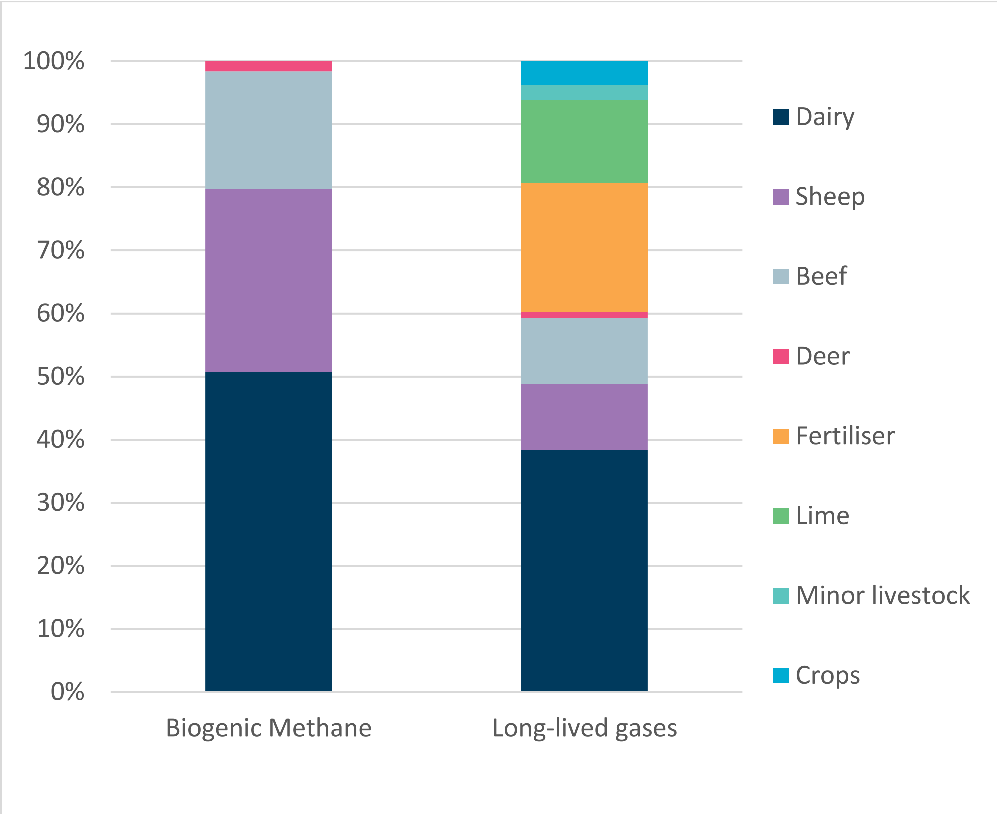

Figure 4c.1: The breakdown of Aotearoa agricultural emissions in 2018. [2]

The profile of agricultural emissions in Aotearoa has changed since 1990. Since the 1980s, many sheep and beef farms have converted all or portions of their land to dairy farming, forestry, or have retired the land. This is reflected in animal populations and emissions,[3] see *Chapter 7: Where are we currently heading*?

Emissions of both agricultural methane and nitrous oxide in Aotearoa have increased by about 17% since 1990.[4] Yet, large improvements in productivity mean that the sector's emissions intensity – greenhouse gases produced per unit of product – has fallen by about 20% over the same period.[5]

This gain in emissions efficiency has come about through a range of productivity improvements and farmer innovation. Selective breeding has resulted in more productive animals with the potential to grow faster, produce more milk and have more offspring. Improved pasture and feed management, improved animal health and more effective use of fertiliser have also enabled farmers to improve efficiency. Without these changes, current emissions would have been 40% higher.[2]

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[2] (Ministry for the Environment, 2020)
[3] (Ministry for the Environment, 2020)
[4] (Ministry for the Environment, 2020)
[5] (Interim Climate Change Committee, 2019)

Improvements in productivity are expected to continue for some time, though at a declining rate.[6] This means there will likely be ongoing improvements in average emissions intensity on farms for some time, even without the introduction and uptake of additional emissions reduction options.

There are new farming techniques that could incrementally (and perhaps cumulatively) accelerate the increase in efficiencies and reduce overall emissions.[7] There are also promising technologies under development which, if successfully brought to market, could lead to substantial emissions reductions.[8]

Practices and technologies that lead to further reductions in biological emissions are likely to have co-benefits for other environmental outcomes, such as supporting biodiversity and continued improvements to water quality.[9] They also likely align with, and support, the wellbeing dimensions and the tikanga outlined in He Ara Waiora (HAW) framework as they apply to the realms of Te Taiao and the Ira Tangata - refer to *Chapter 6: Perspectives from Tangata Whenua* for further explanation of HAW framework.

Box 4c.1: Sources of livestock emissions[10]

Cattle, sheep and other ruminant livestock produce **methane** as part of their digestive process. Billions of microbes inside the rumen break down grass and other feed through a process of fermentation. Some of these microbes produce methane, which the animals then burp out.[11] Methane emissions are largely a function of the amount of feed an animal eats. Each additional kilogram of pasture consumed adds about the same amount of methane emissions.[12] This methane (termed 'enteric methane') makes up 95% of agricultural methane with almost all the remaining 5% from the microbial breakdown of manure.

Nitrous oxide emissions are largely a function of the amount of nitrogen added to the land through urine, dung and fertiliser. The nitrogen deposited on the ground is broken down by microbes in the soil. Some of the nitrogen is taken up by plants, some is converted into nitrate, and a small amount is converted into nitrous oxide and emitted into the atmosphere. Because excess nitrogen is excreted in urine, nitrous oxide emissions are directly related to the amount of nitrogen animals consume. The quantity of nitrous oxide that is released also depends on other factors such as soil and weather conditions.[13]

Nitrous oxide is also generated from nitrogen in synthetic fertiliser through the same process noted above. This makes up 25% of direct agricultural nitrous oxide emissions.

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[6] Emissions intensity declined at a rate of about 1% per annum between 1990 and 2012, but the rate is expected to reduce over subsequent periods – to 0.3-0.6% between 2015 and 2030, and 0.3-0.5% between 2030 and 2050 (Reisinger & Clark, 2016)

[7] (Reisinger et al., 2017)

[8] (NZAGRC, 2020)

[9] (Primary Sector Council, 2020)

[10] (Ministry for the Environment, 2020)

[11] These methane producing microbes are called methanogens, and the methane produced via this process is knows as 'enteric methane.'

[12] At about 21 grams of methane for each kilogram of pasture consumed.

[13] For example, if soil is heavily compacted it is harder for plants to take up nitrogen, and the microbes that produce nitrous oxide thrive in waterlogged conditions.

There are also small amounts of **carbon dioxide** emissions from agriculture arising from the application of lime and urea. Changes in land use (and sometimes management) can also impact on soil carbon. On-farm emissions and removals of carbon dioxide from the use of fossil fuels, planting, harvesting and deforestation are included in *Chapter 4a: Reducing emissions – opportunities and challenges across sectors: Heat, industry and power*, *Chapter 4b: Reducing emissions – opportunities and challenges across sectors: Transport, buildings and urban form,* and *Chapter 5: Removing carbon from our atmosphere* of our draft supporting evidence for consultation.

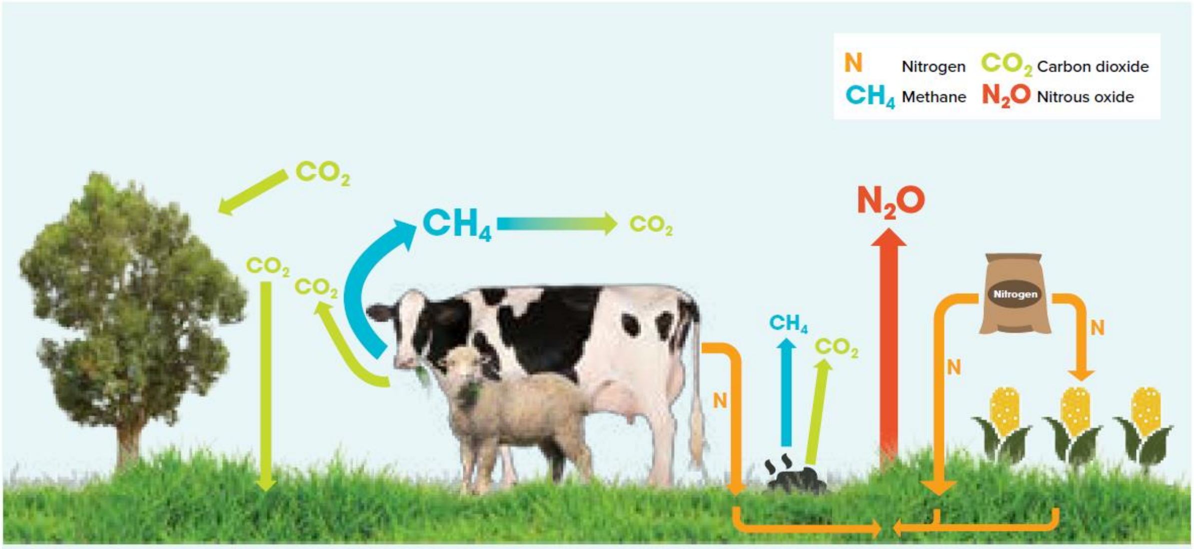

Figure 4c.2: Sources and sinks of greenhouse gas emissions on a farm.[14]

4c.1.1 Options for reducing emissions

Agricultural emissions can be reduced through either adjusting on-farm management or the use of emissions reduction technologies.[15,16]

Reducing agricultural emissions on-farm using farm management such as reducing stocking rates, reducing total feed being produced or purchased and then consumed by animals, as well as reducing nitrogen being deposited onto land. The Biological Emissions Reference Group (BERG) estimated that changing practice on farms with existing technologies could reduce emissions by up to 10%.[17]

There are a range of new technologies under development or working towards commercialisation and licencing that have the potential to reduce on-farm emissions. These technologies are likely to include a mix of vaccines, inhibitors, novel feeds, breeding and methane capture. There can be limits on the effectiveness of these technologies, due to the relevance of the approach to Aotearoa farming systems and rates of adoption. Collectively these could reduce emissions by up to 30%.[18] However, not all of these technologies are additive. For example, a methane inhibitor and a methane vaccine would likely target the same methane producing microbes.

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[14] (Interim Climate Change Committee, 2019)
[15] See https://www.pggrc.co.nz/ and www.agmatters.nz
[16] (Hamill & Stephenson, 2020)
[17] (BERG, 2018)
[18] (BERG, 2018)

The Government has developed an Agritech Industry Transformation Plan to accelerate the growth of agricultural technology in Aotearoa to make the sector more productive, sustainable and inclusive as part of a low emissions economy.[19] Agritech refers to technological changes that aim to improve value such as improving yield, efficiency or sustainability. The plan has identified the barriers to the growth of agricultural technology, which include shortage of capital to invest and connectivity within the sector. The plan has a number of actions to respond to the barriers identified, alongside progressing a number of priority agricultural technology projects.

The package of actions described here is targeted at emissions from pastoral agriculture. Emissions reduction options in horticulture and arable farming have not been discussed in detail, as they are a small proportion of agricultural emissions. Options to reduce emissions in horticulture and arable farming largely relate to reducing nitrogen oxide released from fertiliser, including through more efficient application, timing of application and reducing overall fertiliser use.

Assuming these options do become available to farmers in the future, BERG estimated that taken as a package combining all emissions reduction options, and assuming varied rates of adoption by farmers, overall biological emissions could potentially be reduced by between 10% and 21% by 2030, and by 22% and 48% in 2050 from baseline projections at the time the report was prepared.[20]

Emissions reductions beyond those achievable with management change could be achieved with land use change and/or significant reductions in livestock numbers. Where these are pursued by landowners, they are likely to have a significant impact on sources of revenue generated by that land. Whether such changes happen would depend on a range of factors, including other management options, targets set and associated policies, and the feasibility or desirability of such changes. The potential emissions reductions and impacts of different combinations or levels of action are considered in *Chapter 8: What our future could look like*.

Many actions taken to reduce emissions will also reduce impacts on water quality, and vice versa. This is because both nitrous oxide emissions and leaching of nitrogen into waterways are caused by nitrogen being deposited on soils. The Freshwater regulations recently implemented will also contribute to reductions in greenhouse gas emissions.[21]

Whenua Māori faces particular challenges. Treaty of Waitangi settlements have left many Māori with steeper, less versatile land that is often underdeveloped. In addition, many Whenua Māori have reduced the intensity of their production in line with a Te Ao Māori view. Any legislation that 'benchmarks' in environmental performance based on intensity of the current use lowers the flexibility of less intensively used land. Governance arrangements for Māori trusts (e.g. established under Te Ture Whenua Act 1993) are often complex, with several people required to make decisions for parcels of land.

Exploring alternative land use and land use diversification was a common theme in our discussions with Ahu Whenua Trusts. As kaitiaki of the whenua, we learnt that Opepe regularly makes trade-offs between culturally appropriate practice, industry best practice, governance responsibilities, owners' aspirations and the commercial realities of managing a farm and a forest (both of which were imposed through historic government policy). While transition away from dairy is within the

[19] (Ministry of Business, Innovation & Employment, 2020)
[20] Ibid.
[21] (Djanibekov & Wiercinski, 2020)

aspirations of the trustees, land conversion could be asking to wind back years of significant investment that poses a risk to the owners.

Achieving diversification within the farming system was discussed as a financial and environmental risk management strategy in our discussions with Ahu Whenua. In discussions with Opepe Farm Trust, we learnt that Opepe view that the time for large scale expansive pastoral agriculture had passed and that a mixed land use approach to farming was the future.[22]

Box 4c.2: Why is there concern over methane, but no recognition of the carbon sequestered by grass?[23]

During our work, we have been asked why the methane emitted by ruminant livestock is counted, but not the carbon dioxide removed by grasses as they grow.

The carbon removed by grass is ingested by the animal, and then ultimately returned to the atmosphere either rapidly (through respiration and urine or dung) or over a few years (as products and carcasses eventually decay). However, some of that carbon is converted to methane in the animal's rumen and expelled to the atmosphere before it eventually decays back to carbon dioxide after 12-20 years.

While the methane is in the atmosphere, it has a warming effect far greater than if the same amount of carbon dioxide were emitted – 84 times greater if the warming over 20 years is considered, or 25 times greater if the warming over 100 years is considered.

So, while this is effectively a carbon neutral cycle, the presence of methane in the cycle means there is a net warming effect above what would have happened if the animal had not eaten the grass.

The agricultural sector, Government, and Māori Primary Sector Climate Action Partnership published guidance on managing greenhouse gas emissions within farm planning in December 2020.[24]

On-Farm Management changes

The actions described below can potentially reduce both methane and nitrous oxide – though some will impact one gas more than the other.

Table 4c.1: Opportunities and challenges of on-farm management changes for reducing agricultural emissions

Options	Opportunities and challenges
Adjusting stocking rates and feed	Two closely linked elements play an important role in the overall emissions efficiency and profile of an individual farm: stocking rates and how feed is managed. These elements of farm management interact with each other, so changes to one would have implications for emissions in other parts of the farm system. **Stocking rate** refers to the number of animals being grazed per hectare. Adjusting stocking rates can help to optimise herd productivity and reduce emissions. A herd with fewer cows that maintains the same production (through higher production per cow) would require less feed overall. This can lead to lower methane and nitrous oxide

[22] Engagement with Opepe Farm Trust
[23] (Ag Matters, 2020)
[24] (He Waka Eke Noa, 2020)

Options	Opportunities and challenges
	emissions. Stocking rates can be adjusted by improving livestock reproductive performance or removing unproductive animals. The BERG found that reducing stocking rates, and improving productivity per animal could reduce emissions by up to 10% for dairy farms, and between 2% and 5% for sheep and beef farms. This could also lead to increased profitability, depending on the improvements in productivity. This finding was consistent across different farm systems and was the case even when pasture quality was assumed to decline slightly due to lower fertiliser use. Because such a system required fewer inputs, BERG also found the economic benefits of reduced stocking rates were greater when milk solid payouts were lower.[25] Farmers generally **manage feed** to optimise the productivity of their herd. Most livestock in Aotearoa graze on pasture, and skilled management is required to manage pasture growth and optimise its nutritional value. Many farms also use supplementary feed to deal with gaps in pasture growth, and/or to boost production. There is a direct link between feed consumed by livestock and the emissions they produce, as discussed in Box 4c.1 on sources of livestock emissions. Some types of feed can help to reduce nitrous oxide emissions by reducing the amount of nitrogen eaten and excreted onto pasture. Feed that is more easily digested and requires less fermentation in the rumen can also lead to lower methane emissions and increase animal efficiency. The amount of nitrogen added to the farm system in the form of feed and fertiliser, as part of feed management, will affect how much nitrous oxide is emitted from soil. A system that has fewer animals but maintains the same production requires less feed and thus less nitrogen fertiliser or imported feed inputs, which would reduce N_2O emissions. Precision farming approaches, such as the use of sensors or targeted application mechanisms, may enable further reductions in fertiliser use without compromising pasture growth. Care must also be taken to not reduce one set of emissions at the expense of another. Forage rape for example, has been shown to reduce methane emissions[26], but can lead to an increase in nitrous oxide emissions.[27] Using supplementary feed can help to boost production, but methane emissions would increase if an animal consumes more feed overall. The additional cost of using supplementary feed would also eventually be greater than the marginal revenue received from the additional production it supports.

[25] (Reisinger et al., 2017, p. 36)
[26] (Sun et al., 2015, 2016)
[27] (AgMatters, 2020b; Carlson et al., 2016)

Options	Opportunities and challenges
	Careful balancing of stocking rates, pasture and fertiliser management and supplementary feed can lead to a farm system where production, profit and emissions are optimised. Farms are complex biological systems and the mix of animals, plants, soils and feed mean that each farm has its own unique emissions profile. Changing one element of the farm system will have impacts on other parts of the system, and on emissions. For example, changing what an animal is fed will affect how much meat or milk it produces, how much methane it emits, as well as how much nitrogen is deposited on soils. What an optimal system looks like will vary considerably between farms, and the total emissions reductions a given farm can achieve will depend on how that farm is managed overall. For example, dropping stocking rates too far can make it difficult to manage pasture quality and weed growth for a given area of grazed land. There is a lot of information available for farmers; however, it can be difficult for farmers to identify or take up relevant information. This information is often focussed on a specific farm management issue and is not tailored around farm-wide actions that could reduce emissions. This could be addressed through avenues such as access to trusted sources, sharing information across farming communities and independent farm advisors. Better rural connectivity would help farmers access new ideas and information, and to share what they learn. It is also a critical component of precision agriculture, which requires data to be both collected on farm and shared with central servers. Much of the existing research in this area, including the research drawn on here, is focused on driving emissions improvements within Aotearoa existing farm systems. As a result, the research has considered actions farmers could take that would reduce emissions without significant decreases in production or profitability.
Low nitrogen feed	The type of feed livestock eat can affect how much nitrogen is excreted and thus the nitrous oxide emitted from agricultural soils. As noted above, most of Aotearoa livestock feed on pasture, and this pasture has a relatively high nitrogen content. This means that grazing livestock generally consume more nitrogen than they need, and the excess ends up in the livestock’s urine and dung. Some pasture species, such as plantain, can reduce total nitrogen excretion in urine. Pasture can also be supplemented with lower nitrogen feed, such as fodder beet.[8] Research is also underway to develop a genetically modified type of ryegrass with lower nitrogen

Options	Opportunities and challenges
	than the current pasture – this will be discussed further in the following section. Some farmers could reduce emissions by using low nitrogen supplementary feed – for example, replacing use of Palm Kernel Expeller/Extract (PKE) with lower-nitrogen maize silage.[28] The use of PKE has been controversial in the public domain in Aotearoa in recent years. Use of palm products in supply chains have been linked to increases in emissions from deforestation overseas (in regions such as South East Asia).[29] The overall impact of using low nitrogen feed on emissions levels will depend on other aspects of farm management.[30] Increasing the proportion of these feeds in animals' diets may reduce emissions, but likely only where these feeds are used as substitutes, rather than increasing overall feed demand. There are limits to the amount some feeds can be used. For example, feeding fodder beet above certain levels can be toxic for animals. Implementation time for low nitrogen feeds is relatively short, as new crops can be grown in a matter of months.
Once a day milking	Switching from a twice a day milking system to once a day milking can result in lower methane and nitrous oxide emissions, but could maintain profitability if reduced labour costs balance a reduction in total milk production.[31] The extent to which this is the case is uncertain, and will vary widely depending on breed, farm management, farm layout and farmer skill. If cows are only milked once a day, they require less feed to support milk production, which would lead to a drop in methane emissions. On some farms supplementary feed would be reduced to match lower production, which could lead to less nitrogen excreted onto soils and lower nitrous oxide emissions. Because fewer inputs (feed and labour) would be required, profitability would likely be maintained despite lower overall production. The BERG estimated that once a day milking could potentially lead to a 6-7% drop in emissions, without affecting profitability. Yet they note that there is limited experience with this approach in Aotearoa, so there is a high degree of uncertainty around the potential emissions reductions from this approach.[32] There may also be a 'rebound' effect as farmers seek to regain the lost production and use unutilised feed by increasing stock numbers.

[28] (Bryant et al., 2020)
[29] This controversy persists even though efforts have been made to source sustainable PKE.
[30] For example, whether supplementary feed is used in addition to pasture to support higher stocking rates.
[31] (BERG, 2018)
[32] (BERG, 2018)

Options	Opportunities and challenges
Further integration of the dairy and beef industry	Using calves from the dairy industry for beef production reduces the need for beef breeding cows. The reduction in beef breeding cows implies less food is consumed, and therefore there are fewer greenhouse gas emissions (see Figure 4c.2 on sources of emissions).[33] However, it is unlikely that the feed not consumed by beef breeding cows would be left to go to waste. A farm manager could use this feed for other animals and keep total emissions levels about the same, similar to the rebound effect described in once a day milking.
Creating a diversified landscape	Different land uses, both within a farm and across farms, have different footprints. One action farmers could take to reduce emissions would be to switch some of their land away from livestock farming to lower emission uses. Many farmers have already done this by planting areas of pasture into crops, allowing native bush to regenerate on pockets of less productive land within their farms and riparian planting along waterways. Planting forests and woody vegetation, or supporting regeneration of native bush offers considerable carbon benefits and will be discussed in the next chapter, *Chapter 5: Removing carbon from our atmosphere*. Beyond forestry, horticulture land use could offer much higher profitability while producing considerably lower biological greenhouse gas emissions per hectare.[34] Estimates suggest that more than 1.5 million hectares of land currently in livestock farming could be (in principle) suitable for horticulture or arable cropping.[35] However, significant change in land use has not happened despite horticulture already being more profitable per-hectare than dairy or livestock farming, which indicates there are some barriers to shifting land use in this way. Some of the barriers identified are: • Labour constraints particularly around horticulture are well documented.[36] • Capital requirements and high existing debt can make it difficult to invest to build the scale and infrastructure to support a higher production[37] – confidence is needed by both the landowner and their bank. • Gaining access to new markets is a slow process, linked to the negotiation of international agreements[38] and addressing non-

[33] (van Selm et al., 2021)
[34] The BERG estimates that that biological emissions from dairy are about 12 tCO_2e per hectare, and between 3.5-2.1 tCO_2e for sheep and beef. They estimate that biological emissions from horticulture range from 0.17 -1 tCO_2e per hectare.
[35] (Reisinger et al., 2017, p. 8). For example, apples, kiwifruit, grapes, vegetables and pulses.
[36] (NZIER, 2019)
[37] Productive kiwifruit orchards sell for about NZ$350,000/ha for Green and NZ$500,000/ha for Zespri Gold, severely limiting new entrants to the industry (Cradock-Henry, 2017).
[38] (Horticulture New Zealand, 2019)

Options	Opportunities and challenges
	tariffs barriers (e.g. government-to-government negotiations, biosecurity regulations).[39] • Fragmented pockets of land suitable for horticulture and arable may not be sufficiently large for standalone enterprises. • Limited supply chains and market saturation, particularly for expansion into new areas and/or crops. • Cultural barriers – some landowners identify themselves as livestock farmers and prefer the lifestyle. • Access to water is becoming more difficult with tightening restrictions and few new large-scale projects. Currently horticulture accounts for less than 3% of Aotearoa biological emissions from agriculture, but this may increase if more land goes into horticulture. The careful use of fertiliser and irrigation will be important to minimise biological emissions from these land uses, as well as efforts to minimise the use of energy and fossil fuels for production and processing of horticultural products. As with pastoral farming, precision agriculture and on-farm decision support tools could assist with this, but rural connectivity may hinder their uptake.
Soils	Studies suggest there is potential for some soils to increase the quantity of carbon they store, even though Aotearoa generally has naturally high soil carbon stocks.[40] Some farm practices (for example the use of deeper-rooted pasture plants, inversion tillage or no-till pasture renewal) have been advocated by stakeholders as ways to increase how much carbon is stored in the soil. However, there is currently no robust evidence of their long-term effectiveness in Aotearoa. Soil carbon can also be lost quickly during periods of drought or from soil erosion events (such as slips).[41] It is not completely clear whether Aotearoa is increasing or decreasing in soil carbon stock overall. There is ongoing research to determine changes in soil carbon and how management practices, such as those outlined in the regenerative approach below, affect this. It may take decades of data to establish reliable links between management practices and soil carbon levels.[42,43] Other areas of current focus for soil carbon research linked to practices include irrigated land use, and full inversion tillage for pasture systems as part of long-term pasture renewal (e.g. once every ~30 years). More information on soil carbon can be found in *Chapter 5: Removing carbon from our atmosphere*.

[39] (Westpac, 2016)
[40] (McNally et al., 2017)
[41] (Schipper et al., 2017)
[42] (NZAGRC, 2019b)
[43] (Smith et al., 2020)

Options	Opportunities and challenges
Regenerative agriculture	Regenerative agriculture involves techniques that focus on improving the quality and health of the whole ecosystem, including soils.[44] Practices and principles that have been referred to as regenerative agricultural practices include no-till techniques, use of organic fertiliser, increasing diversity of plant species, cover cropping, and minimal use of herbicides, pesticides and synthetic fertilisers. These kinds of practices have been applied in other countries to increase the carbon stored in soil, protect the soil from erosion, minimise soil disturbance and reduce nutrient loss. Many farmers in Aotearoa have started applying some of these practices. Research on the efficacy of regenerative agriculture in Aotearoa are ongoing and there are no robust estimates of the potential emissions reductions. Some farmers have told us that the reduction in input costs, market premium and increased ecosystem services derived from using more regenerative practices has increased their profitability and resilience.[45]

Technological changes

Some technologies target both methane and nitrous oxide, while others reduce one specific gas. The technologies are at various states of readiness, with some on the market (e.g. urease inhibitors), some expected to be on the market in the next few years (e.g. nitrous oxide inhibitors) and others still being developed in laboratories (e.g. methane vaccines).

The use of any compounds of veterinary medicines to help manage plants and animals is controlled by the Agricultural Compounds and Veterinary Medicines (ACVM) Act 1997. This plays an important role in making products from Aotearoa are safe and trusted in international markets.

The use of inhibitors could pose risks to trade, food safety and animal and plant health. We have heard from stakeholders that it is not clear whether inhibitors are covered by the ACVM, and that it could be a long process for approving them under the ACVM if they are.[46]

[44] There are no formal definitions of regenerative agriculture. For an overview of the latest definitions see: (Newton et al., 2020) and a summary of principles: (White, 2020).
[45] (Maan, 2020)
[46] (Ministry for Primary Industries, 2020)

Table 4c.2: Opportunities and challenges of technological changes for reducing agricultural emissions

Options	Opportunities and challenges
Breeding for low emissions animals	Just as livestock can be bred for favourable traits like improved meat or milk production, selective breeding of animals to be low emitting is attracting increasing attention as an emissions reduction option. Targeted breeding of livestock to emit less methane per kilogram of feed consumed has been an active area of research in Aotearoa for many years. Research has identified a large variation in the amount of methane different sheep (with the same diet) emit. This low methane trait has been shown to be heritable. It is starting to be introduced into the national flock,[47] and could filter through the sheep population in a couple of decades as the national flock turns over. Low methane sheep have been monitored for growth, reproduction and performance, and they appear to be outperforming high methane sheep on commercial breeding values.[48] The sheep are now being trialled by breeders with effort focused on how this low methane trait can be added into the sheep breeding index. Research into the potential for breeding low emission cows is less advanced. Some studies have confirmed that their methane yield also varies significantly and the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) is working to identify genetic traits for low emitting cattle, and the potential impacts on animal production. If the low methane trait is shown to be heritable in cattle, it could be incorporated into the dairy cattle population relatively easily as most dairy cattle in Aotearoa are bred from a small number of bulls. It would likely take at least 10-15 years to introduce this approach to the national herd, as the research is in early stages, and the turnover rate for an average dairy herd is around 8-10 years.
Plant breeding/modification	New research has focused on new types of low emission feed. Scientists at AgResearch have developed a type of genetically modified ryegrass with the potential to reduce emissions of both methane and nitrous oxide. Initial modelling suggested the grass may lead to a 15% reduction in methane emissions per kilogram of feed consumed, and a 10% reduction in nitrous oxide emissions.[49] In theory, a low emission ryegrass could have the technical potential to replace current dominant ryegrass species used as pasture in Aotearoa. However, the product is still in its early stages and its efficacy is far from certain. Furthermore, regulatory and public acceptability barriers exist to its deployment in Aotearoa.

[47] (Rural News Group, 2020)
[48] (NZAGRC, 2019a)
[49] (Reisinger et al., 2018)

Options	Opportunities and challenges
	Views on gene editing (GE) in Te Ao Māori deserve further exploration. The level of uptake of GE ryegrass is hard to predict.
Methane inhibitors	Methane inhibitors are chemical compounds that, when fed to livestock, reduce emissions by targeting the methane-producing microbes (methanogens) within the rumen. An inhibitor can reduce the emissions methanogens produce either by killing them, or by depriving them of the hydrogen they need to produce methane. A single dose of a methane inhibitor would not permanently reduce methane production. For it to be effective, the inhibitor would need to be inside the rumen while feed is being digested. For this reason, it would need to be administered frequently (for example, mixed in with feed or water).[50] Mixing an inhibitor into animal feed is not well suited to Aotearoa pastoral system. An alternative approach could be to deliver it by inserting a bolus or tablet that would slowly dissolve inside the rumen – though this would take time and effort to administer and would require a compound that is effective at low concentrations. There are already methane inhibitors that are close to market. The product 3-nitrooxypropanol (3NOP, manufactured by the Dutch-owned company DSM) is well advanced, and likely to be available to European producers in the next few years.[51] Several long-term tests have shown 3NOP to be effective at reducing methane emissions by around 30%, but it has been developed to work in feedlot-type systems where the compound is mixed into every mouthful of feed the animals consume. DSM are working with partners in Aotearoa to develop a slow release or pasture-based delivery system that would be better suited to Aotearoa pastoral system, and which could also be on the market in the next few years, subject to the progress on regulations governing the use of inhibitors in Aotearoa.[52,53] Some readily available compounds, such as bromoform, have also been proven to act as a methane inhibitor. However, they have not been widely used as they are suspected carcinogens and ozone-depleting substances. Some seaweeds contain bromoform, and research is currently underway to see if feeding cows or sheep seaweed could effectively and safely reduce methane emissions.[54]
Methane vaccine	The goal of a methane vaccine is to trigger an animal's immune response to generate antibodies that supress the activity of methanogens. These

[50] (NZAGRC & PGfRc, 2017)
[51] (DSM, 2019)
[52] (AgMatters, 2020a)
[53] The availability is likely to be impacted by the work of the Ministry for Primary Industries, which is considering options for managing the regulatory oversight of inhibitors to make sure the primary sector can safely and effectively use inhibitors, see (Ministry for Primary Industries, 2020)
[54] (CSIRO, 2018)

Options	Opportunities and challenges
	antibodies would be produced in the animal's blood and saliva, and continually delivered into the rumen through the saliva.[55] Because a vaccine would trigger the production of antibodies, one dose of a vaccine would, in theory, supress methane production over a prolonged period. Research suggests that once developed, a methane vaccine could be effective globally, and it is particularly well-suited to Aotearoa pasture-based farming system as it would only need to be administered periodically. Research to develop a methane vaccine is still in relatively early stages. Researchers have had some success in laboratory trials, but to date the process has not been proven to work in animals.[56] The BERG report assumes that a successful methane vaccine could achieve a similar level of reduction to a methane inhibitor – reducing methane emitted per animal by around 30%. Without a working prototype, the methane reduction potential of this approach remains speculative. Researchers estimate that any vaccine is still a long way off and it is almost certain that a vaccine, if it can be developed, would not be available before 2030.
Nitrification inhibitor	Nitrification inhibitors are chemical compounds that slow down the rate at which microbes in the soil convert nitrogen into nitrous oxide.[57] Inhibitors can be spread onto pasture or incorporated into nitrogen fertilisers. Although nitrification inhibitors already exist, they are treated here as a future emissions reduction option because the use of these nitrification inhibitors have been discontinued. The nitrification inhibitor dicyandiamide (DCD) was used in Aotearoa for a number of years, until it was withdrawn from use in 2012 after traces of the compound were found in milk. Although it is considered harmless in trace amounts, there is currently no international food safety standard for DCD, which means a default limit of zero applies. It could be available for use again once food standard regulatory processes are complete, which could be within the coming years.[58] Urease inhibitors are coated onto fertiliser and supress the microbial processes that break down the urea in the fertiliser which lead to nitrate and nitrous oxide. Urease inhibitors can also increase the effectiveness of fertilisers and they already make up a substantial proportion of market sales.[59] Based on experience with DCD, the effectiveness of nitrification inhibitors varies widely, affected by factors like temperature, soil moisture and the

[55] (Reisinger et al., 2018)
[56] (NZAGRC, 2019a)
[57] (Ruser & Schulz, 2015)
[58] (Reisinger et al., 2018, p. 34)
[59] Ravensdown – personal communications.

Options	Opportunities and challenges
	timing of fertiliser application. A series of studies around the country showed that the effectiveness of DCD on individual urine patches ranged from 18% to 82%, with an annual effectiveness of about 40%.[60] As its application would be limited to accessible land, only a proportion of farmers might use an inhibitor. Research is underway into novel inhibitors that are more effective than DCD, lower cost, and present minimal risk of residues. There are also regulatory barriers to using some of these approaches. Most inhibitors are regulated under the Hazardous Substances and New Organisms (HSNO) Act 1996, which protects the environment and the health and safety of people and communities by preventing or managing the adverse effects of hazardous substances and new organisms. However, HSNO does not manage risks such as trade risks from residues, as occurred with DCD.[61]

[60] (Parliamentary Commissioner for the Environment, 2016)
[61] (Ministry for Primary Industries, 2020)

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