“Achieving Outcomes by Building Capability”

The AgriBusiness Group™

Report on agricultural Greenhouse Gas mitigation technologies.

Prepared for He Pou a Rangi Climate Change Commission

Prepared by The AgriBusiness Group and Journeaux Economics

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Contents

Please Read

Executive Summary

The AgriBusiness Group and Journeaux Economics have been contracted by He Pou a Rangi Climate Change Commission to provide a report on current, potential, and future practices and technologies for reducing on-farm greenhouse gas emissions, to feed into the Commission's analysis and modelling.

A descriptive summary of the result of the literature review and interviews of the Scientific and Technological Mitigations can be found in ES Table 1 and the Farm Systems Mitigations can be found in ES Table 2.

ES Table 1: Summary of the literature review and interviews for the Scientific and Technological Mitigations.

Mitigation Type	Description
Genetics	Breeding cattle and sheep that produce less emissions.
Methane inhibitors	Chemical compounds that block critical pathways in rumen-dwelling methanogens, restricting their growth and ability to produce methane.
Nitrous oxide inhibitors	Chemical compounds that reduce nitrous oxide emissions by suppressing the action of microbes in the soil
Seaweed - bromoform	Seaweed contains a compound that can inhibit a digestive enzyme that produces methane
Methane Oxidation	Process of removing methane from the atmosphere. It can be done by reacting methane with hydroxyl radicals (OH) to form carbon dioxide and water
GM ryegrass	High Metabolisable Energy ryegrass
Probiotics	Fonterra trademarked, Kowbucha™, to describe the work they are doing using dairy fermentation and cultures to attempt to reduce methane production in cows
Zelp	ZELP's oxidation technology works by routing the methane exhaled by cattle through a catalytic mechanism arranged within a patented energy recovery-system. The methane gets oxidised, resulting in a combination of CO2 and water vapor.
EcoPond	Iron Sulphate additive through EcoPond inhibits the growth of methanogens from producing methane within a dairy effluent management system.
Fluoride and tannin additive to manure.	The gases are mitigated by the addition of fluoride and tannin combination inhibitor and acidification.
Methane Vaccine	Methane vaccines which trigger antibodies that suppress methane in animals.
Zeolite or membrane extraction	By treating zeolite with a small amount of copper they become very effective at absorbing methane from the air

ES Table 2: Summary of the literature review and interviews for the Farm Systems mitigations.

Mitigation Type	Description
Lower stocking rate/improved productivity	Reduced emissions by lowering stock numbers or improving productivity per kg DM consumed.
Reduce replacement numbers	Reduced emissions by lowering stock numbers.
Shorter finishing times	Improving productivity per kg DM consumed.
Reduced exogenous inputs - supplementary feed	Reducing emissions by reducing the amount or type of supplementary feeds used.
Reduced exogenous inputs -nitrogen fertiliser	Reducing emissions by reducing the amount of nitrogen fertiliser used.
Once-a-day milking	Production efficiency gain.
Change in stock types	Reducing emissions by changing stock type to a more efficient animal.
Different forage types	Reducing emissions by using plant types which induce lower emissions.
System change.	Change to a lower emissions farming system.

The majority of mitigations which are theoretically possible to reduce GHG's have been developed for systems which are designed for high levels of supplementary feeding of livestock or systems where animals are farmed in close contact in housed systems. These are either not relevant to or require significant changes to them to make them suitable for the New Zealand farming system which is predominantly pasture based in the open.

That is why the NZAGRC has concentrated its research efforts on methane inhibitors that can be delivered to the individual animal in a pasture based system on a non-regular basis. Unfortunately, this has meant that New Zealand are world leaders in that research and so have a huge task in front of us to identify and prove the worth of the compounds that can achieve that aim.

Currently the barriers to use are quite considerable. These range from:

- the currently available techniques of Sheep Genetics being constrained by the availability low emissions rams and EcoPond being uneconomic,
- the proven techniques like Bovaer and Zelp not yet being proven as being suitable for New Zealand farming systems,
- the techniques which are the best bet for New Zealand farming systems such as the methane inhibitors and vaccine are lacking the identification of a suitable inhibitor or antigen,
- alternative techniques which either haven't been proven to be effective in New Zealand farming systems or require us to change our systems in order to take advantage of them,
- to the case of genetic engineered ryegrass which is currently precluded from use in New Zealand.

Unfortunately for New Zealand there is not one scientific and technological mitigation which does not have any barriers to use. In most cases the barriers to use are quite considerable, effectively precluding their adoption currently.

The reporting of the efficacy of the range of methane mitigation techniques are taken from the results of the literature review and the interviews which were carried out. What we can take from ES Table 73 is that only four of the technique's efficacy ratings are based on sound peer reviewed research. Three are based on research results that either haven't been peer reviewed or weren't publicly available and the remainder are based on estimates which are based on scientific theory. We note that the two techniques which are assumed to make the biggest potential reductions in New Zealand farming systems, that is the inhibitors and vaccines, are estimates at this stage.

ES Table 3: Efficacies of the Scientific and Technological Mitigations.

Mitigation Type	Efficacy (%)	Source of the estimate
Genetics	Dairy 10 – 20	Assumed based on research.
	Sheep 5 - 6	Research
Methane inhibitors	10 – 30	Estimate.
Methane Vaccine	30	Estimate
Nitrous oxide inhibitors	>50	Research
GM ryegrass	20 - 30	Estimate
Bovaer	40	Research
Probotics - Kowbucha	20	Assumed based on research.
Methane Oxidation (Zelp)	50 - 60	Research – not peer reviewed.
EcoPonds	80 - 90	Research

All of the efficacies for the farm systems mitigation techniques are taken from farm systems modelling which was carried out in either Farmax or Overseer; both of these models are able to report GHG's. It reports the order of reductions that were achieved in a with and without analysis of the farm system. The difference between the without the mitigation and the with the mitigation modelling is given as the efficacy of the technique.

Both of those models are complicated models which model a specific farming system therefore the range of efficacies of the techniques will vary considerably according to the data that is entered into the model. Nevertheless, the modelling which has been reported reflects a good range of average farming systems.

Calculation of the cost of the levy which is used in this report to reflect the lowest cost of mitigation until it exceeds the actual cost of an individual mitigation technique is based on an assumed Carbon price and using an allocation system which was derived from the He Waka Eka Noa recommendations starts at \$4.20/tCO2e in 2025 and rises to \$127/tCO2e in 2050. The cost of the mitigation techniques modeled are reported in ES Table 4.

ES Table 4: Costs of the mitigation techniques ($/ tCO2e)

Mitigation	Costs calculated for this exercise.	Costs calculated AbacusBio*.
Genetics - Sheep	34	[redacted]
Genetics - Dairy	25	[redacted]
Methane inhibitors - Dairy	49	[redacted]
Methane inhibitors - Beef		[redacted]
Methane Vaccine - Dairy	25	[redacted]
Methane Vaccine - Beef	44	
Methane Vaccine - Sheep	40	
Nitrous oxide inhibitors	1,703	[redacted]
GM ryegrass / Dairy	12	
GM ryegrass / Beef	16	
GM ryegrass / Sheep	27	
Bovaer	73	
Probiotics - Kowbucha	111	
Methane Oxidation (Zelp)	99	
EcoPond	233	
Lower stocking Rate – Sheep and Beef	91	
Lower stocking Rate – dairy	597	
Lower stocking rate/improved productivity – Sheep and Beef	-348	
Lower stocking rate/improved productivity – Dairy	-848	
Reduce replacement numbers Dairy	-2,858	
Reduce replacement numbers S&B	-494	
Shorter finishing times	n/a	
Reduced exogenous inputs - supplementary feed	$91	
Reduced exogenous inputs -nitrogen fertiliser	145	
Once-a-day milking	217	
Change in stock types	-90	

[redacted]

The ADOPT modelling of the adoption rate of the mitigation techniques show that the time to peak adoption in years is predominantly in the mid to late teens and that the peak adoption level is very dependent on whether the mitigation will provide a positive financial result and the degree of that financial result.

The key points that we can take out of the expression of the timeline for uptake are that:

- The alternative cost of methane expressed as the HWEN proposed levy have a very large negative impact on the potential for uptake for the majority of mitigation techniques.
- The mitigation techniques that appear to have a lower cost and therefore potentially high rates of adoption are still in the potential or discovery stage and face a long time before they are adoptable even when they are proven to work.
- ADOPT indicates that unless a technology has a low cost, and it is easily implemented the time to peak adoption is in the mid to high teens.

1 Background

The AgriBusiness Group and Journeaux Economics have been contracted by He Pou a Rangi Climate Change Commission to provide a report on current, potential, and future practices and technologies for reducing on-farm greenhouse gas emissions, to feed into the Commission’s analysis and modelling.

Key areas that the report is required to cover are:

- The timeline to implementation.
- Barriers to use in Aotearoa New Zealand.
- Estimated Costs.
- Potential adoption rates.
- Potential efficacy.

In Section 2 of this report we discuss the range of possible mitigations that are theoretically available to reduce the impact of GHG across the New Zealand farming sector which reports the results of the literature search and our interviews with key stake holders in the research, government and commercial sectors.

In Section 3 we list and discuss the barriers to use of the range of techniques which were identified in the literature review and interviews.

In Section 4 we report on the efficacy of the range of methane mitigation techniques that we assessed as being applicable for use in New Zealand.

In Section 5 we discuss the impact of and quantify the cost of the alternative cost of methane that was developed by He Waka Eka Noa and report our calculation of the potential costs of the mitigation techniques where we had sufficient information to do so.

In section 6 we discuss the impact of extension theory and report the results of our putting the available mitigations through the ADOPT program to assess the time taken to achieve peak adoption level and the percentage of the population that are engaged at peak adoption.

In Section 7 we report the timeline to 2050 for each mitigation option, reporting the years when they move from potential to discovery to commercialisation to adoption taking into account the impact of the alternative levy price on emissions.

2 Identification of the range of possible mitigations.

The following section is the discussion around the range of possible mitigations that are theoretically available to reduce the impact of GHG across the New Zealand farming sector which reports the results of the literature search and our interviews with key stake holders in the research, government and commercial sectors.

The identification of possible mitigations has been split into two sections:

- Scientific – Technological mitigations; and;
- Farm Systems mitigations.

2.1 Scientific – Technological mitigations.

2.1.1 Genetics

A considerable amount of research has gone into identifying if methane production is hereditary and if we can breed livestock that produces less methane by identifying these characteristics in their genetics.

Dairy Cows

A trial funded by the New Zealand Agricultural Greenhouse Gas Research Centre and conducted by CRV and LIC has been conducted in New Zealand to explore ways to reduce methane emissions from cattle through genetic improvements. This trial has been ongoing for slightly over two years and involves the placement of 350 bulls in yards for approximately 35-40 days (McNaughton, 2023). Methane measurements are taken from samples collected in feed bins as depicted in Figure 1 (McNaughton, 2023).

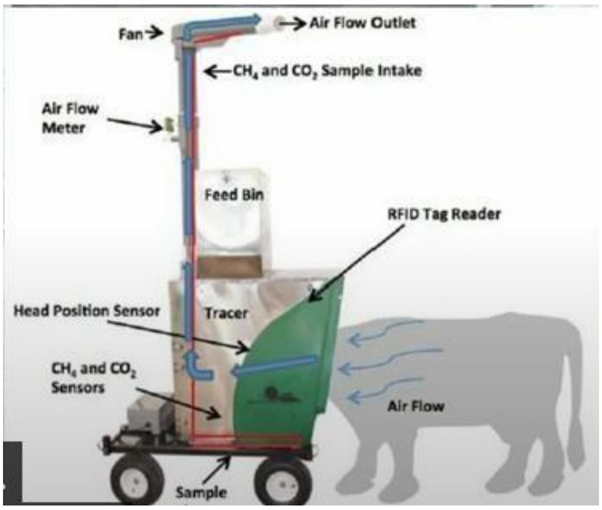

Figure 1: NZ Methane Trialing Device

The first stage of data collection for this trial will require a minimum of three years to complete. The preliminary results indicate a heritability of 0.1, slightly lower than the initial expectations (McNaughton, 2023). However, when accounting for the variation in feed intake, it was found that 77% of the kinetic variation in methane emissions remains, suggesting that there is potential for breeding cattle that produce less methane at the same level of production.

The trial's next phase will focus on validation, which involves inseminating a herd of cows. The expectation is to have 400 daughters, with 200 sired by a high methane producer and 200 sired by a low methane producer (McNaughton, 2023). The trial will measure various output-related aspects such as milk production, composition, and methane emissions. In the future, the researchers aim to expand the trial to include lactating cows and explore the use of other technologies like Cowpac (portable accumulation chamber for cattle) or sniffers to increase its scale allowing for the measuring of emissions on a larger scale.

LIC and CRV anticipate developing breeding values by 2025, although the accuracy of these values is expected to improve over time. Dr Lorna McNaughton from LIC expressed the view that genetics could provide a solution by 2050, with a potential reduction of 10-20% in methane emissions per kilogram of dry matter (KGDM) by that time (McNaughton, 2023).

Taking a closer look at international research, an extensive trial was conducted in the Netherlands to investigate the potential of cattle genetics in reducing emissions. The study involved analysing data from 100 dairy farms in the Netherlands, specifically examining variables such as emissions based on breed and emissions at the farm level (Haas, Aldridge, & Breukelen, 2021). The researchers aimed to explore how genetics could contribute to reducing emissions from cows. To conduct this trial, they employed sniffer technology, which enabled them to test a large number of cows.

The estimated genetic parameters derived from the sniffer data revealed a heritability of 0.23 for methane emissions (Haas, Aldridge, & Breukelen, 2021). This value was considered sufficient to achieve genetic progress in reducing emissions. However, the researchers noted that further research on other breeding goal traits is necessary before genetic progress can be fully recognized as a mitigation technique (Haas, Aldridge, & Breukelen, 2021). They did not provide a specific timeframe for when they anticipate genetics to begin exerting positive effects on total emission production.

Sheep

In New Zealand, Pac Chambers were employed to conduct tests on sheep and determine if there were any differences in methane production among them (Breir, 2021). The initial findings indicated a 4% variation in emissions between sheep that produced high levels of methane and those that produced low levels. It was also discovered that this trait had a heritability of approximately 0.2, thereby establishing the possibility of breeding for this desirable characteristic. Consequently, efforts were made to selectively breed sheep with a focus on low emissions, resulting in an increased variation of 12% between high-emitting and low- emitting sheep (Breir, 2021).

Extensive studies have demonstrated that breeding for this trait has not adversely affected the productivity of the sheep. Researchers anticipate a cumulative decrease in sheep emissions of 1% per year, which is deemed achievable (Breir, 2021). It is worth noting that a report published in 2018 by NZAGRC predicted a maximum feasible divergence of 30% between high-emitting and low-emitting sheep (Reisinger , et al., 2018) .

As of 2020 low greenhouse gas traits have been added to the Sheep Improvement Database. In 2019 New Zealand introduced breeding values for methane emissions for sheep breeders through Beef and Lamb genetics (Beef and Lamb, 2020)

The portable accumulation chamber tool is also relatively low-cost giving breeders the opportunity to measure the methane emissions from their own flocks. South Island ram breeders were amongst the first to measure methane emissions and generate methane-emitting breeding values with their stud rams. This cost them $7,500 to measure 84 rams for two tests (a further $7,500 was paid by PGgRC as part of its breeding incentive scheme) (Beef and Lamb, 2020).

New Zealanders have been the first to be able to breed low-methane sheep and have led studies internationally around the topic. There are now a small number of rams available to purchasers which have breeding values for methane production.

2.1.2 Methane Inhibitor

A methane inhibitor is a chemical compound that blocks critical enzymatic pathways in rumen-dwelling methanogens, therefore restricting their ability to produce methane.

Extensive research is being conducted within New Zealand to identify a suitable compound that can be used in New Zealand's predominantly grass-fed farming system. Several organizations, including AgResearch, DairyNZ, Victoria University, and the University of Auckland, are actively involved in projects aimed at addressing this issue. These initiatives primarily revolve around the development, application, and feasibility of methane inhibitors on farms (NZAGRC, n.d.).

AgResearch is specifically focusing on formulating slow-release capsules for animals raised on pasture. The objective is to create a capsule that can effectively inhibit 30% of methane emissions and remain functional within the animal's system for up to 320 days (Ronimus, 2023). Achieving this requires the development of a potent and stable inhibitor that can be incorporated into the capsule formulation. Currently, the emphasis is on exploring a new class of inhibitors.

AgResearch have discovered a compound with inhibitory properties through one of its screening assays. Initial derivatives of this compound have been tested on sheep, resulting in an 11% reduction in methane emissions (Ronimus, 2023). AgResearch acknowledges that there is potential for further enhancement within this inhibitor class to achieve the desired dosage for effective capsule delivery.

It is predicted that methane inhibitors will be available in New Zealand in 2-5 years and will have an efficacy rate of 30% (NZAGRC, n.d.).

2.1.3 Methane Vaccine

A methane vaccine operates by introducing antibodies from saliva into the rumen, where they interact with antigens to disrupt the growth and survival of methanogens, leading to the reduction in methane emission (Janssen, 2023).

In New Zealand there has been intensive research into the potential for methane vaccines due to their suitability to the New Zealand farming system. New Zealand researchers and scientists have been aiming to create a vaccine that reduces methane emissions by 30% but also state that this efficacy could be higher (Janssen, 2023). To date there have been no successful vaccine trials on sheep although some positive results have come out of in vitro research. There have been positive findings in in vivo trials. These findings demonstrate that a vaccine can generate sufficient antibodies in sheep saliva, which then bind to corresponding antigens in rumen fluid. They also suggest that these antibodies have shown the ability to bind to a range of target methanogen species within the rumen fluid. Further research that is being carried out in the area includes identification of the right antigens that will inhibit the growth and function of methanogens in the rumen (Janssen, 2023).

Commercial availability of a vaccine is estimated to take 7-10 years after demonstration of a prototype and this prototype has yet to be available as the product is still in the development phase (AgMatters).

2.1.4 Nitrous Oxide Inhibitor

Nitrification inhibitors are chemical substances that can be added to fertilizers or to the soil to reduce the emission of nitrous oxide by suppressing soil microbes responsible for converting nitrogen to nitrate, which leads to nitrous oxide production. Up until 2011 the nitrification inhibitor dicyandiamide (DCD) was available in New Zealand and was used on some farms (NZAGRC, Nitrification Inhibitors, n.d.). However, traces of DCD were detected in milk, resulting in its removal from the market in New Zealand. This severely limited New Zealand options around reducing nitrous oxide emissions.

NZAGRC-funded research has been conducted by AgResearch and Pastoral Robotics and has resulted in the identification of a potential inhibitor that has been trialed in both field and laboratory experiments with similar efficacy to DCD without the risks. There are predictions that this product should be available in the next 3-5 years and have an efficacy rating of up to 50% (NZAGRC, Nitrification Inhibitors, n.d.).

Overseas, there are commercially available nitrification inhibitors such as nitrapyrin and dicyandiamide (University of Nebraska, 2019). Nitrapyrin is a chemical that can be added to ammonia-based fertilizers and urea to reduce nitrate leaching and nitrous oxide emissions (USGS, 2021). However, there is a lack of comprehensive analysis regarding its indirect effects, although the Environmental Protection Agency (EPA) has set exposure thresholds for it (USGS, 2021).

Nitrapyrin’s impact on nitrate leaching has shown inconsistent results, ranging from 43% less leaching to 32% more leaching (USGS, 2023). Similarly, its effect on nitrous oxide emissions varies, with reported reductions ranging from no benefit to up to 70% (USGS, 2023).

2.1.5 GM Ryegrass

AgResearch has been conducting research on the development of a genetically modified ryegrass called highly metabolizable energy ryegrass (HME) offshore. Initial experiments were conducted in 2018 and yielded encouraging outcomes. The initial findings demonstrated that HME ryegrass exhibits accelerated growth, up to 50% faster than traditional ryegrass, has enhanced energy storage capabilities, increased resistance to drought, and reduced methane emissions by up to 23% (International Service for the Aquisition of Agri-biotech, 2018).

AgResearch has primarily focused on selectively breeding the most desirable traits into the ryegrass and ensuring its compatibility with New Zealand's growing conditions (AgResearch, 2019). Additional research conducted in 2019 reported a 22% decrease in total emissions and a 30% reduction in methane emissions from fresh HME ryegrass (Winichayakul, 2020).

Recent studies have also indicated that the HME ryegrass exhibits significant changes in fatty acid composition, ranging from 59% to 66%. It is worth noting that fatty acids, when used as a feed additive, have been observed to positively impact methane emissions (Beechey-Gradwell, 2022). The upcoming phase of the trial involves animal feeding trials, where the measurement of methane and nitrous oxide emissions will be further evaluated (Beechey-Gradwell, 2022).

After attempting to gain registration of HME in Australia AgResearch have changed the direction of their research and are looking to gain the same results which they have had with HME with a ryegrass that is sourced from another plant family.

2.1.6 ZELP

The concept of Zelp was first developed in 2017. The device works by detecting and oxidizing methane as soon as it is exhaled and through a catalytic chamber producing the by-product of carbon dioxide and water vapor (Norris, 2021) The device was tested in September 2020 and mitigated 53% of methane emissions (Norris, 2021). The founders indicated that they expected to have the product publicly available by August 2022 with an efficacy of 60% reduction in methane, however, on their website, it does not indicate when the devices will be available or any additional information on efficacy.

Zelp has also been evaluated as to whether the device has any negative effects on animal welfare and concluded that they found no impact on production yields, rumination, rest, activity periods and feed intake indicating welfare is not influenced (Norris, 2021).

An indicative price given back in 2021 was $80 an animal per year, note that the founders were looking at this being processor paid not farmer paid (Norris, 2021). A review from Scotland Rural College at the beginning of 2023 was critical in that there had been no peer-reviewed papers published around efficacy and insufficient information available to encourage uptake of the technology.

A trial has been conducted on the Zelp wearable devices on dairy cows and their effects on their health and well-being (Buijs, Weller, & Budan, 2023). This trial was over the period of 3 weeks and involved 44 dairy cows (Buijs, Weller, & Budan, 2023). The results show that there was limited immediate response to the wearable devices and no signs of distress. The immediate response did show that the cows tended to hold their heads lower and transitioned from sitting down to standing up more often (Buijs, Weller, & Budan, 2023). The results in the first week suggested reasonably quick habituation of the device. Over the three-week period the following was found (Buijs, Weller, & Budan, 2023).

- Cows wearing the devices tended to take more steps.
- There was no large difference in the amount of transitioning from standing to sitting down.
- Cows that were wearing the devices tended to eat 1.6% less.
- Cows wearing the devices produced slightly (1%-3%) less milk yield and milk lactose content.
- The devices had no effect on the mobility of the cows.
- There were significantly more bald spots observed on cows wearing the devices.
- There was also an increased amount of physical displacement witnessed.

No longer term trials have yet to have been published around wearable devices and therefore the long-term effects of the devices on animal health are yet to be known.

2.1.7 Zeolite Technology

Zeolite has demonstrated the potential to oxidize methane effectively when it is combined in a controlled heated environment at very high temperatures (600^0 C+). Zeolite contains crystalline aluminosilicate materials that are commonly used for commercial adsorbents (Mortensen , Noack, Pedersen, & Mossin , 2022).There has been a large amount of research into investigating the lowest possible effective temperature that would be effective under ideal conditions (Mortensen , Noack, Pedersen, & Mossin , 2022). Issues around catalytic stability under realistic real-world conditions (more realistic gas compositions) are also yet to be faced around the use of Zeolite. Researchers also outline that this system may be suitable where there are relatively high levels of methane such as in dairy farm housing barns and coal mines (Mortensen , Noack, Pedersen, & Mossin , 2022). This is due to these systems generally having air handing systems already installed. Researchers also outline that the technology could be relatively straightforward to implement, because there are very few components related to the technology (Chandler, 2022). They do however outline that large volumes of gas do not easily flow through clay therefore further research is required on ways to structure the clay material to aid air flow. Due to this substance primarily being used for cat litter, zeolite is a very cheap option for methane oxidation (Chandler, 2022)

This is unlikely to be a solution in New Zealand’s agricultural system due to the lack of containment of emissions in the country’s’ pastoral systems.

1.1.8 Manure Management

Tannin and fluoride additive to manure

Tannin and fluoride additives (TA-NaF) have been seen to have an influence on methanogenic pathways in swine manure. To date, there have been no studies conducted on the application of this technology in pastoral farm settings or its efficacy outside the controlled laboratory environment.

The existing studies examining its effectiveness have produced varying results. Trials have demonstrated significant reductions, such as a 95% decrease in ammonia emissions, up to 99% reduction in methane emissions, and over 50% reduction in odor when TA-NaF is introduced to pig manure (Fedrick, et al., 2020). However, other studies have shown minimal effects on emissions when TA-NaF is added to manure. In the trial observed there was little impact. It has been noted that this could be due to amount of TA-NaF used however there is no clarification that this is the cause of the inconsistency (Dalby, Nikolausz, Hansen, & Feilberg , 2021). The effectiveness of tannin and fluoride remains uncertain. This is particularly true as this treatment has not been tested in uncontrolled environments and with different species of manure. It is also unknown what the effect of the additives would be if added to effluent that was going to be spread.

EcoPonds

Ravensdown, in collaboration with Lincoln University (Roberts, 2023), developed EcoPonds as a solution for managing methane emissions from livestock manure, specifically targeting dairy farm effluent (Roberts, 2023). Livestock manure managed through effluent systems contributes to approximately 7% of dairy emissions (Roberts, 2023).

EcoPonds operate by introducing iron sulphate to fresh effluent, which enhances the activity of iron-reducing bacteria and sulphate-reducing bacteria, effectively inhibiting the growth of methanogens (Roberts, 2023). As a result of this the production of methane is stopped.

EcoPonds have proven to be highly successful in reducing emissions from effluent ponds, with methane emissions decreasing by up to 99% and carbon dioxide emissions decreasing by 50% (Ravensdown, n.d.). EcoPonds also demonstrate effectiveness in reducing E. coli levels by up to 99% (Ravensdown, n.d.).

Given the significant effectiveness of EcoPonds, if implemented across all dairy farms within New Zealand, they have the potential to reduce methane emissions by 1,123,559 tons of CO2 equivalent (Roberts, 2023). Importantly, the addition of iron sulphate is minimal and has negligible impact when the effluent is spread, making it unlikely to be detectable in soil tests for many years (Roberts, 2023).

EcoPonds are currently available in the market and have shown positive results thus far.

2.1.8 Anaerobic Digestors

Anaerobic digestion is the process which breaks down organic matter such as food waste and manure with oxygen. This captures biogas such as methane and carbon dioxide from the conversion of biodegradable organic matter. This biogas can be used as a source of energy and is used in vehicles and machinery in America. Although some studies indicate that there are potential reductions in emissions from this process others do not take that same view.

The European Biogas Association suggests that anaerobic digestors can reduce global greenhouse gas emissions by 10 to 13% (European Biogas, 2019). They outline that this can be achieved through the generation of renewable energy from biogas combined with emission avoided through the management of organic waste and avoided fossil fuel manufacture, crop burning and deforestation (European Biogas, 2019). In their report they discuss the potential to transition from coal fire electrical consumption that produces additional emissions to anaerobic digestion a naturally produced energy that would meet 16% to 22% of the world electricity consumption yearly (European Biogas Association, 2019). They conclude that anaerobic digestion is a ready to use technology with the ability to decarbonize heating our buildings and transportation while additionally providing natural fertilizer that can be recycled back into the soil (European Biogas Association, 2019).

A study carried out around 30 cogeneration plants in France with the aim of detailing whether anaerobic digestion really does help reduce greenhouse gas emissions (Malet, 2023). In their study they found that on average the 30 anaerobic digestors did not provide any additional benefits in terms of greenhouse gas emissions in comparison to the baseline. They found the substitution effects from fossil fuel to biogas were limited. This study also found that the variability in net greenhouse gas emission of anaerobic digestors was high and this was mostly dependent on soil carbon efficiency in the baseline and difference in the technical management of the anaerobic digestors (Malet et al., 2023). The technical management practices included the amount of methane leakage, type of biogas end-use, heat recovery, and digestate handling. The study did however note that with optimal anaerobic digestor management this could lead to significant improvement in net greenhouse gas emissions (Malet, 2023).

This outlines that there may be potential for anaerobic digestors to reduce emissions however the management of these is critical to see positive results out of them.

2.1.9 Low emissions feeds and supplements

Ionophores/Monensin

Ionophores such as monensin have been examined to see if they have the potential to cause reductions in emissions. The use of monensin as a feed additive has been explored due to its potential to reduce emissions. The trial results for the use of Monensin have been inconsistent (Appuhamy, 2013). The meta-analysis in the American Dairy Science Association report looks at 22 controlled studies (Appuhamy, 2013). The results of this meta-analysis showed significant reductions in CH_4 emissions in beef steers but only had marginal impacts on CH_4 emissions in dairy cattle. The study also notes that a higher supplement rate of monensin (mg/day) could potentially reduce CH_4 emissions in dairy cattle.

There has also been additional research on ionophores having positive impacts on feed efficiency (PennState Extension, 2017). This has been seen to have a significant effect in American feedlot situations increasing the return on investment by 5% to 10% through efficiency gains (PennState Extension, 2017).

There were two trials using monensin in New Zealand in 2005 and 2008. In the 2005 trial by Van Vugt, cows in ryegrass-dominant pasture fed indoors measured a reduction of 12% in CH_4 emissions 11 days after dosing. The reduction in this trial persisted for 2 months with a reduction of 9.2% CH_4 emissions (Van Vugt, 2005). In this study, they had a delivery rate of 320mg of monensin per day from a slow-release capsule (Van Vugt, 2005). The 2008 study by Waghorn worked on lower dosage rates of 10.8 to 14.5mg of monensin/kg of DMI (the previous study 30 to 35mg of monensin of DMI) and did not find any effect on CH_4 emissions (Waghorn, 2008).

Seaweed

There have been a number of studies around feeding livestock seaweed and its effectiveness on reducing methane emissions. Asparagopsis taxiformis has been found to have positive effects on methane production with results showing up to a 99% reduction in emissions at a dosage rate of 2% however these results are variable (Vijn, 2020). From the large quantity of results gathered there is a correlation between the concentrate of bromoform in the seaweed and the efficacy of methane reductions (Vijn, 2020).

The safety of bromoform usage has generated varying opinions internationally. A report from Wageningen University recognizes bromoform as an effective inhibitor but also highlights its toxicity. The report states that the long-term consequences of using bromoform are still unknown. In trials, the rumen wall of two out of 12 cows exhibited abnormalities and signs of inflammation when examined (Wageningen University Reseearch, 2021).

To ensure safety, there are limits on the maximum allowable concentration of bromoform in drinking water due to its harmful nature in its pure form. However, other research suggests that no conclusive evidence indicates that animal health and product quality are compromised at minimum effective feed inclusion levels (Algal Research, 2022). This research concludes that bromoform may not have a negative impact on health or food quality (Algal Research, 2022).

AgResearch is currently investigating bromoform as a potential methane inhibitor. The results of the AgResearch study are yet to be published.

Research conducted in Australia revealed that when cattle were fed asparagopsis, their methane production decreased by 28% (Readfearn, 2023). However, an unintended consequence was observed as the cattle consumed less feed, ultimately leading to a 15kg reduction in their weight by the time they were sent for slaughter (Readfearn, 2023). This study highlighted some challenges associated with asparagopsis and concerns about potential adverse effects of feeding it to livestock.

Future feeds are one of the first to make available Asparagopsis seaweed that has seen positive effects on methane emissions (FutureFeed, n.d.).

Bovaer

Bovaer is a feed additive that is produced in Germany and is now commercially available in 45 different countries (DSM, 2022). Its mechanism of action involves suppressing the enzymes responsible for methane production, resulting in reduced methane emissions. When administered as a feed supplement, a quarter of a teaspoon added to a cow's feed can take effect in under 30 minutes. With over 60 on-farm trials conducted, Bovaer has already contributed to a reduction of 49,671 tons of CO2 since its commercial availability (DSM, 2022). The product claims to save 1 ton of CO2 per cow every year. On average the product has had the ability to reduce emissions by 30% in dairy cattle and 45% in beef cattle (DSM, 2022). An article published in 2022 estimated the cost of Bovaer to be 1 cent per litre of milk (Bodde, 2022).

Although Bovaer must be fed in every mouthful to gain full efficiency it has seen 7% reductions in pastoral systems (DSM, 2022). Bovaer are in the process of trialing a slow-release formulation in Spain. This product is not available in New Zealand currently but is in the process of being registered, when approval will take place is unknown at this point in time (Nieuwland, 2023). A recent report suggests that a decision could be made on Bovaers availability in New Zealand as soon as September 2023 (Uys, 2023).

Probiotics

Probiotics consist of live bacteria and yeast that have been researched to have multiple positive health effects. Fonterra have developed a probiotic called Lactjcaseibacillus Rhamnosus which they found reduced the amount of methanogens in pigs (Bassett, 2023). With this discovery they decided to investigate the possibility of this effect being able to be transformed to cattle.

Fonterra report that Kowbucha is a probiotic with no known side effects (Bassett, 2023). They outline how probiotics are frequently used on livestock and are known for being safe for animals and having no residual effect. Kowbucha has gone through thorough testing and has shown some very positive results (Bassett, 2023). Fonterra have used a step-by-step approach with Kowbucha to identify the strains with the highest level of methane inhibition (Bassett, 2023).

Through this research they have successfully:

- Screened 1800 strains
- 4 assays of inhibition for different methanogens
- Identified strains that reduce methane in rumen fluid assays.
- Performed 8 feeding studies on calves, sheep, and pigs.
- 100 strains have been identified that show >50% inhibition.
- Up to 50% less methane observed in some strains.

The studies have shown that the presence of bacteria is important for the development of the gut and immune system. It has also been shown that feeding Kowbucha from birth may alter the development of rumen microbiome meaning the effects of feeding Kowbucha could be long lasting on animals fed the supplement from birth (Bassett, 2023).

There are currently 4 Kowbucha strains being assessed in animal trials. In the animal trials there have been an ongoing 20% reduction in methane emissions and the reduction in emissions has been seen even after 12 months (Bassett, 2023).

Work is continuing around developing new and faster ways to screen and identify the promising strains. Fonterra are ensuring that the positive results that they have been seeing are consistent across different farming systems. Fonterra are also working on a go to market plan and are working to ensure that the Kowbucha will be affordable for farmers (Bassett, 2023).

Numerous studies conducted abroad have explored the potential of probiotics in reducing enteric methane emissions. Various types of probiotics have been investigated, including propionic acid bacteria, lactic acid bacteria, acetic acid bacteria, enterococcus faecium SROD, bacillus licheniformis, and saccharomyces cerevisiae (Sun, 2020). Among these, acetic acid bacteria have shown the most promising effectiveness thus far (Sun, 2020).

Research indicates that proteiniphilum acetatigenes, a strain of acetogenic bacteria, exhibits the lowest methane production compared to other probiotics tested. In vitro results suggest that this strain can be utilized as a directly fed microbial to inhibit methanogenesis (Kim, 2020). In vivo trials conducted with this probiotic also indicate that it prevents any reduction in milk yield and milk fat during the summer season by maintaining rumen fermentation in lactating cows (Kim, 2020). Research on this potential methane-reducing probiotic is still in its early stages compared to Kowbucha, which is poised to enter the market as one of the first probiotics with the ability to reduce methane emissions.

Biochar

Biochar, a form of charcoal that comes from woody debris has been used for thousands of years to treat digestive disorder in animals. Biochar has been seen to have several positive health effects on livestock including toxin absorption, digestion, feed-use efficiency, cell numbers in milk and livestock weight.

Evidence first came to light that Biochar may have the ability to reduce emissions through an in vitro trial in Vietnam which revealed that 0.5% and 1% additions of biochar could reduce methane production by 10 and 12.7% respectively (Schmidt, 2019). It was found that high levels of biochar did not have any further effects on methane production. All these experiments were trialed with a 2% presence of urea as a non-protein source of nitrogen. It is expected that this additional effect of the combined biochar and nitrate supplement enhances the electron accepting and redox properties of biochar. The same researchers have done an in vivo experiment and found that methane could be reduced by 20% when 0.6% of biochar was added to regular feed, this effect was doubled when it was combined with 6% potassium nitrate (Schmidt, 2019). The biochar in these experiments was created in extremely high temperatures from silicon-rich rice husk which would suggest that it may have high electrical conductivity and buffering capacity (Schmidt, 2019). This characteristic means that not all biochar will perform as effectively as seen in these trials and the properties of biochar should be considered if being used.

Danish researchers did a test on poorer manufactured biochar made from wood and straw. The results show methane emissions reduced between 11% and 17% (Schmidt, 2019). Other results have not been as positive with a few other studies only showing results of no effect or small effects (7%) however this variation could possibly be due to the characteristics of biochar being used. Biochar isn't advertised in New Zealand as a feed additive but is advertised due to its soil enhancement properties. There is also a lack of data around the long- term impacts of feeding biochar (Schmidt, 2019).

Mootral

Mootral is a feed additive that was developed in the UK. Mootral works via targeting archaea which are a group of microbes that are responsible for production of methane inside the rumen (Mootral, n.d.).

Mootral directly inhibits the activity of the archaea leading to reductions in methane production. This product in vivo tests showed almost complete inhibition of methane production and did not affect the bacterial synthesis of fatty acids which are important for cows' energy.

In the United Kingdom, in vitro tests were conducted to assess the impact of Mootral Ruminant (Roque B, 2019). The trial administered Mootral in pellet form, on two breeds of cattle: Friesian and Jersey. Over a period of 12 weeks, the cattle were fed the pellets, and the outcomes revealed promising effects on methane production. The results from this trial showed an average reduction of methane of 30% with the addition of 3-5% increases in milk yield (Eger M, 2018).They also did not discover any negative impacts on cow health or milk quality.

Trials have also been performed in the US at the University of California Davis. These trials were located on a feedlot with 20 Angus-Hereford cross steers (Vrancken H, 2019). The steers were supplemented with Mootral in pellet form for a total of 12 weeks and results showed up to 23% reductions in methane emissions with no negative effects of weight gain or animal health (Vrancken H, 2019).

Another trial was performed at Purdue University which has similar results but showed that Mootral is more effective when fed for longer. This study also found that steers that were fed Mootral showed a tendency to have decreased fat and produce higher yields. Purdue university also investigated the effect of Mootral and different forage concentrations on methane production. While Mootral still had a positive effect on a higher forage diet however the magnitude of this effect was smaller.

A trial was carried out in the Netherlands on Holstein calves that saw an average of 23% efficacy. In this trial Mootral was fed with a small amount of sugar after being fed milk.

These results show a high level of consistency. There have yet to be any studies on whether this approach would be useable in pastoral systems however the likelihood of this is low due to the inability to feed the pellets in high frequency.

Agolin Ruminant

Agolin Ruminant is a specific blend of essential oils that has been found to have positive effects on feed efficiency and decrease enteric methane produced by cattle.

A meta-analysis of 23 selected studies was carried out in 2020 and outlines the potential efficacy of the product. The results of these trials showed that short term exposure to Agolin had no effect and the supplement only had positive effects after being fed for 4 weeks (Belanche, 2020). The longer treatments however saw positive results both increasing feed efficiency and decreasing methane emissions (Belanche, 2020). The analysis also showed that within all the studies Dry Matter Intake was not affected by the supplement, it also showed in same cases that it had the ability to increase milk yield fractionally (2%) while having no adverse effect on milk composition.

The researchers however did note that the exact impact involved in Agolin decreasing emissions is unclear and further research should be done around the impact of Agolin on the rumen microbiome.

This additive is commercially available and has the Carbon trust certificate, FamiQS quality assurance certificate and is organically certified.

Essential Oils

The idea that essential oils can reduce methane emissions is not a new concept with a large number of studies showing their potential (Benchaar, 2011). The table below outlines the results found in essential oils ability to reduce methane emissions. On some accounts essential oils only had an effect when used at very high dose rates. There is limited research around the toxicity of essential oils when fed at a high rate (Benchaar, 2011).

Table 1: Essential Oils Potential Impact on Methane Emissions (Benchaar, 2011)

Essential Oils	Efficacy (%)	Dosage Rate (mg/l of cultured fluid)	Comments
Horseradish Essential Oil	19	20g/KG dietary DM	This did decrease DM intake by 10%
Garlic oil	19	300	
Cinnamalde hyde	0-26	132-396	Low dosages showed no effect on methane emissions
Thymol	0-94	300-400	Low dosages showed no effect on methane emissions
Carvacrol	13-98	225-750	Results showed a linear response, the larger amount of Carvacrol cause a larger decrease in emissions
Eugenol	30-35	400-500	

As Table 1outlines there is a large potential for essential oils to have a positive impact on methane emission suppression, however the results are highly variable and untested in pastoral situations. The long-term health effects on animals have not been tested.

Daffodil Extract

A recent study conducted in the UK has yielded promising results from the incorporation of daffodil extract as a feed additive (Byrne, 2023). In the lab trial this technology received remarkable reduction of 90% of methane emissions. On-farm trials did not show as significant effects but did reduce enteric methane from cattle by 30% (Byrne, 2023). While these finding are still very fresh and specific details around this research is limited the research into this technology is ongoing and could be a technology to watch. Researchers in the UK plan to assess and test the technology on multiple commercial dairy farms across the UK (Byrne, 2023).

Tannins

There have been a large number of studies around tannins as a feed additive to reduce methane emissions (Nawab, 2020). There have been a range of results from these studies including some that have shown significant reductions in emissions (57%) and others that have shown no impact.

The trials where they have used both hydrolysable tannins (HT) and condensed tannins (CT) had a greater affect than those that used one or the other.

It has been observed that tannin supplementation has direct inhibitory effects on methanogenesis by affecting rumen specific microorganisms called archaea. Through these various studies it has also been shown that tannin extracts containing phenolic fractions are more effective than plant leaves comprising tannins. This report also notes that the variation in results is likely due to the supplement source, concentration, composition, dosage rate and the period of tannins adaption (Nawab, 2020).

Tannins have been reported to be a natural feed additive that is safe for consumption (dose dependent) for all animals and out of many studies there have been no reported environmental hazards.

The Panel on Additives and Products or Substances used in Animal Feed (FEEDAP) does report tannins as a hazardous product. They acknowledge tannins potential works through effects from inhalation or exposure through direct contact with skin, eyes, and mucous membrane. This technology is untested in the pastoral environment and due to the high dosage rates of 177g/kg this is unlikely to be achievable (Nawab, 2020).

2.1.10 Toilet Training Livestock

According to a recent study (Dirksen, 2021), efforts to toilet train cattle have been deemed "partly successful." Through reward-based training, it has been demonstrated that animals can be taught to respond to internal experiences with appropriate training. The study revealed that cattle can exercise control over their micturition reflex and utilise a designated latrine for urination. In this trial, 16 individual calves underwent toilet training across multiple stages. The results indicated that 11 out of the 16 calves quickly learned how to control their urinary reflexes. These calves exhibited the ability to use the latrine for urination approximately 77% of the time (Dirksen, 2021). This performance level is comparable to that of young children and suggests cognitive capabilities that can be harnessed.

Modeling conducted in conjunction with the trial revealed the potential to reduce ammonia emissions by 50% if cattle consistently used the latrines for urination 80% of the time (Dirksen, 2021). Although ammonia itself is not a greenhouse gas, upon deposition to soil it can be converted to nitrous oxide which is a recognized greenhouse gas. It is important to note that training a large number of cattle may require a significant amount of time, and this study highlights the fact that not all cattle possess the same learning capacity. This poses challenges in scaling up the implementation of cattle toilet training.

2.1.11 Vegetation

Trees and vegetation can reduce the amount of carbon in the atmosphere by sequestering carbon throughout its growth process. As trees and vegetation grow, they store more carbon holding it in accumulated tissue. The amount of carbon sequestered annually is dependent on the size and health of the trees.

He Waka Eke Noa has made recommendations that the New Zealand government should recognize existing and new vegetation as an offset against emissions. This is recommended under two broad categories permanent vegetation and cyclical vegetation (He Waka Eke Noa, 2022).

Permanent Vegetation is proposed to include plants and regenerated indigenous vegetation that will not be harvested and that is self-sustaining (He Waka Eke Noa, 2022). The land must also remain in permanent vegetation.

Permanent vegetation includes.

"a) Indigenous vegetation established before 1 January 2008: At least 0.25ha of land wholly or predominantly in indigenous woody vegetation either planted, regenerated, or a combination. Stock must be excluded from the area. Stock exclusion can include fencing, geographic boundaries and/or dense vegetation that stock can't access.

b) Indigenous vegetation established on or after 1 January 2008 (unless there is evidence of establishment between 1990 and 2008): At least 0.25ha of land wholly or predominantly in indigenous woody vegetation either planted, regenerated, or a combination, that was in pasture prior to 1 January 2008 (unless there is evidence of establishment between 1990 and 2008). For regenerating, a seed source needs to exist within 100m of the regenerating vegetation area. A declaration will be required stating that the land was not in vegetation prior to 1 January 1990.

c) Riparian vegetation established on or after 1 January 2008 (unless there is evidence of establishment between 1990 and 2008): Plantings suited to margins and banks of waterways including wetlands, minimum of 1m wide from the edge of the bank of the waterway/wetland. Predominantly15 woody vegetation including indigenous and/or a mix of non-indigenous plants used for environmental benefit. Non-woody vegetation such as flaxes and toetoe are included but must not be the predominant species."

Cyclical vegetation is defined as vegetation that is planted but maybe felled and re-established. This form of vegetation is not self-sustaining and needs to be replanted continuously. To be eligible cyclical vegetation must be planted on 1st January 2008 or after.

Categories of cyclical vegetation include (He Waka Eke Noa, 2022).

"a) Perennial cropland: An orchard and/or vineyard greater than 0.25ha in size.

b) Scattered forest: Minimum of 0.25ha for any area counted with minimum stocking rate of 15 stems per hectare. Scattered forest is not eligible if it is >1ha, and >30% canopy cover at maturity, and >30m wide (i.e., once it meets the NZ ETS criteria).

c) Shelterbelts: A linear vegetation feature consisting of one or more rows of trees and/or shrubs planted on or after 1 January 2008 with a minimum linear canopy cover of 90%. The shelterbelt is not eligible if it is >1ha, and >30% canopy cover at maturity, and >30m wide (i.e., once it meets the NZ ETS criteria).

d) Woodlots/tree-lots: Up to 1ha and at least 0.25ha of tree species that have greater than 30% canopy cover."

Trees and vegetation give farmers an additional option when looking to reduce their carbon footprint on farm. Restoring wetland and riparian plantings can also not only positively impact the sequestration of carbon but also support biodiversity and make improvements to freshwater quality.

2.2 Farm Systems Mitigations

2.2.1 Background

The key drivers of greenhouse gas (GHG) emissions at a farm level are:

(i) The amount of dry matter consumed. There is a direct correlation with methane production (approximately 21 grams CH_4 per kg DM), and a strong correlation with the amount of nitrous oxide emissions, although N_2O emissions are also strongly driven by:

a. The amount of protein in the diet. Ruminants generally need 16-18% protein content, whereas much of New Zealand pasture contains 20-30+% protein. The excess protein is excreted, resulting in issues with NO_3 leaching and N_2O emissions.

b. The amount of nitrogen fertiliser applied. While there is some direct emissions of N_2O and CO_2 from applying nitrogen fertilisers, the main reason for the application is to grow more dry matter – back to point (i).

Changes to farm systems therefore is around manipulating these factors in order to reduce GHG emissions while maintaining the financial viability of the farm business.

2.2.2 Mitigations

Reducing Stocking Rates

While the amount of DM consumed is a major driver of GHG emissions, reducing this at an individual animal level has the impact of reducing the productivity and the financial returns from that animal. The overall strategy then becomes one of reducing stocking rate in order to reduce total DM consumption.

Simply reducing stocking rate on its own will definitely reduce GHG emissions – usually almost linearly relative to the stocking rate reduction but will certainly also significantly reduce the financial returns to the farm. Modelling work on case study farms,[1] assuming a 10% reduction in stocking rate, and no corresponding improvement in productivity in the remaining animals, has resulted a 8-12% reduction in GHG emissions (CH_4 + N_2O), and a 10-40% reduction in farm EBITDA.

Reducing stocking rate but then increasing productivity in the remaining animals (e.g. increased per cow milksolids production, increased lambing/calving/fawning %, increased carcass weights) results in a GHG reduction approximately half that if no productivity improvements are made, with a -5 to + 30% improvement in Farm EBITDA[2].

There are two key factors to consider under a “reduced stocking rate/improved productivity” scenario:

[1] Takahuri-Whenua-approaches-to-systems-and-land-use-change-to-reduce-ghg-emissions. https://www.nzagrc.org.nz/publications/takahuri-whenua-approaches-to-systems-and-land-use-change-to-reduce-ghg-emissions/

[2] EBITDA = Earnings before Interest, Tax, Depreciation, and Amortisation number was reduced down to 15%, showed a 2-3% reduction in total GHG emissions from the farm, while improving farm EBITDA by around 3%.

- By reducing the stocking rate, less DM is consumed. But to increase productivity, the animals need to consume more DM. This results in a degree of trade off around total DM consumption, and therefore the degree of reduction in GHG emissions.
- Increasing the productivity of the farm assumes that there is room to achieve this. If a farm is already operating at a high level of efficiency/productivity, there is very limited room to improve this. Modelling work also indicated that with stocking rate reductions above 15-20%, it was very hard to achieve improvements in productivity in order to maintain or improve farm profitability.

Reduced Replacement Rates

Many farms operate with a 23% replacement rate – i.e. there are 23% replacement animals run relative to the number of mature breeding animals on the farm. Modelling work whereby this number was reduced down to 15%, showed a 2-3% reduction in total GHG emissions from the farm, while improving farm EBITDA by around 3%.

The GHG emission reduction is achieved because there are less animals consuming DM, and the improvement in EBITDA is due to the saving in operating costs (e.g. less animal health, less supplementary feed).

There is a very important precondition in contemplating such a reduction: death rates must be low, and in-calf/in-lamb rates must be high. If either of these conditions aren't met, then genetic gain on the farm will be severely reduced.

Shorter Finishing Times

This relates to finishing stock to similar slaughter weights, but in a shorter time period. For example, assume steers are being finished to 300kg carcass weight by 24 months. If they are finished to 300kg CW by 20 months, then GHG emissions will reduce by 2-3%, and farm profitability increases by around the same amount; 2-3%.

Essentially the reduction in GHG emissions is due to the reduced maintenance cost (in dry matter) of carrying the animals for the shorter time.

Reducing External Supplementary Feed Inputs

Supplementary feeding via external sources tends to be a much greater factor in the dairy sector compared with sheep & beef farms. Modelling the (total) withdrawal of external supplementary feed on a range of dairy farms showed GHG reductions varying from -5 to -11% (average -7%), and an impact on farm EBITDA of +5 to -22% (average -5%).

Removing external supplementary feed essentially is reducing the amount of dry matter within the system, and hence the reduction in GHG emissions. The level of GHG reductions is related to the proportion that the supplementary feed makes up of total feed within the system. So for a farm which relies heavily on supplementary feed inputs the removal will have a much higher proportional impact.

This also relates to the impact on farm profitability – the greater the system reliance on external supplementary feed, the greater the proportional impact when it is removed.

For some farms removing or reducing the amount of external supplementary feed had a positive impact on farm profitability. In this instance, the marginal benefit from the supplementary feed was less than the cost, so its removal actually lifted farm profits. Something farmers need to consider when purchasing in supplementary feed.

Manipulating supplementary feed also gives the opportunity to adjust the level of protein in the diet. For a number of dairy farms, the difference in feeding palm kernel (moderate protein) compared with maize silage (low protein) was modelled. For methane there was no difference, given that the same amount of dry matter was fed, but it did reduce nitrous oxide emissions by 1-2%.

Reducing nitrogen fertiliser Inputs

Nitrogen fertiliser input into dairy farms is much greater compared with sheep & beef farms so again the modelling has concentrated on dairy farms. While applying nitrogen fertiliser results in some direct emissions of N2O and CO2, the main reason for using nitrogen fertiliser is to grow more dry matter, and the withdrawal of nitrogen fertiliser again essentially reduces the amount of dry matter available within the farm system.

Modelling the withdrawal of half the normal nitrogen fertiliser usage on a number of dairy farms shows a -3% to -9% (average -4.5%) reduction in GHG emissions and -1% to -14% (average -4%) reduction in farm EBITDA.

Modelling the withdrawal of all nitrogen fertiliser on a few dairy farms gave a -7% to -16% (average -12%) reduction in GHG emissions, and a -5% to -7 % (average -6%) reduction in farm EBITDA.

Similar to the supplementary feed modelling, the impact on the individual farms varied depending on the relative importance of nitrogen fertiliser used within the farm system. This can be important for irrigated farms, where the reliance on nitrogen fertiliser to drive a profitable system tends to be much higher.

It is important to note that if additional supplementary feed is substituted for a reduction in nitrogen fertiliser, then any reductions in GHG emissions are likely to be minimal to zero, and costs are also likely to be higher.

Fertigation

Fertigation is the term used when using an irrigation system to apply fertilisers. Fertigation can be a significant advantage over conventional broadcast methods as timing, quantity and accuracy of application can be greatly improved. Generally, an irrigation system with fertigation must be managed differently than conventional irrigation.

One recent example from a Canterbury dairy farm (S Breneger, BP Consulting pers com) which has installed a fertigation system showed an improvement in nitrogen use efficiency from 60-70% from conventional solid application of nitrogen fertiliser to 85% when using fertigation. This meant the farmer reduced nitrogen fertiliser input by 21% (from 190kg N/ha to 150 kg N/ha) and achieved similar dry matter responses.

Overseer analysis showed a 4.6% reduction in N_2O emissions, a 9.3% reduction in embedded CO_2 emissions, and a 1.9% reduction in total GHG emissions. Nitrogen leaching also decreased 3%.

While there was an up-front capital cost for the fertigation equipment, this was recovered within 2 years via lower spreading and lower nitrogen fertiliser purchasing costs.

Once-a-day milking

Once-a-day milking (OAD) refers to the dairy herd only being milked once a day over the lactation period. The impact on GHG emissions varies, depending on a range of circumstances which comes back to the total amount of dry matter consumed by the farm system.

Initially, many herds switching from twice-a-day to OAD can see a drop in production of up to 20%., particularly if the twice-a-day herd is high-producing. This reduction is very largely driven by the impact of OAD on cows bred (for decades) to be milked twice-a-day, and physiologically they cannot handle OAD. The reduction in production is driven by a reduction in dry matter consumption, which is accompanied by a reduction in GHG emissions in the order of 6-7%.

There is a degree of variation around this due to:

- A number of farmers may increase cow numbers to compensate for the reduction in milksolids production, which will result in similar if not more dry matter consumption, and hence no reduction, and possibly an increase, in GHG emissions. Some farmers will also swap breeds to achieve this, by, for example, switching from (larger) Friesians to a larger number of (smaller) Jerseys. Again the impact of this on GHG emissions is very largely driven by the total amount of DM consumed within the system.

- Over time, many OAD herds increase their production as the twice-a-day cows that can't handle it are culled out, and more "OAD-compatible" cows are retained in the herd. The result is an increase in GHG emissions.

The impact on farm profitability also varies. While the drop in production will reduce farm income, usually OAD results in a reduction in farm operating costs, and on many farms the two can equate, especially if production rises as the OAD system beds in. Any reduction in production and subsequent profitability would also be exacerbated with high payouts.

Change in stock types

This option is based around changing stock types that are less productive/profitable with animals that are more productive/profitable. In a simple sense this may be a matter of swapping breeding animals for finishing animals, where the DM maintenance cost of maintaining the animal is less.

An example here would be swapping breeding cows for finishing bull beef/steers/heifers, with the latter being much more profitable on average.

Modelling this on a number of sheep & beef farms showed a change in GHG emissions of +6% to -15% (average -2%), with a corresponding change in farm EBITDA of -22% to +53% (average +30%).

Some caution is needed here, as the important factor in altering GHG emissions is stocking rate, rather than stock type. A stock unit is an animal which eats 6,000MJ ME/year (which equates to 555kg DM of 10.8MJME/kg DM). So a change in stock type, if they are run at the same stocking rate, will result in the same GHG emissions.

An exception here is altering sheep:cattle ratios, as sheep produce slightly less N_2O relative to cattle. So if sheep:cattle ratios are increased, (i.e. more sheep, less cattle), and the stocking rate is maintained at the original level, then CH_4 emissions will be the same, but N_2O emissions will be slightly less (usually 1-2% down).

There are also farm management issues to be considered; many farmers prefer breeding cows for their ability to clean up rough feed without affecting their performance, and many also dislike bulls because of their behaviour – fighting, wrecking fences, digging holes, and being kept away from neighbors' female cattle.

Different forage types

There are some forages which are known to reduce either CH4 or N2O emissions when consumed. Some feeds ferment differently in the rumen educe methane production, while others have a lower protein level meaning less nitrogen is excreted and therefore reduce N2O emissions.

Both forage rape and fodder beet are known to reduce the amount of CH4 per unit of feed consumed. Forage rape, when fed as a sole feed, has been found to consistently reduce methane emissions by around 30%, whereas fodder beet is only effective at very high rates of inclusion (>75%).

Maize and fodder beet both have lower protein concentrations compared with the standard grass/clover diet. Increasing the proportion of these feeds in the diet lowers total dietary nitrogen concentration, resulting in lower nitrogen excretion and thereby will reduce N2O emissions.

In the case of maize, however, this effect may be partly offset because the energy content of maize silage can be lower compared with that of fresh grass/clover pasture. As a result, the amount of dry matter consumed to reach a given level of production could increase, which would in turn increase methane emissions.

Research on plantain is ongoing, but the indications are that it can reduce N2O emissions as well as reducing NO3 leaching. For nitrous oxide, there are 2 parts to it - reduction in N concentration in urine causing lower N in the urine patch, and reduction from greater retention of N in the soil. It appears that this effect is somewhat linear, from 0% to 60% of plantain in the diet, with research indicating that having 30% plantain in the diet will achieve around a 4% reduction in N2O (K Fransen, Dairy NZ, pers com).

The key issue with these forages relates to how they can be incorporated within a farm system. Finishing lambs (say) on forage rape, or wintering dairy cows on fodder beet, will reduce methane emissions while they are on the crop, but the impact across the wider farm GHG emissions will be relatively small. Similarly, maintaining a pasture sward at (say) 30% plantain, or 30% of a farm in plantain, presents major farm management/farm system challenges.

Pasture Quality

Maintaining or improving pasture quality can have a major impact on GHG emissions, in that it reduces the amount of DM required to achieve a level of animal performance. This can be illustrated via a trial carried out by Beef+Lamb NZ investigating the feed requirements relative to energy levels, to grow Friesian bulls from 300 to 600 kg liveweight.

Table 2: B+LNZ results of trial investigating the impact of feed quality on grow rate of Friesian bulls.

Feed quality (MJME/kg DM)	Bull LWG (kg/day)	Weeks to finish	Feed Efficiency (kg DM/kg LWG)	Feed Required (kg DM)	kg CH4
9	0.4	113	20.4	6,123	129
10	0.98	44	10.7	3,209	67
11	1.47	29	8.0	2,423	51

As can be seen from Table 2, bulls fed 11 MJME/kg DM pasture took 25% of the time to reach the desired weight, ate 40% of the pasture, and produced 40% of the methane, compared to animals fed pasture at 9 MJME/kg DM.

Winter housing/stand-off pads

Removing stock from pasture during winter or at other times when soils are very wet can help to reduce nitrous oxide emissions.

Research has shown that the microbes in the soil that convert nitrogen into nitrous oxide are at their most active when soils are very wet. By removing stock from wet pasture using winter housing or stand-off pads, the amount of nitrogen deposited onto the soil in dung and urine at these critical periods can be reduced.

This reduces both leaching and nitrous oxide emissions although by how much is situation and weather specific. A potential downside is that the dung and urine produced while livestock are removed from pasture may need to be stored and this produces more methane emissions than if it was deposited onto soils during grazing.

Research is underway to quantify reductions of nitrous oxide emissions achievable through this action, under different farming regimes and in different parts of the country. Research is also underway into the effects on methane emissions of collecting and managing effluent from winter housing and stand-off pads.

Some caution is needed here, as often the construction and use of feed pads or wintering barns can lead to an increase in feeding for animals, which will increase GHG emissions (Journeaux & Newman, Economic & Environmental Analysis of Dairy Farms with Barns., n.d.).

Land Use Change

This pertains to land use change from a pastoral farming operation (or part thereof) into either a horticultural or arable cropping situation. For GHG emissions, this essentially means an “averaging down” of total GHG emissions across the whole business.

An example of this is a case study dairy farm, where 13% of the farm was planted into kiwifruit. The base level emissions from the farm were 8.4Tonnes CO2e/ha, whereas the emissions from the kiwifruit were 0.2 T CO2e/ha. This means that for each hectare of kiwifruit planted, the total emissions from the farm reduced by 8.2 T CO2e. The resultant total emissions post development were 10% lower than the original base level emissions (NZAGRC, Farm Systems Modelling for GHG Reduction on Māori Owned Farms: Achieving the Zero-Carbon Targets., n.d.).

This raises an important point, that in order to achieve a significant reduction in GHG emissions, land use change at a farm level also has to be relatively significant. As per the above example 13% of the farm was converted, resulting in a 10% GHG reduction. Notwithstanding that the business profitability increased significantly.

So the idea of setting up a relatively small horticultural operation on the farm will have a limited impact on GHG emissions. Plus has implications at a national level – given there are approximately 9 million hectares in pastoral farming, planting say 10% to achieve a 10% GHG reduction would equate to 900,000 hectares, or 6.75 times more than currently planted in New Zealand, which raises a number of issues discussed in the "Barriers" section.

Land use change into arable cropping is also problematic, given that research by the Foundation of Arable Research has shown the average biological GHG emissions from mixed cropping regimes is 3.1 Tonne CO_2e/ha – only slightly lower than the sheep & beef average. Or for pure crops, emissions vary between 2.1 – 2.8 T CO_2e/ha (MPI, n.d.). Which means that the "averaging down" would be relatively smaller and therefore much larger areas would need to be converted in order to achieve any significant reduction in GHG emissions. Other research work has also indicated that conversion of pastoral land to arable cropping often also results in an increase in nitrogen leaching (Journeaux, et al., 2022).

While land use change from pastoral farming to horticulture/arable cropping is an option to reduce GHG emissions, essentially it has to be done at scale to achieve any degree of significant reduction.

2.3 Summary

A descriptive summary of the result of the literature review and interviews of the Scientific and Technological Mitigations can be found in Table 3 and the Farm Systems Mitigations can be found in Table 4.

Table 3: Summary of the literature review and interviews for the Scientific and Technological Mitigations.

Mitigation Type	Description
Genetics	Breeding cows and sheep that produce less emissions.
Methane inhibitors	Chemical compounds that block critical pathways in rumen-dwelling methanogens, restricting their growth and ability to produce methane.
Nitrous oxide inhibitors	Chemical compounds that reduce nitrous oxide emissions by suppressing the action of microbes in the soil
Seaweed - bromoform	Seaweed contains a compound that can inhibit a digestive enzyme that produces methane
Methane Oxidation	Process of removing methane from the atmosphere. It can be done by reacting methane with hydroxyl radicals (OH) to form carbon dioxide and water
GM ryegrass	High Metabolisable Energy ryegrass
Probiotics	Fonterra trademarked, Kowbucha™, to describe the work they are doing using dairy fermentation and cultures to attempt to reduce methane production in cows

Methane Oxidation	ZELP's oxidation technology works by routing the methane exhaled by cattle through a catalytic mechanism arranged within a patented energy recovery-system. The methane gets oxidised, resulting in a combination of CO2 and water vapor.
EcoPond	Iron Sulphate additive through EcoPond inhibits the growth of methanogens from producing methane.
Fluoride and tannin additive to manure.	The gases are mitigated by the addition of fluoride and tannin combination inhibitor and acidification.
Methane Vaccine	Methane vaccines which trigger antibodies that suppress methane in animals.
Zeolite or membrane extraction	By treating zeolite with a small amount of copper they become very effective at absorbing methane from the air

Table 4: Summary of the literature review and interviews for the Farm Systems mitigations.

Mitigation Type	Description
Lower stocking rate/improved productivity	Reduced emissions by lowering stock numbers or improving productivity per kg DM consumed.
Reduce replacement numbers	Reduced emissions by lowering stock numbers.
Shorter finishing times	Improving productivity per kg DM consumed.
Reduced exogenous inputs - supplementary feed	Reducing emissions by reducing the amount or type of supplementary feeds used.
Reduced exogenous inputs -nitrogen fertiliser	Reducing emissions by reducing the amount of nitrogen fertiliser used.
Once-a-day milking	Production efficiency gain.
Change in stock types	Reducing emissions by changing stock type to a more efficient animal.
Different forage types	Reducing emissions by using plant types which induce lower emissions.
System change.	Change to a lower emissions farming system.

The majority of mitigations which are theoretically possible to reduce GHG's have been developed for systems which are designed for high levels of supplementary feeding of livestock or systems where animals are farmed in close contact in housed systems. These are either not relevant to, or require significant changes to them to make them suitable for the New Zealand farming system which is predominantly pasture based in the open.

That is why the NZAGRC has concentrated its research efforts on methane inhibitors that can be delivered to the individual animal in a pasture based system on a non-regular basis. Unfortunately, this has meant that New Zealand are world leaders in that research and so have a huge task in front of us to identify and prove the worth of the compounds that can achieve that aim.

3 Barriers to Use

In Table 5 we list the barriers to use of the range of techniques which were identified in the literature review and interviews for the Scientific and Technological mitigations. Currently the barriers to use are quite considerable. These range from:

- the currently available techniques of Sheep Genetics being constrained by the availability low emissions rams and EcoPonds being uneconomic,
- the proven techniques like Bovaer and Zelp not yet being proven as being suitable for New Zealand farming systems,
- the techniques which are the best bet for New Zealand farming systems such as the methane inhibitors and vaccine lacking the identification of a suitable inhibitor or antigen,
- alternative techniques which either haven't been proven to be effective in New Zealand farming systems or require us to change our systems in order to take advantage of them,
- to the case of genetic engineered ryegrass which is currently precluded from use in New Zealand.

Unfortunately for New Zealand there is not one scientific and technological mitigation which does not have any barriers to use. In most cases the barriers to use are quite considerable, effectively precluding their adoption currently.

Table 5: Barriers to use of the Scientific and Technological Mitigations.

Mitigation Type	Barriers to Use
Genetics	Availability of low emission rams (numeric). The potential clash with productivity genetic gain.
Methane inhibitors	Identification of a stable inhibitor that can be scaled up and released in a bolus for wide use.
Methane Vaccine	Awaiting the identification of the correct antigen.
Nitrous oxide inhibitors	Scaling up of the inhibitor and release to the market.
GE Ryegrass	Breeding up of the ryegrass with all of the desirable productivity traits. Gaining approval to allow a GM Ryegrass to be used in New Zealand.
Zelp	Awaiting further trial results as to efficacy and impact on animal health and wellness. Economics.
Manure Management - Tannin and fluoride additive.	No research into its application in the farm setting.
Manure Management - EcoPonds.	Currently commercially available but not yet at an economic level for adoption on farm.
Ionophores	Availability on farm.
Seaweed - bromoform	Awaiting the results of trials on efficacy particularly the impact on animal health.
Bovaer	Awaiting registration in New Zealand. Requires adaptation to be useful in a grazing system.

Probiotics	Awaiting the scale up of the technology to be made available.
Agolin Ruminant	Awaiting firm research results on it effectiveness.
Essential Oils	Awaiting the results of tests in pastoral systems.
Daffodil Extract	Awaiting the results of tests in pastoral systems.
Tannins	Awaiting firm research results on the degree of mitigation and the applicability of the use in a grazing situation.
Toilet Training Livestock	Difficulty in scaling up to New Zealand farming systems
Zeolite or membrane extraction	Lack of research into how it can be adapted to grazing systems.

In order for a farmer to decide to make a change to their current farming system there must be a driver to instigate that change. Currently the only driver for farmers to make changes that will reduce their emissions is the impact of the Emissions Trading Scheme offering farmers an economic incentive to change from livestock farming to forestry. This to date has been incredibly successful with large amounts of hill country converting out of livestock farming to forestry. We note in Table 6 that there are some signs of market signals occurring but to date these have only been discussions and there haven't been many strong signals that would cause farmers to make changes to their systems in order to meet that requirement. The authors are confident that market signals will occur sometime in the future and that at that time farmers will respond to them.

A key factor which is a barrier to system change is the degree of regulatory uncertainty. Farmers are very unwilling to adopt new technologies and/or systems if the regulatory framework is uncertain or changes regularly.

In the case of different forage types for farmers to use them it would require a major change to their farming system which currently isn't a viable economic option.

Table 6: Barriers to use of the Farm Systems Mitigations.

Mitigation Type	Barriers to Use
Lower stocking rate/improved productivity	Currently the cost of carbon to a farmer is still uncertain and there are no other drivers to encourage use other than voluntary uptake. There are some signs of market signals coming to encourage uptake. Requires a higher level of farm management, particularly grazing management skill to implement without a drop in productivity and profitability.
Reduce replacement numbers	See above
Shorter finishing times	See above
Reduced exogenous inputs - supplementary feed	See above
Reduced exogenous inputs -nitrogen fertiliser	See above
Once-a-day milking	See above
Change in stock types	See above
Different forage types	The science indicates that the different forages must be fed as the majority of the animal's diet, which presents significant problems incorporating this into the farm

	system
Land use change.	System change from pastoral to forestry is happening already as a result of the Emissions Trading Scheme. System change from pastoral to horticulture is restrained by a range of factors, including regulatory restraints(particularly access to water for irrigation), access to labour, and the absence of market channels These issues are discussed in depth in a report by Journeaux et al, 2017 (Journeaux P. , Analysis of Drivers and Barriers to Land Use Change. , 2017) and by Hunt et al 2021)

4 Efficacy

The reporting of the efficacy of the range of methane mitigation techniques are taken directly from Section 2 Identification of the range of possible mitigations and the interviews which were carried out.

What we can take from Table 7 is that only four of the technique's efficacy ratings are based on sound peer reviewed research. Three are based on research results that either haven't been peer reviewed or weren't publicly available and the remainder are based on estimates which are based on scientific theory. We note that the two techniques which are assumed to make the biggest potential reductions in New Zealand farming systems, that is the inhibitors and vaccines, are at this stage estimates.

The level of confidence in the efficacy percentages that are shown in the right hand column of Table 7 are based on our knowledge of the source of the estimates. Those that are based on research which has been peer reviewed have been given a high degree of confidence rating, those that are effectively an assumed efficacy based on comparable research but not on research results on the actual technique itself have been given a medium degree of confidence rating and those that are estimates of their efficacy which are based on results from research which is not directly comparable or those that the research has not been peer reviewed have been given a low degree of confidence rating.

Table 7: Efficacies of the Scientific and Technological Mitigations.

Mitigation Type	Efficacy (%)	Source of the estimate	Confidence
Genetics	Dairy 10 – 20	Assumed based on research.	Medium
	Sheep 5 - 6	Research	High
Methane inhibitors	10 – 30	Estimate.	Low
Methane Vaccine	30	Estimate	Low
Nitrous oxide inhibitors	>50	Research	High
GM ryegrass	20 - 30	Estimate	Low
Bovaer	40	Research	High
Probotics - Kowbucha	20	Assumed based on research.	Medium
Methane Oxidation (Zelp)	50 - 60	Research – not peer reviewed.	Low
EcoPonds	80 - 90	Research	High

All of the efficacies that are shown in Table 8 are taken from farm systems modelling, which was carried out in either Farmax or Overseer, both of these models are able to report GHG's. This data reports the efficacy of the mitigations when they are used in the farm system being modelled.

It reports the order of reductions that were achieved in a with and without analysis of the farm system. The difference between the without the mitigation and the with the mitigation modelling is given as the efficacy of the technique.

Both of those models are complicated models which model a specific farming system therefore the range of efficacies of the techniques will vary considerably according to the data that is entered into the model and the actual makeup of the model. Nevertheless, the modelling which has been reported reflects a good range of average farming systems.

Table 8: Efficacies of the Farm Systems Mitigations.

Mitigation Type	Efficacy (%)
Lower stocking rate/improved productivity	10% reduction in Stocking Rate = 10 -12% reduction in methane emissions.
Reduce replacement numbers	Reduction from 23% to 15% = 2-3% reduction
Shorter finishing times	17% reduction in time = 2-3% reduction
Reduced exogenous inputs - supplementary feed	Nil external supplements = 5 – 11%
Reduced exogenous inputs -nitrogen fertiliser	Half the normal rate of N = 3 – 9% ave 4.5% reduction. Removal of all N = 7-16% ave 12% reduction
Once-a-day milking	6-7%
Change in stock types	Breeding cows to bull beef = 2%
Different forage types	Only successful at very high proportion of the diet >30%
System change.	Example of 13% of a dairy farm was converted to Hort (Kiwifruit) for a 10% change

Note: The above reductions are all in total biological CO_2e, with an approximate 80:20 split between methane and nitrous oxide. The exception is different forage types, which are in either methane or nitrous oxide depending on the forage.

The degree of confidence in the results shown in Table 8 is high because it is derived from two highly regarded farm systems models which have been run by people who are very experienced in their operation. That being said, they report the results of modelling of some representative but very specific farm systems. As the nature or makeup of the farm system changes, we would expect that the efficacy of the mitigation would change.

We have assessed the potential for the various mitigation techniques to be used in combination with one another. Some will be able to achieve the same level of efficacy when they are used with another mitigation and others will most likely have their efficacy reduced when used with another mitigation. The results of that assessment are displayed in table form in Appendix A.

5 Estimated Costs

The mitigations that were chosen to be used in the remainder of our reporting were chosen because they were techniques which were relevant to the New Zealand pastoral and arable farming systems, they had a sound scientific background to their use and efficacy and because they were techniques which were actively being researched and developed for use in the New Zealand context.

It is our opinion that this list of mitigation techniques will provide the majority of reductions in emissions in the New Zealand farming systems within the period up to 2050.

5.1 Alternative costs of methane emissions.

He Waka Eka Noa (He Waka Eke Noa, 2022) (HWEN) is the Primary Sector Climate Action Partnership was formed in 2019 to design a practical, credible, and effective system for reducing emissions at farm level, as an alternative to government policy to bring agriculture into the New Zealand Emissions Trading Scheme (NZ ETS). In 2022 it recommended to government on a farm-level pricing system as part of a broader framework to encourage emissions reductions.

The HWEN recommendation on pricing was for a set price on methane based on $/kg CH_4, and a price for N_2O based on $/T CO_2e, with the N_2O price based on 5% of the ETS price in 2025 (i.e. a 95% free allocation) with this price increasing by 1% per year through to 2030.

HWEN recommended that there would be a System Oversight Board with expertise and representation from the primary sector, working closely with an Independent Māori Board to recommend levy rates, prices, and incentive discounts, and set the strategy for use of levy revenue.

The government accepted the way that the price levy was calculated and used but didn't agree to the price being set by the System Oversight Board and suggested that the government would set the price. There has been much discussion on how best to resolve this issue but in the meantime the initiative has stalled. There have been recent announcements by both major political parties that they would re examine the issue post the election and Labour has suggested that they would start the levy charge in 2025 and National have said that they would re examine the issue in 2030.

The price that the levy is set at is important because it sets the bottom line for farmers to compare the mitigation options against. Therefore we have set a price which the levy would be set at to use in our consideration of the alternative costs of methane emissions to set our timeline for uptake of each mitigation.

We have used the expectations of the New Zealand Units (NZU) price that were published by the Climate Change Commission in 2021. We are not aware of any alternative expectations for NZU pricing that cover the period out to 2050. In that table they expected the price to be $84/NZU in 2025 and $250/NZU in 2050. This price path is shown in Figure 1.

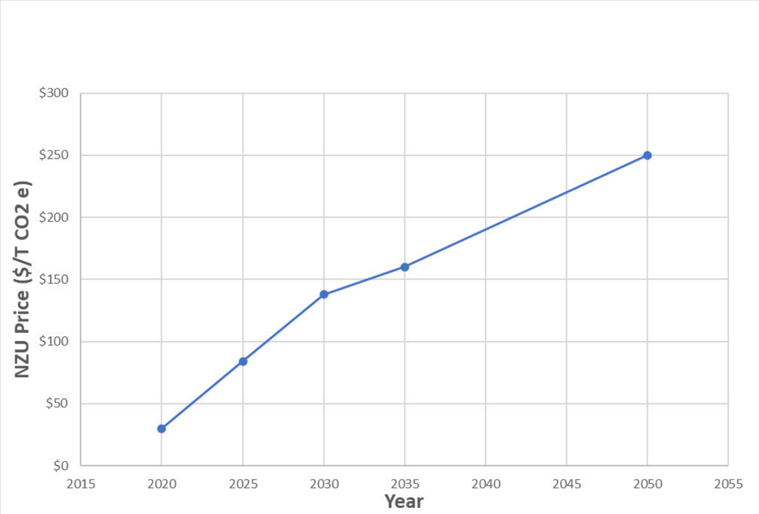

Figure 1: Climate Change Commissions expectation of NZU price out to 2050.

If we are to assume that the levy price recommended by HWEN is adopted and follows a path similar to the one which was legislated for the Industrial sector which means that the annual increase rises to 2% for the second 10 year period and 3% for the final three year period then the levy price over the period starts at $4.20/tCO2e ($0.11/kg CH4) in 2025 and rises to $127/tCO2e ($3.18/kg CH4) in 2050 as shown in Figure 2.

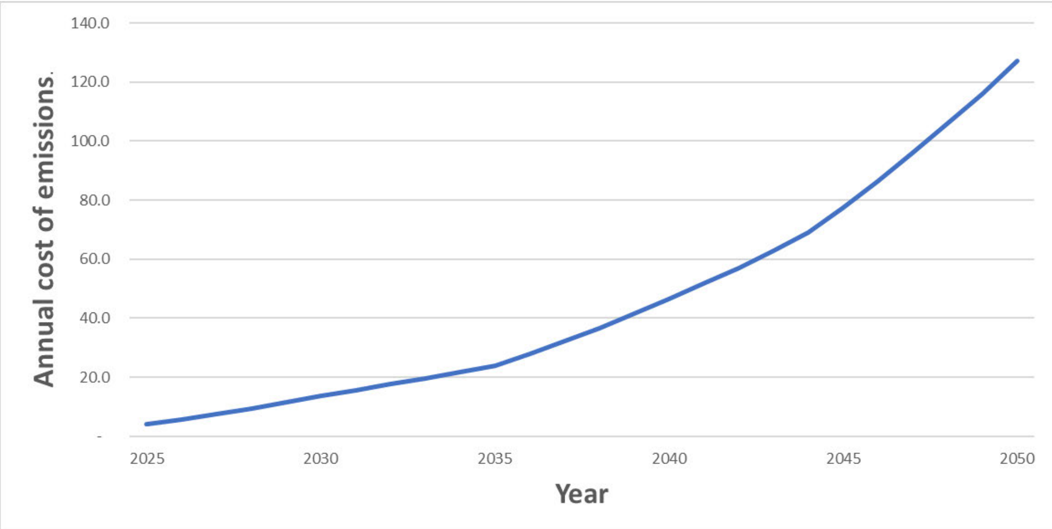

Figure 2: The price path of the levy charge under the assumptions that the authors have used.

5.2 Calculated Mitigation Costs

The costs of the feasible techniques were calculated using the following formula:

Cost per unit / production of CO2e per unit / efficacy = Cost of the mitigation technique used /tCO2e.

The units used ranged from different animals to hectares to the whole farm.

The following is an explanation of the main assumptions which were made in creating the costs that are shown in Table 9. The third column lists some costs that were created by AbacusBio for HWEN, they are displayed to create a reference for our work.

Sheep genetics is based on a report by AgResearch that the cost per sheep would be $1.72.

Dairy genetics assumes that low methane is just another production factor which will be offered in their genetics package which is sold by the straw. We have assumed that the cost will be $10 / straw higher than the standard straw.

Methane inhibitor costing is based on the fact that the majority of the investment in its creation has been carried out with public investment and there is no attempt by the government to recover that investment in the cost of the inhibitor therefore the cost is the application of two boluses per year.

The same assumption as to the development costs being not recovered so the cost is the cost of a vaccine and its application.

The nitrification inhibitors costing was based on the cost of applying DCD. We acknowledge that the main purpose of applying DCD is to prevent Nitrogen leaching through the soil profile.

The GM ryegrass assumption is that the grass seed is sold at a small premium to normal grass seed in order to recover the development costs.

Bovaer is based on the cost of Bovaer overseas.

Probiotics – Kowbucha is based on the cost of the core ingredient (acetic acid) which is added to the in shed supplementary feeding system.

EcoPond is based on the cost for an average farm which is approximately $65,000 for the delivery mechanism and then an annual cost of $16,000. We acknowledge that the owners of the technology, Ravensdown have informed us that they expect to reduce the initial cost as a result of further research which is currently underway.

The farm systems costings are as a result of the systems being modeled in Farmax which is able to report the financial result of the modelling. The results reported are from a with the mitigation minus a without the mitigation model result of the financial performance which is then divided by the change in tCO2e between the with and without models to give the cost per tCO2e for the mitigation being modelled.

You will note that the farm systems utilising intensification techniques which are reported all have a negative cost which means that the reduction in methane emitted is accompanied by an increase in farm profit.

Table 9: Costs of the mitigation techniques ($/tCO2e and ($/kg CH4)

Mitigation	Costs calculated ($/tCO2e)	Costs calculated ($/kg CH4)	Costs calculated AbacusBio*. ($/tCO2e)	Costs calculated AbacusBio*. ($/kg CH4)
Genetics - Sheep	34	0.86	[redacted]	[redacted]
Genetics - Dairy	25	0.62	[redacted]	[redacted]
Methane inhibitors - Dairy	49	1.22	[redacted]	[redacted]
Methane inhibitors - Beef			[redacted]	[redacted]
Methane Vaccine - Dairy	25	0.62	[redacted]	[redacted]
Methane Vaccine - Beef	44	1.11		
Methane Vaccine - Sheep	40	0.99		

Nitrous oxide inhibitors	1,703		[redacted]	[redacted]
GM ryegrass / Dairy	12	0.31		
GM ryegrass / Beef	16	0.40		
GM ryegrass / Sheep	27	0.67		
Bovaer	73	1.83		
Probiotics - Kowbucha	111	2.78		
Methane Oxidation (Zelp)	99	2.47		
EcoPonds	233	5.83		[redacted]
Lower stocking Rate – Sheep and Beef	91	2.28		
Lower stocking Rate – dairy	597	14.93		
Lower stocking rate/improved productivity – Sheep and Beef	-348	-8.70		
Lower stocking rate/improved productivity – Dairy	-848	-21.20		
Reduce replacement numbers Dairy	-2,858	-71.45		
Reduce replacement numbers S&B	-494	-12.35		
Shorter finishing times	n/a			
Reduced exogenous inputs - supplementary feed	91	2.28		
Reduced exogenous inputs -nitrogen fertiliser	145	3.63		
Once-a-day milking	217	5.43		
Change in stock types	-90	-2.25		

[redacted]

Note the farm system costs are per tonne biological GHG (ie CH_4 + N_2O), so the indicative CH_4 price shown assumes the total price shown is solely for CH_4.

6 Potential Adoption Rates

6.1 Introduction

6.1.1 Extension Theory

The potential rates of adoption relates to a wide range of factors, including adult learning, social factors, characteristics of the innovation, communication channels, and the institutional extension environment. These factors are discussed at length in Journeaux 2009, and Journeaux et al 2017 as per earlier references, but a brief precis of this follows:

Most adult learning is cognitive in nature, where the person is self-motivated and active in planning their own learning and development, and in most learning projects are motivated by some fairly immediate problem, task, or decision that demands certain knowledge or skill. The most effective learning is in a one-to-one situation, followed by participating in a small group.

The diffusion of innovations is commonly defined as "the acceptance, overtime, of some specific item, idea, or practice, by individuals, groups, or other adopting units, linked to specific channels of communication, to a social structure, and to a given system of values or culture". This often involves a 5-step process:

- Awareness of an innovation;
- Interest in the innovation;
- Evaluation of the innovation;
- Trialling of it; and
- Assuming a successful trial, adoption.

Important factors in determining the uptake of an innovation or new technology, or new system are:

(i) Characteristics of the innovation (as outlined in the "Time to Implementation" section):

  - Relative advantage - this is often expressed in economic terms, although there are other measures such as saving in time or labour, or reduced risk, or environmental compliance
  - Compatibility with the existing system
  - Complexity – the simpler the change the more likely the adoption
  - Trialability - the degree to which an innovation may be experimented with on a limited basis
  - Observability – the more observable the impacts of the innovation, the more likely the adoption.

(ii) Characteristics of the Individual. This covers a wide range of factors, such as educational level, personal and family circumstances, goals and objectives, support networks, financial security.

(iii) Characteristics of the social system. This relates to the norms, beliefs, and values of the social system. A more traditional social system may slow the adoption of innovations, whereas a more cosmopolitan one may improve adoption rates.

(iv) Channels of communication. This is the means by which messages travel from a source to a receiver, and in an extension context there are two main channels:

- Mass media, which involves such things as television, radio, printed material, field days, conferences, social media, which can reach a wide audience rapidly, spread information, and can lead to changes in weakly held attitudes.
- Interpersonal channels which involve face-to-face exchanges between individuals or within small groups. It allows for a two-way exchange of ideas and can be used to persuade receiving individuals to form or change, strongly held attitudes.

(v) Advisors, who function as a communication link between parties. They have a major influence on adoption and diffusion of innovations, both through the methods they use, and their availability.

There is a strong public good rationale for government involvement in environmental extension programmes (Journeaux & Stephens 1997) (MAF, 1997) and evaluations have shown a very good rate of return on public extension programmes (Scrimegour et al 1991, Fuglie et al 1996).

Currently within New Zealand, extension on "sustainable land management" and all its facets is relatively small and disparate. Achieving significant gains in addressing environmental issues, such as on-farm greenhouse gas emissions, will not be possible until this issue is addressed.

Overall therefore, there are a number of key factors affecting adoption of environmental mitigation/adaptation measures:

(i) To state the obvious – the criticality of extension in order to ensure the adoption of research findings and innovation.

(ii) There are a range of factors that affect the adoption of innovations: characteristics of the innovation, the farmers, the social system, and the channels of communication. Two significant issues with respect to these issues are:

- Many environmental practices are relatively complex, it is difficult to observe/monitor outcomes, and any relative advantages they confer are also difficult to establish.
- Currently communication channels are mostly based around mass media-type approaches, which are effective in raising awareness, whereas the complexity of the issues would indicate that a one to one approach is likely to gain much more acceptance and adoption.

(iii) Much of the current environmental extension tends to be top-down in its approach. Adoption is very much a social process, and the research shows that when these social factors are taken into account, including participatory or collaborative approaches, farmer understanding and acceptance of the issues, and the resultant rate of adoption is much greater.

(iv) There is a major lack of human capability in this area, with relatively limited number of people with good skills and understanding across both farm management/animal production, and environmental issues.

(v) The key drivers are a combination of regulatory push (from Government) and market pull from marketing companies. Of the two, the latter is far more powerful, and likely to grown stronger in coming years.

Overall therefore, the rate of adoption of mitigation strategies and options to reduce GHG emissions, across the majority of the farming population, is likely to be counted in decades.

6.1.2 Practical Considerations

The issue with many environmental mitigations is that it is very difficult to observe many of the characteristics which are related to the reduction of mitigations. For the farm system options discussed earlier, farmers can readily see any changes in production and/or profitability but need models to estimate what impact they may or may not have on GHG emissions.

Another key issue regarding time to adopt is farmer experience and expertise, obviously there is a range of experience and expertise within the farmer population meaning some will adopt new technologies and systems faster than others.

A full discussion on adoption issues relative to mitigating GHG emissions can be found in Journeaux et al, 2017 (Journeaux, et al., 2016).

A major factor in the timing of implementation will also relate to the level of change/improvement required in farm management to achieve the change. In the “reduce stocking rate/improve productivity” options, a key issue arises with grazing management – this becomes more crucial under a lower stocking rate in order to maintain pasture quality, so techniques such as faster rotations, more subdivision, topping of pastures become important.

One of the scenarios investigated for a number of hill country properties was a “reduce breeding ewes/increase lambing percentage by 30%”. Technically such a scenario is possible, but there are a number of farm management factors that would need to be addressed to ensure this approach worked:

- The genetic merit of the ewes would need to be such that they could achieve the higher lambing %
- Replacement stock would need to be grown to achieve target weights
- Ewes would need to be well fed at mating
- Ewes would need to be very well fed over lambing
- Lambs would need to be very well fed post-weaning in order to ensure they reach acceptable slaughter weights
- Given the quite high lambing %, the system would be vulnerable to storms over the lambing period.

All of which means that for many farms, achieving such a scenario would likely take 5-10 years to achieve.

Yet another factor driving uptake is the degree of regulatory “push” from government, and “pull” from the markets. Each of these provides their own incentives to act, although of the two, market pull generally achieves results much faster.

Another key factor is the level of extension being carried out to raise awareness of the issues and provide advice and support to farmers to adopt new innovations. This is discussed further in the section on adoption.

Operating a farm system is a multi-faceted operation, as is management of environmental factors. Farmers will not address greenhouse gas emissions in isolation – it is just one of several factors, including water quality, biodiversity, erosion control, etc. The complexity of managing and integrating all these components means that the time taken to achieve measurable goals can be significant.

There are many factors that affect the rate of adoption and almost all of them would indicate that for environmental best management practices, the majority of these factors would work against rapid uptake. If the average time taken to adopt innovations on-farm through the middle part of the twentieth century was 23 years, when there were clear economic incentives to adopt, and a major extension workforce promoting these innovations, then one could expect a longer time period when most factors – lack of economic incentives, lack of a large and coordinated extension workforce, coupled with complex, hard-to-measure issues, are working against rapid adoption.

A survey of farmers carried out in 2009 (Journeaux, 2009) asked farmers what a realistic time frame would be to adopt environmental best management practices. Some felt that 1-3 years was a sufficient time frame, while most opted for 5-10 years. Others were more nuanced: if the new technology or system was not disruptive to the existing farming system, then 2-3 years was sufficient. If it were disruptive to the farming system, then 12-15 years would be required. If it were disruptive, and/or difficult to demonstrate or see the benefits, then it would take 25-30 years (i.e. generational).

It is difficult therefore to ascribe a "timing to implementation" for farm system changes given the wide range of factors that influence this.

6.2 ADOPT

ADOPT (Adoption and Diffusion Outcome Prediction Tool) is a web-based tool that allows you to evaluate and predict the likely level of adoption and diffusion of specific agricultural innovations with a particular target population in mind (ADOPT, n.d.). ADOPT is run by the CSIRO and it was developed through funding by the Cooperative Research Centre for Future Farm Industries, and support from GRDC, ACIAR, CSIRO, University of Western Australia, DAFWA and Victorian DEPI. Ongoing development has been in collaboration with the University of Western Australia.

ADOPT is structured around **four categories of influences** on adoption:

- Characteristics of the innovation
- Characteristics of the target population
- Relative advantage of using the innovation
- Learning of the relative advantage of the innovation.

ADOPT users respond to **qualitative and quantitative questions** for each of twenty-two variables influencing adoption. Going through this process also leads to increased knowledge about how the variables relate to each other, and how they influence adoption and diffusion.

It is a highly regarded tool for predicting farmer uptake of new agricultural practices.

Running a practice through adopt results in a very detailed report which not only reports the time to near peak adoption level in years and the percentage of farmer uptake at that peak adoption level, but it also reports the yearly adoption levels and includes quite an extensive sensitivity analysis to the identified highly sensitive question and all of the questions.

6.3 ADOPT Results

Mitigation	Time to near-peak adoption level (years)	Peak adoption level (% of the population)
Genetics - sheep	16	63
Genetics - Dairy	14	97
Methane inhibitors - Dairy	14	73
Methane inhibitors - Beef	14	73
Methane Vaccine - Dairy	15	92
Methane Vaccine - Beef	14	38
Methane Vaccine - Sheep	16	36
Nitrous oxide inhibitors	16	1
GM ryegrass / Dairy	15	33
GM ryegrass / Beef	16	11
GM ryegrass / Sheep	16	11
Bovaer	15	60
Probiotics - Kombucha	17	31
Methane Oxidation (Zelp)	14	53
EcoPonds	18	8
Lower stocking Rate – Sheep and Beef	18	42
Lower stocking Rate – dairy	n/a	n/a
Lower stocking rate/improved productivity – Sheep and Beef	14	94
Lower stocking rate/improved productivity – Dairy	14	87
Reduce replacement numbers Dairy	11	97
Reduce replacement numbers S&B	17	98
Shorter finishing times	n/a	n/a
Reduced exogenous inputs - supplementary feed	13	46
Reduced exogenous inputs -nitrogen fertiliser	11	97
Once-a-day milking	n/a	n/a
Change in stock types	2	9

While we acknowledge that the results of running a mitigation through ADOPT are very dependant on the choice of factors and acknowledge that another person with a different interpretation of the nature of the four categories of influences could receive a different result we would like to point out that the time to peak adoption in years is predominantly in the mid to late teens and that the peak adoption level is very dependant on whether the mitigation will provide a positive financial result and the degree of that financial result.

7 Timeline

7.1 Presentation

The presentation of the timeline is in graphical form with the adoption rate expressed as a percentage on the y axis and the time expressed in years on the x axis.

In this timeline presentation we display four critical stages:

Potential 

This represents an idea that has the potential to reduce methane emissions but it is in the formative stage.

Discovery 

This stage represents the period when the idea is being researched to analyse its effectiveness.

Commercialisation 

This period represents the time that is taken to take a proven technique and develop it into a commercial proposition that can be up taken by farmers.

Adoption 

This represents the stage when the technique is available for adoption.

In the adoption stage we haven't modelled any adoption occurring when the alternative levy price is lower than the cost price of adoption, this assumes that the farmers are rational economic thinkers. Once the levy price exceeds the cost price of adoption of the relevant mitigation technique, we have used the percentage adoption rates gained from the ADOPT results into the timeline figure which reports the percentage of adoption of the number of farms, relevant to the technique, over the time period out to 2050.

7.2 Results

Sheep Genetics

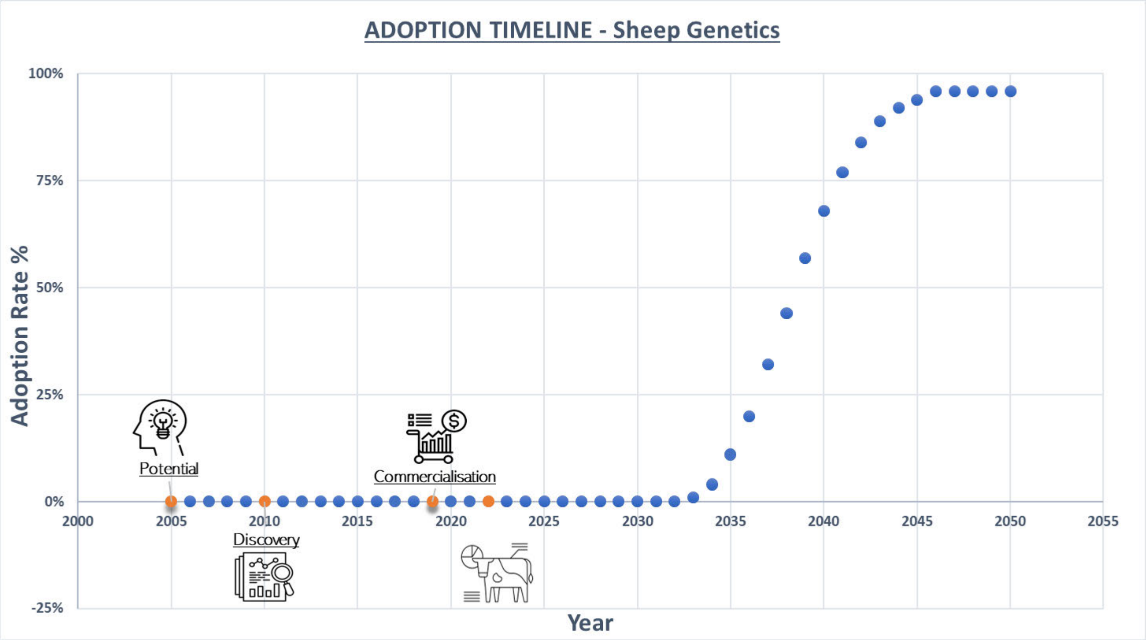

Figure 3: Adoption timeline Sheep Genetics

Sheep genetics has been through the process of recognition of its potential in approximately 2005 which was followed by research into its potential from 2010 to 2019 and then it was commercialised in 2019 and is available for adoption now. Access to this technique is restrained currently due to availability of the number of rams which are offered for sale which have the breeding value for low emissions and the levy price is cheaper than the mitigation price until 2023 but from then on adoption is relatively rapid, assuming that the ram breeders are willing to select for this characteristic and that the demand from commercial breeders is high and reaches peak adoption of 97% in 2046 which is maintained until 2050.

Dairy Genetics

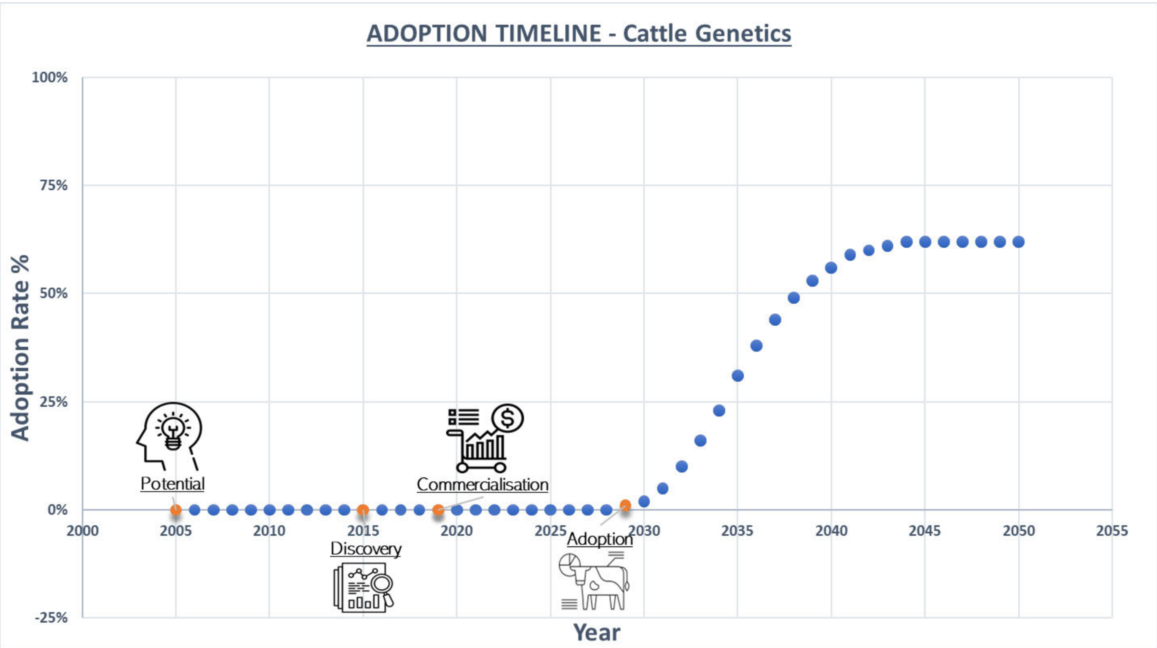

Figure 4: Adoption timeline Dairy Genetics

Currently Dairy Genetics is under trials to identify the Bulls which are able to demonstrate low emissions. Once the low emissions bulls are identified their semen is then used across a number of females and then the female's productive performance is recorded and analysed. Once the low emissions Bulls daughters are proven to both maintain milk production characteristics and low emissions the Bulls semen is then released for commercial use.

It is not expected that Dairy Genetics will become available until at least 2029 but then will have a solid uptake until 2050 when it will reach 62% of the population. This based on the fact that its cost price is still higher than the levy price but the genetics will be offered in a package with other production traits.

Methane Inhibitor

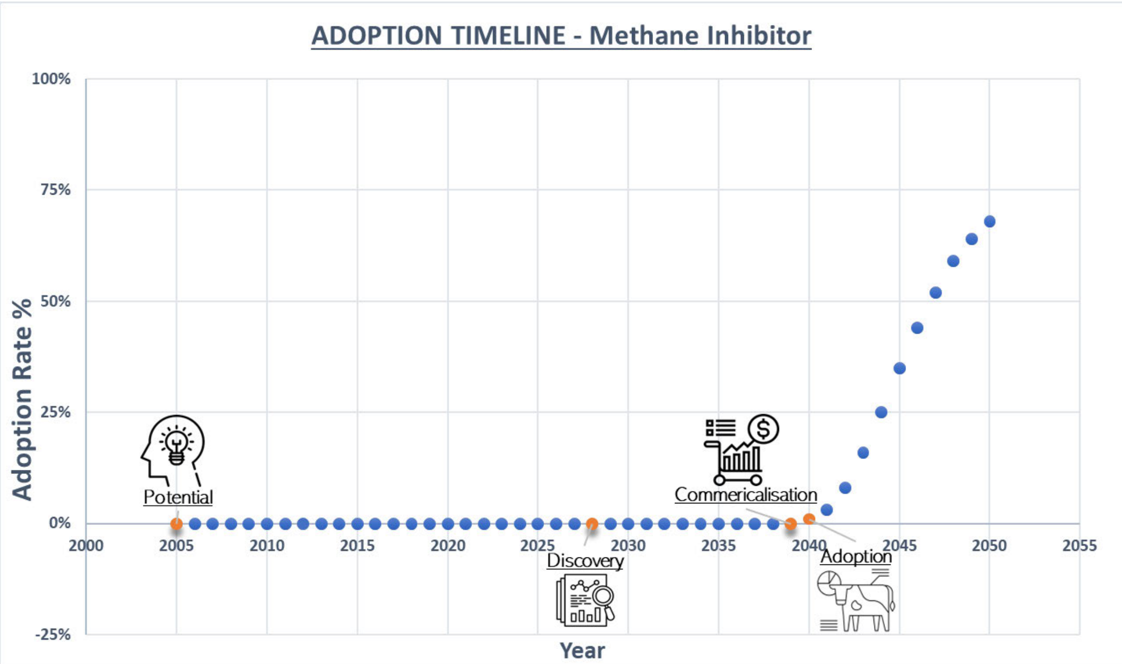

Figure 5: Adoption timeline Methane Inhibitor

The timeline for the methane inhibitor is based on assumptions which we would describe as optimistic because, as yet, an antigen has not been identified and we do not have sufficient information about the length of time for it to be trialed and then put through the necessary approval for use tests. In the timeline displayed it is assumed that the inhibitor will be available for all livestock types.

The timeline assumes that an antigen is discovered in 2028. At this point there is a low level of confidence that we will discover an appropriate antigen by 2028. We have then assumed that it takes 11 years for it to be trialed and proven successful and to pass through approval for use. The cost is lower than the levy price the year after it is commercially available in 2039 and it achieves a high rate of adoption reaching 68% in 2050.

Methane Vaccine Beef

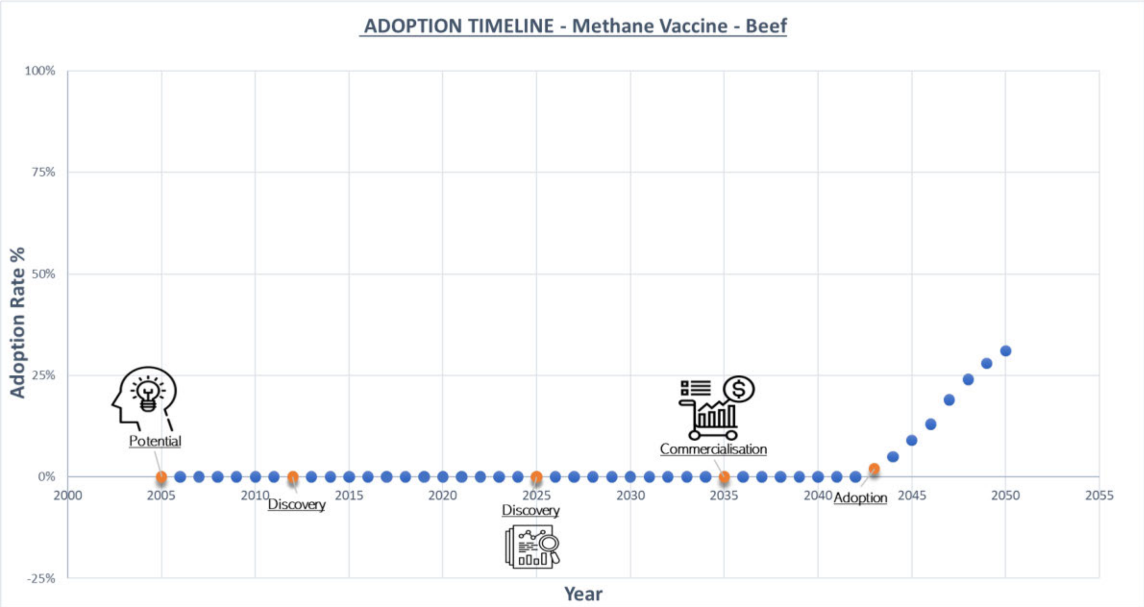

Figure 6: Adoption timeline Methane Vaccine Beef

The timeline for the methane vaccine is based on assumptions which we would describe as optimistic because, as yet a vaccine agent has not been identified and we do not have sufficient information about the length of time for it to be trialed and then put through the necessary approval for use tests.

The timeline assumes that an antigen is discovered in 2025. At this point there is a low level of confidence that we will discover an appropriate agent by 2025. We have then assumed that it takes 10 years for it to be trialed and proven successful and to pass through approval for use. The cost is lower than the levy price the year after it is commercially available in 2043 and it achieves a relatively low rate of adoption reaching 31% in 2050.

Methane Vaccine Sheep

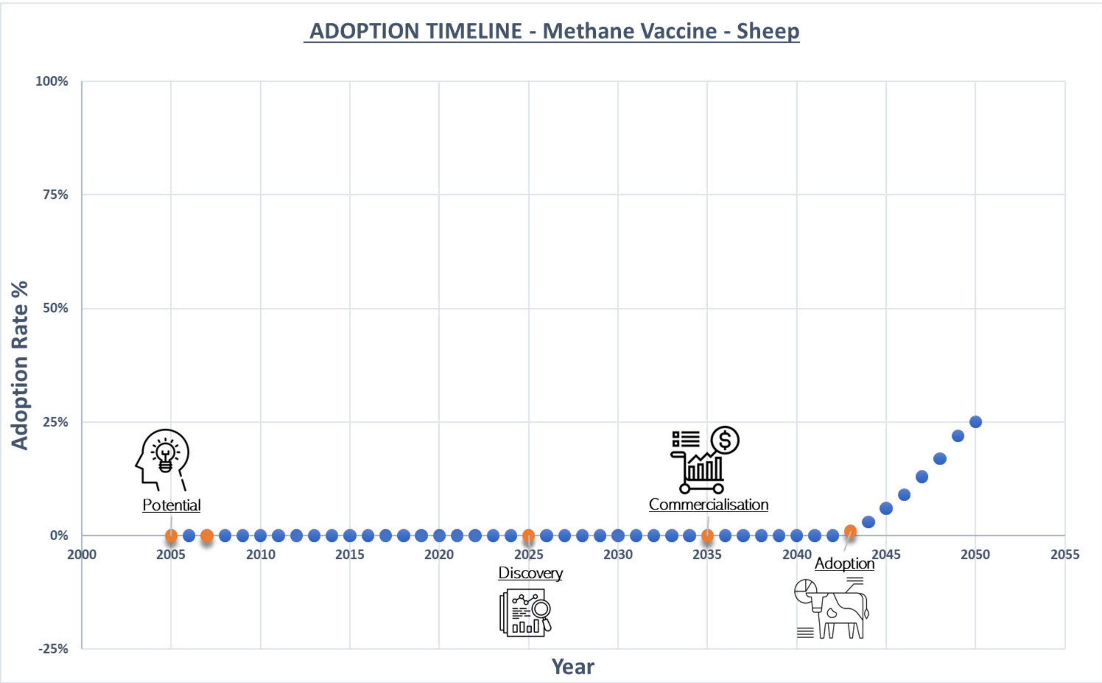

Figure 7: Adoption timeline Methane Vaccine Sheep

The timeline for the methane vaccine is based on assumptions which we would describe as optimistic because, as yet a vaccine agent has not been identified and we do not have sufficient information about the length of time for it to be trialed and then put through the necessary approval for use tests.

The timeline assumes that an antigen is discovered in 2025. At this point there is a low level of confidence that we will discover an appropriate agent by 2025. We have then assumed that it takes 10 years for it to be trialed and proven successful and to pass through approval for use. The cost is lower than the levy price the year after it is commercially available in 2043 and it achieves a relatively low rate of adoption reaching 25% in 2050.

Methane Vaccine Dairy

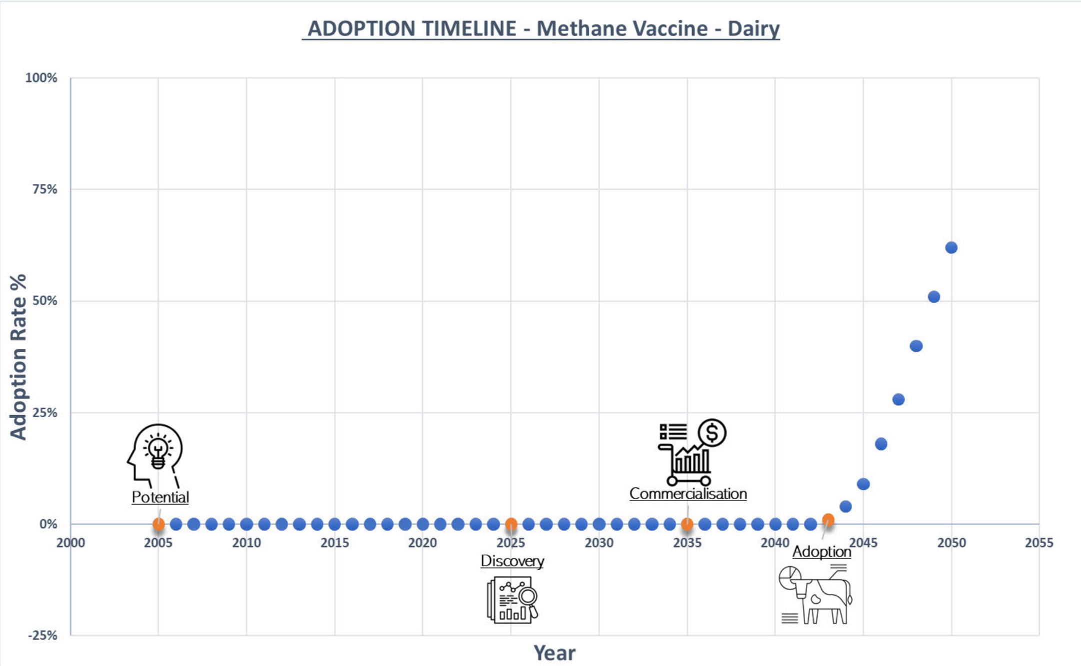

Figure 8: Adoption timeline Methane Vaccine Dairy

The timeline for the methane vaccine is based on assumptions which we would describe as optimistic because, as yet a vaccine agent has not been identified and we do not have sufficient information about the length of time for it to be trialed and then put through the necessary approval for use tests.

The timeline assumes that an antigen is discovered in 2025. At this point there is a low level of confidence that we will discover an appropriate agent by 2025. We have then assumed that it takes 10 years for it to be trialed and proven successful and to pass through approval for use. The cost is lower than the levy price the year after it is commercially available in 2043 and it achieves a high rate of adoption reaching 25% in 2050.

Nitrous Oxide Inhibitor

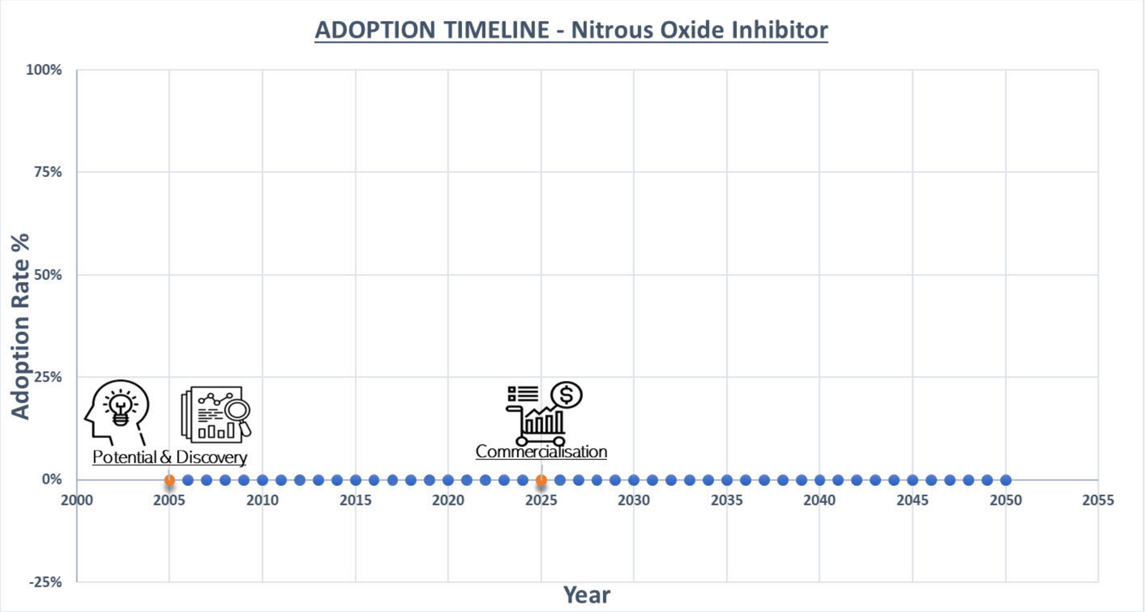

Figure 9: Adoption timeline Nitrous Oxide Inhibitor

The price of the nitrous oxide inhibitor exceeds the levy price so there is no uptake predicted. This assumes that it is used for nitrous oxide reduction only. It may well be used for reduction of Nitrogen leaching which may mean that some advantage is gained from its use but this would be not as a GHG mitigation technique.

Genetically Modified Ryegrass – Sheep and Beef

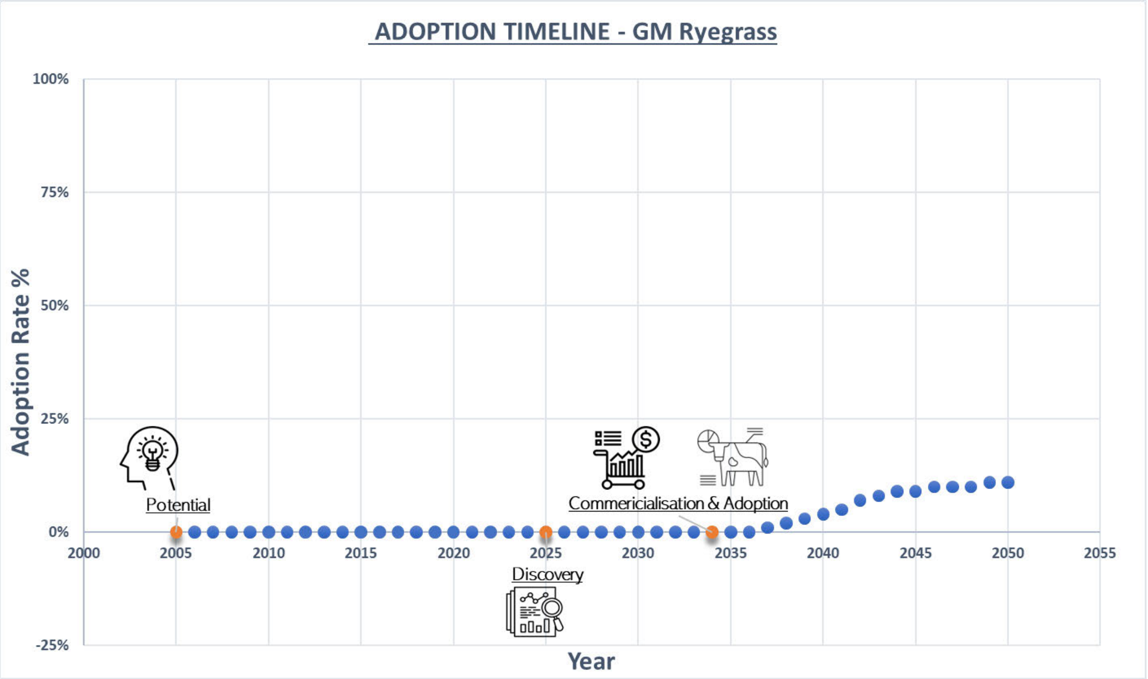

Figure 10: Adoption timeline Genetically Modified Ryegrass – Beef

The timeline for the adoption of genetically modified ryegrass is based on assumptions which we would describe as excessively optimistic because, as yet a genetically modified ryegrass has not been proven as a viable option to reduce methane emissions and we do not have sufficient information about the length of time for it to be trialed and then put through the necessary approval for use tests. It is currently not possible to use genetically modified grasses in New Zealand and so its use would require a change in legislation through Parliament.

In the timeline for Genetically Modified Ryegrass – Beef we have assumed that a suitable ryegrass is created in 2025 and then becomes available in 2035, assuming that legislation is changed to allow genetically modified ryegrasses, when its cost price is less than the levy price so it is immediate available but reaches an uptake of only 11% by 2050 because of the relatively low rate of pasture renewal on Sheep and Beef farms.

Genetically Modified Ryegrass – Dairy

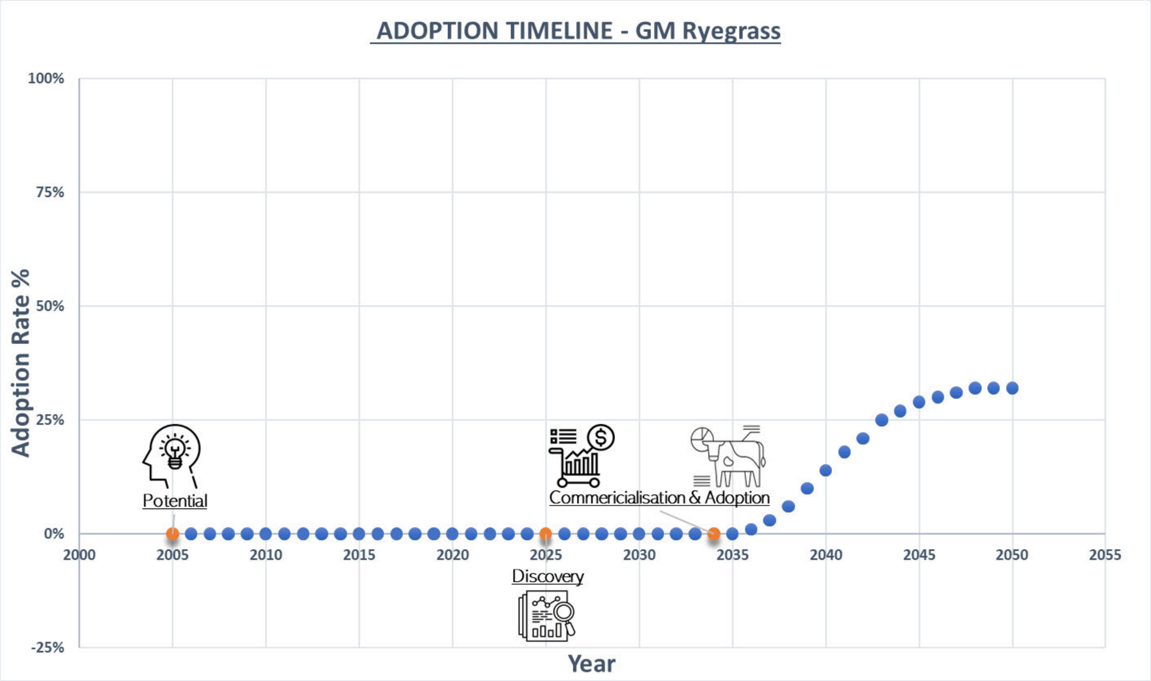

Figure 11: Adoption timeline Genetically Modified Ryegrass – Dairy

The timeline for the adoption of genetically modified ryegrass is based on assumptions which we would describe as excessively optimistic because, as yet a genetically modified ryegrass has not been proven as a viable option to reduce methane emissions and we do not have sufficient information about the length of time for it to be trialed and then put through the necessary approval for use tests. It is currently not possible to use genetically modified grasses in New Zealand and so its use would require a change in legislation through Parliament.

In the timeline for Genetically Modified Ryegrass – Dairy we have assumed that a suitable ryegrass is created in 2025 and then becomes available for use in 2035 when its cost price is less than the levy price so it is immediately available and reaches an uptake of 32% by 2050 because of the relatively high rate of pasture renewal on Dairy farms.

Bovaer

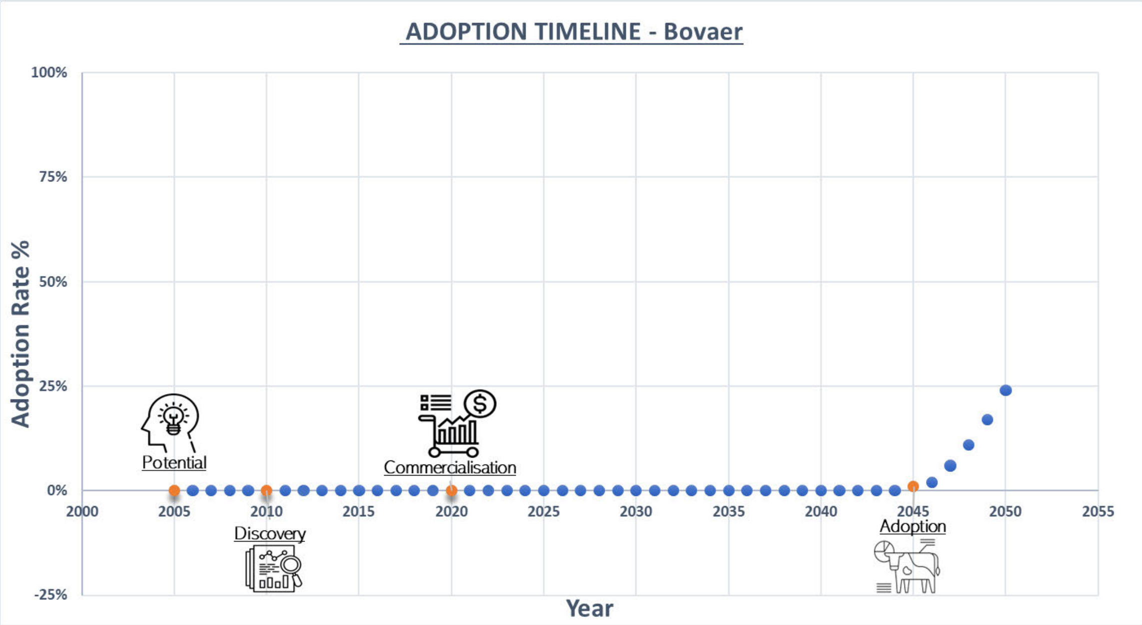

Figure 12: Adoption timeline Bovaer

Bovaer has already been through the discovery stage overseas and is commercially available overseas now. We understand that the product is expected to be put through the New Zealand trail and acceptance process soon. Bovaer is expected to pass through the approval process relatively quickly and be available commercial relatively quickly, but the cost is expected to exceed the levy price until 2045 after which it is expected to achieve a 24% uptake within the dairy and beef farms which are able to feed supplements in contained environments by 2050.

Probiotics

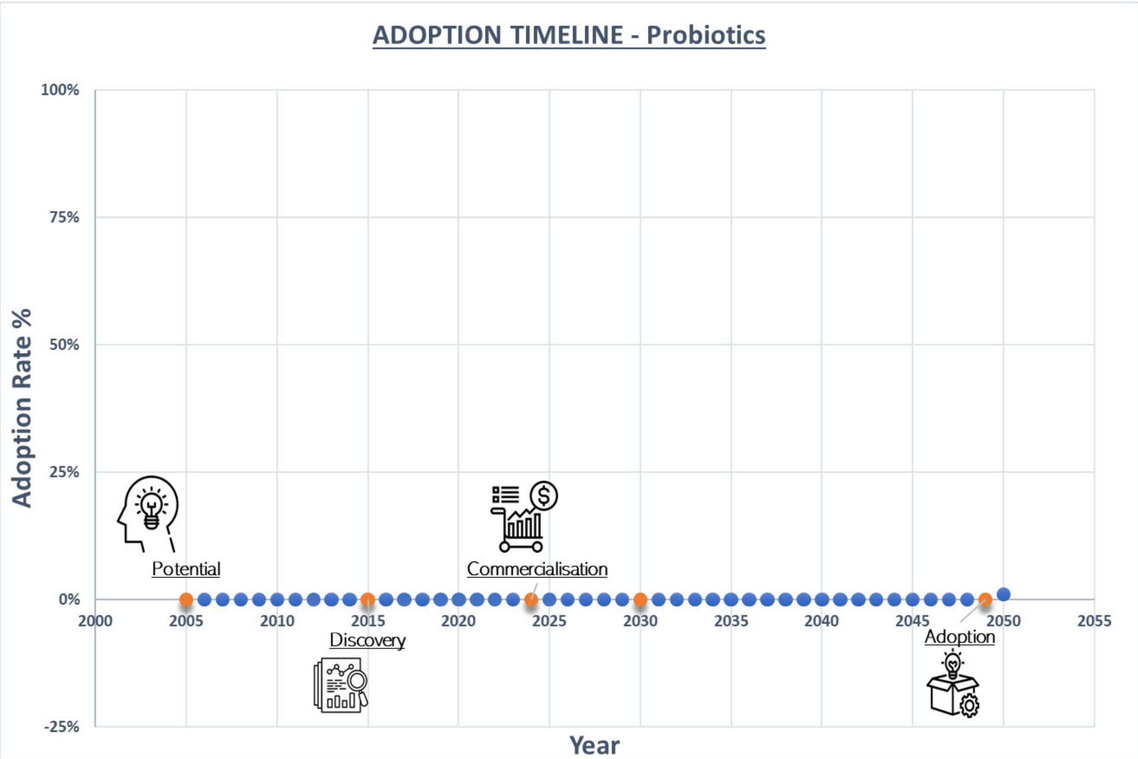

Figure 13: Adoption timeline Probiotics

It is expected that Probiotics will be available by 2024 but the cost will exceed the levy price until 2049 and so there will be very little uptake unless it is proven to achieve efficiency gains in milk production at the same time. The adoption timeline may be improved if Fonterra are able to provide their Kowbucha at a cost which is lower than the levy price and it can be administered to the cows in an efficient manner.

Zelp

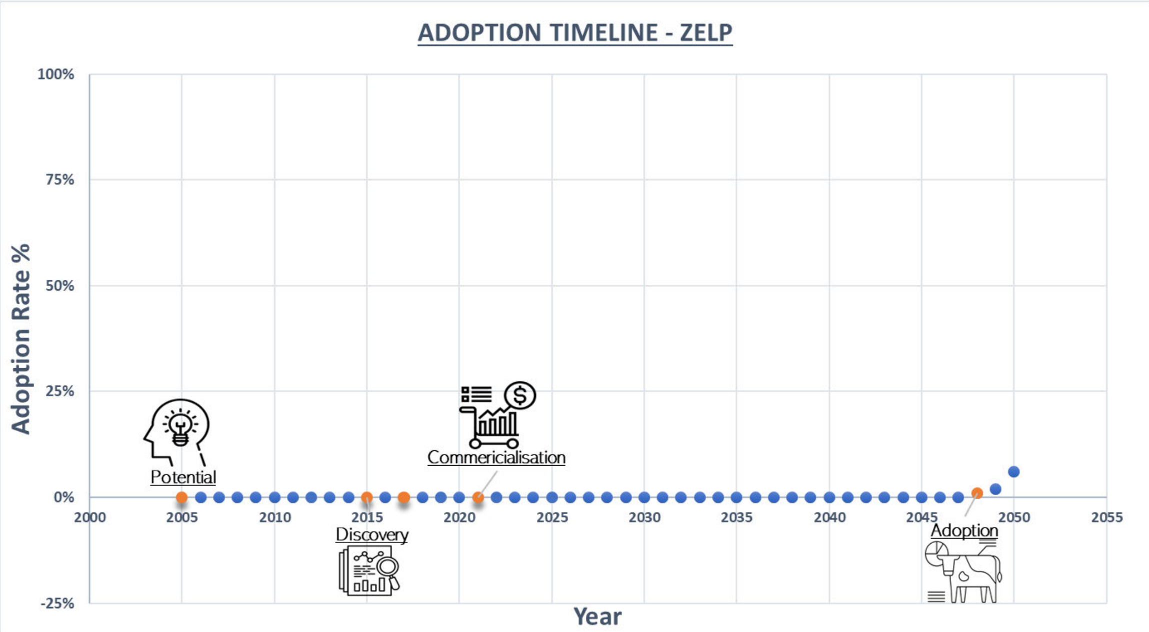

Figure 14: Adoption timeline Zelp

Zelp is currently under animal trials in the United Kingdom. The results of these trails are publicly available but haven't been peer reviewed as yet. Assuming that it is proven to be successful in reduction of methane emissions and that it is proven to not have any negative animal health impacts it will still have to go through approval processes in New Zealand. The cost of Zelp will exceed the levy price until 2049 with adoption being very slow when it does become affordable on Dairy farms.

EcoPond

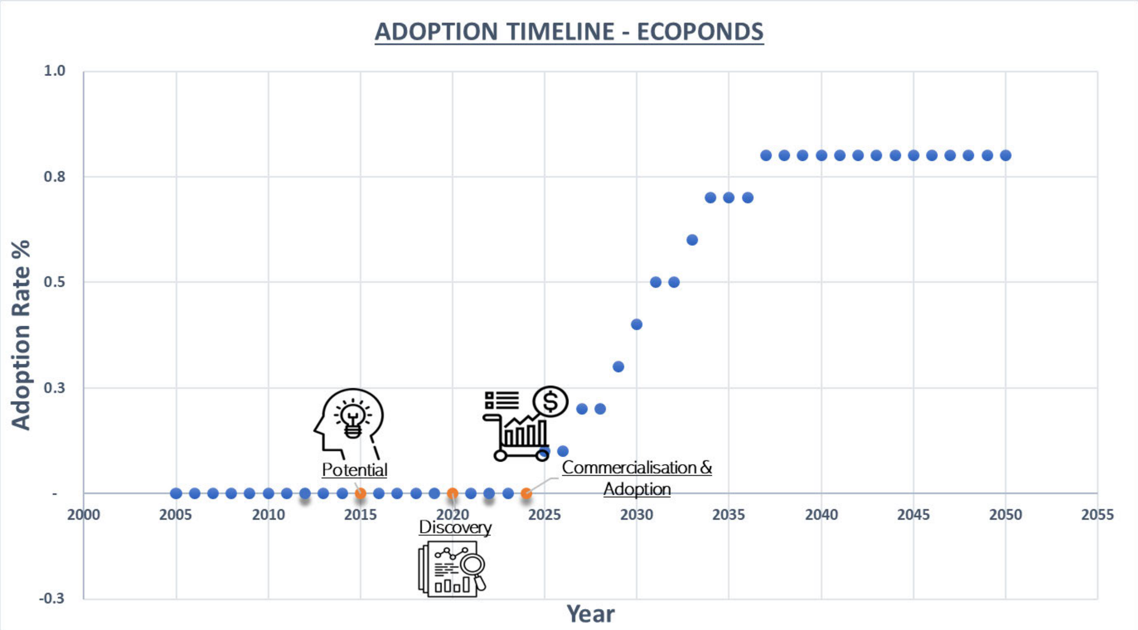

Figure 15: Adoption timeline EcoPonds.

EcoPonds have been through the research stage and it is now going through the approval stage in New Zealand. EcoPonds will remain more expensive than the levy for the lifetime presented here but they are a relatively easy means of reduction, so we have modelled their uptake to achieve 1% of the population of Dairy farms.

Lower Stocking Rate Sheep and Beef and Dairy

The cost of using this farm management practice on both Sheep and Beef and Dairy farms exceeds the levy price for virtually the whole period modelled so we do not expect that there will be any adoption of this practice.

Lower Stocking Rate with Increased Productivity Dairy

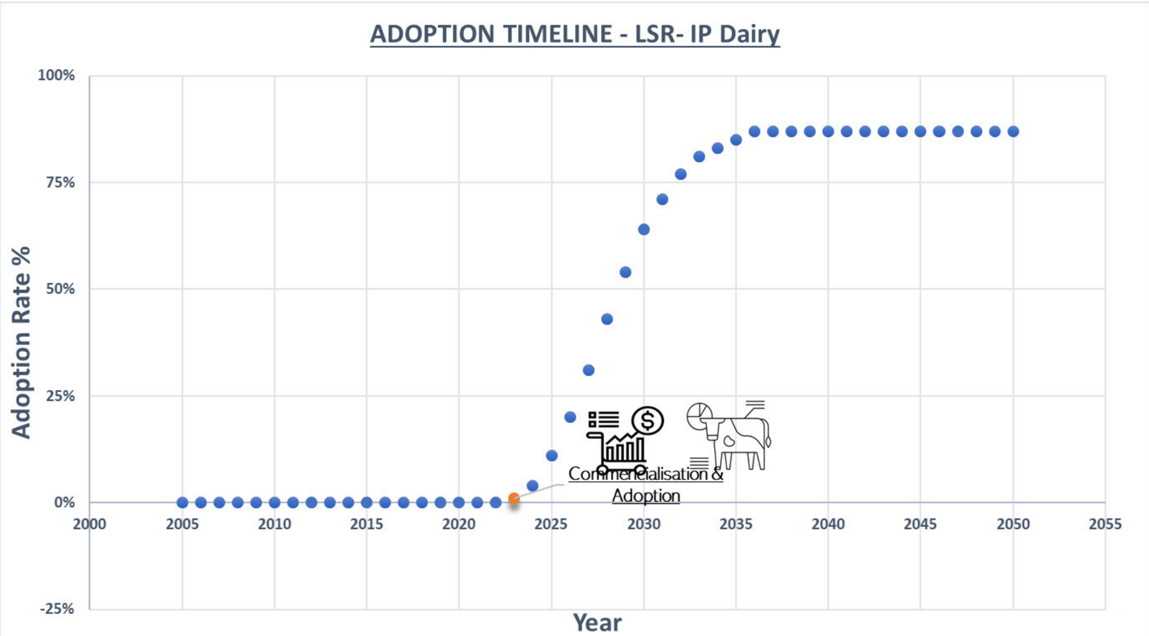

Figure 16: Adoption timeline Lower Stocking Rate with Increased Productivity Dairy.

This technology is available now and there is a positive cost advantage when coupled with increased productivity so adoption will be occurring now. ADOPT shows that a peak adoption of 87% after 14 years (2036) within the dairy industry.

Lower Stocking Rate with Increased Productivity Sheep and Beef

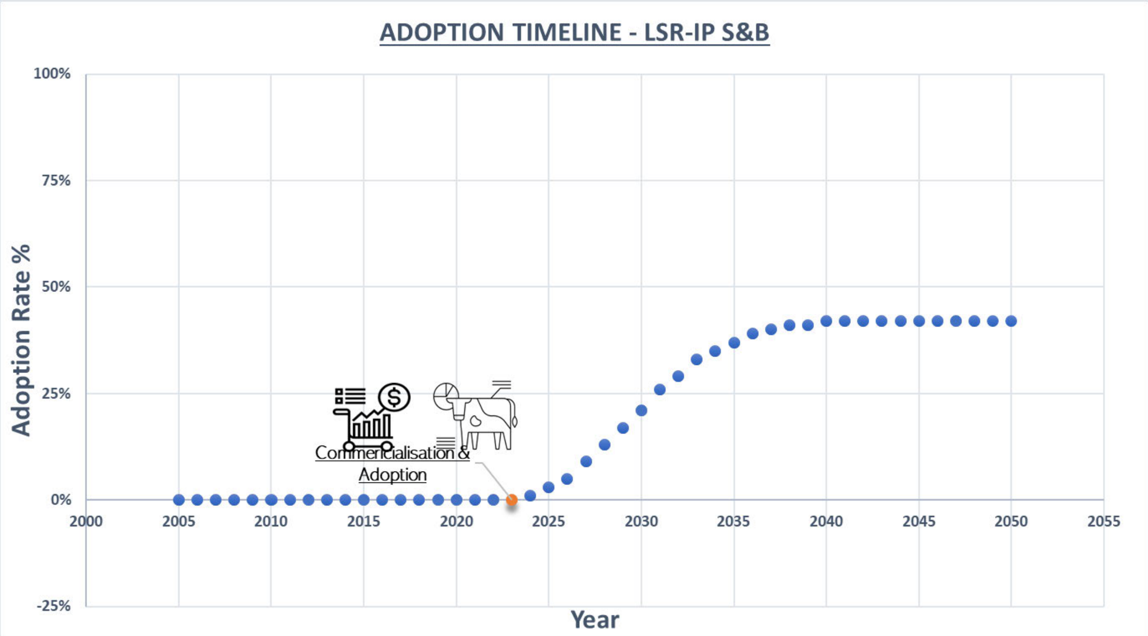

Figure 17: Adoption timeline Lower Stocking Rate with Increased Productivity Sheep and Beef.

This technology is available now and there is a positive cost advantage when coupled with increased productivity so adoption will be occurring now. ADOPT shows that a peak adoption of 42% after 16 years (2040) within the sheep and beef industry.

Reduced Replacement Numbers Dairy

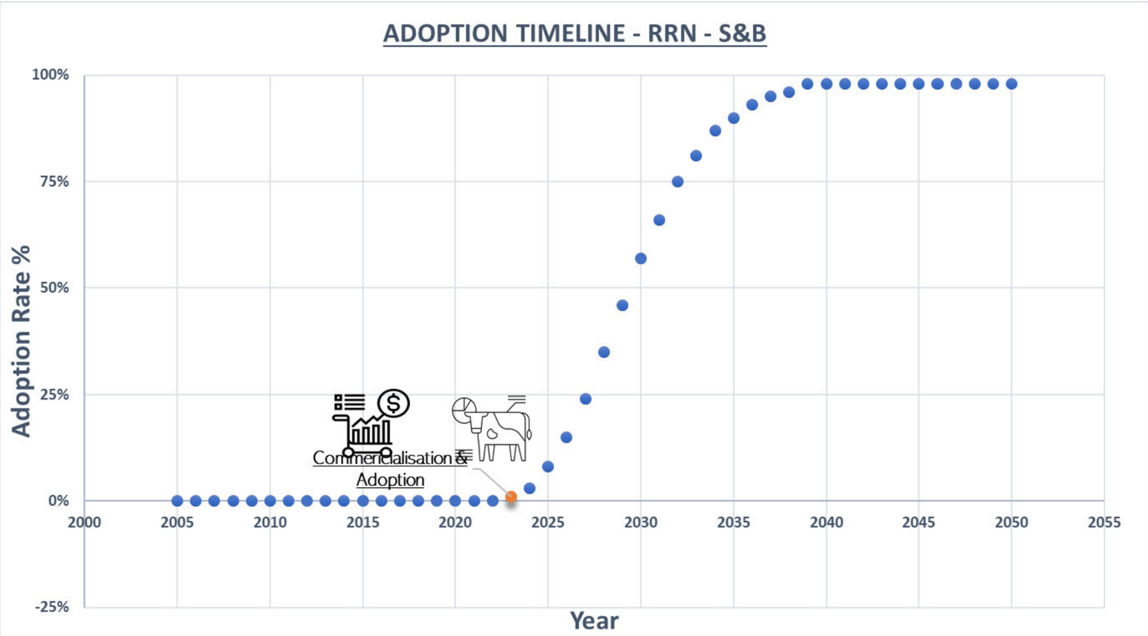

Figure 18: Adoption timeline Reduced Replacement Numbers Dairy.

This technology is available now and there is a positive cost advantage when coupled with increased productivity so adoption will be occurring now. ADOPT shows that a peak adoption of 97% after 10 years (2034) within the dairy industry.

Reduced Replacement Numbers Sheep and Beef

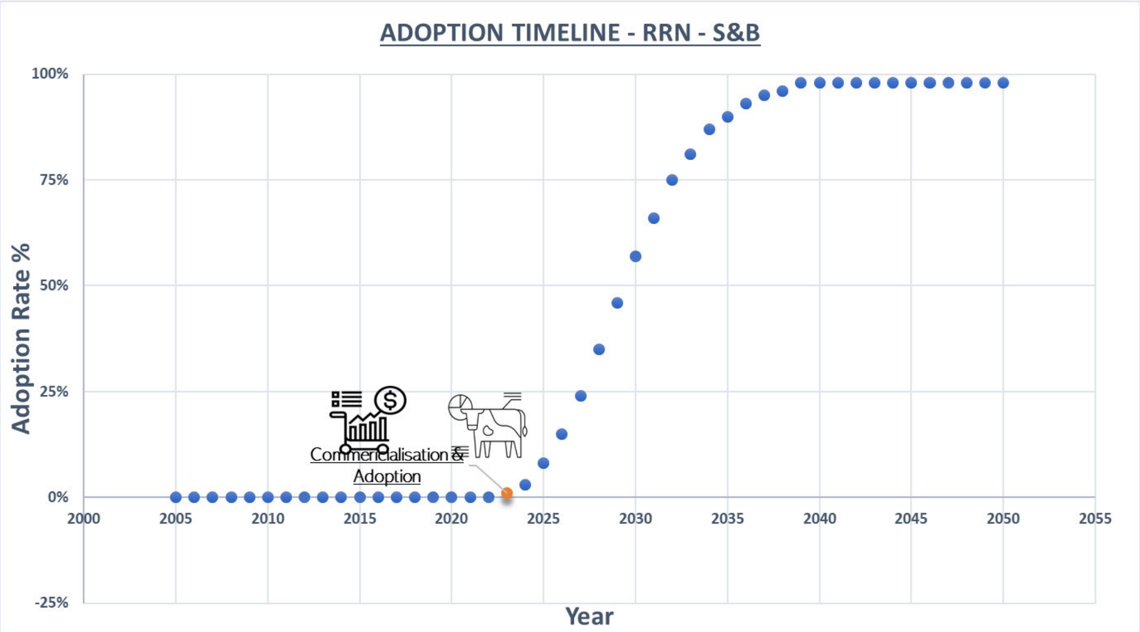

Figure 19: Adoption timeline Reduced Replacement Numbers Sheep and Beef.

This technology is available now and there is a positive cost advantage when coupled with increased productivity so adoption will be occurring now. ADOPT shows that a peak adoption of 98% after 16 years (2039) within the sheep and beef industry.

Reduced Inputs – Supplementary Feed and Nitrogen

For both of these techniques the cost of carrying them out exceeds the levy price for the whole period of the timeline.

Change in Stock Type

For this activity the cost is positive but because of the additional cost of changing stock types from an initial capital perspective and the fact that there is a required change in farming knowledge the potential uptake is very low.

7.3 Discussion

The key points that we can take out of the expression of the timeline for uptake are that:

- The alternative cost of methane expressed as the HWEN proposed levy have a very large negative impact on the potential for uptake for the majority of mitigation techniques.
- The mitigation techniques that appear to have a lower cost and therefore potentially high rates of adoption are still in the potential or discovery stage and face a long time before they are adoptable even when they are proven to work.

- ADOPT indicates that unless a technology has a low cost and it easily implemented the time to peak adoption is in the mid to high teens.

Appendix A: The potential for the mitigation techniques to be used in combination with one another.

	Genetics - sheep	Genetics - Dairy	Methane inhibitors - Dairy	Methane inhibitors - Beef	Methane Vaccine - Dairy	Methane Vaccine - Beef	Methane Vaccine - Sheep	Nitrous oxide inhibitors	GM ryegrass / Dairy	GM ryegrass / Beef	GM ryegrass / Sheep	Bovaer	Probiotics - Kombucha	Methane Oxidation (Zelp)	EcoPonds	Lower stocking Rate – Sheep and Beef	Lower stocking Rate – dairy	Lower stocking rate/improved productivity –	Lower stocking rate/improved productivity –	Reduce replacement numbers Dairy	Reduce replacement numbers S&B	Shorter finishing times	Reduced exogenous inputs - supplementary	Reduced exogenous inputs -nitrogen fertiliser	Once-a-day milking	Change in stock types
Genetics - sheep	✓						✓	✓			✓					✓		✓			✓	✓				
Genetics - Dairy		✓	✓		✓			✓	✓			✓	✓	✓	✓		✓		✓	✓			✓	✓	✓	
Methane inhibitors - Dairy		✓	✓					✓	✓			✓	✓		✓		✓		✓	✓			✓	✓	✓	
Methane inhibitors - Beef				✓				✓		✓						✓		✓			✓	✓				✓
Methane Vaccine - Dairy		✓			✓			✓	✓						✓		✓		✓	✓			✓	✓	✓	
Methane Vaccine - Beef						✓		✓		✓						✓		✓			✓	✓				✓
Methane Vaccine - Sheep	✓						✓	✓			✓					✓		✓			✓	✓				
Nitrous oxide inhibitors	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
GM ryegrass / Dairy		✓	✓		✓			✓	✓			✓	✓	✓	✓		✓		✓	✓			✓	✓	✓	
GM ryegrass / Beef				✓		✓		✓		✓						✓		✓			✓	✓				✓
GM ryegrass / Sheep	✓						✓	✓			✓					✓		✓			✓	✓				

Bovaer		✓						✓	✓			✓			✓		✓		✓	✓			✓	✓	✓	
Probiotics - Kombucha		✓						✓	✓			✓	✓		✓		✓		✓	✓			✓	✓	✓	
Methane Oxidation (Zelp)		✓						✓	✓					✓	✓		✓		✓	✓			✓	✓	✓	
EcoPonds		✓	✓		✓			✓	✓			✓	✓	✓	✓		✓		✓	✓			✓	✓	✓	
Lower stocking Rate – Sheep and Beef	✓			✓		✓	✓	✓		✓	✓					✓		✓			✓	✓				✓
Lower stocking Rate – dairy		✓	✓		✓			✓	✓			✓	✓	✓	✓		✓		✓	✓			✓	✓	✓	
Lower stocking rate/improved Productivity – Sheep and Beef	✓			✓			✓	✓		✓	✓					✓		✓			✓	✓				✓
Lower stocking rate/improved Productivity – Dairy		✓	✓		✓			✓	✓			✓	✓	✓	✓	✓	✓		✓	✓			✓	✓	✓	
Reduce replacement numbers Dairy		✓	✓		✓			✓	✓			✓	✓	✓	✓		✓		✓	✓			✓	✓	✓	
Reduce replacement numbers S&B	✓			✓		✓	✓	✓		✓	✓					✓		✓			✓	✓				✓
Shorter finishing times	✓			✓		✓	✓	✓		✓	✓					✓		✓			✓	✓				✓
Reduced exogenous inputs - supplementary feed		✓	✓		✓			✓	✓			✓	✓	✓	✓		✓		✓	✓			✓	✓	✓	
Reduced exogenous inputs -nitrogen fertiliser		✓	✓		✓			✓	✓			✓	✓	✓	✓		✓		✓	✓			✓	✓	✓	
Once-a-day milking		✓	✓		✓			✓	✓			✓	✓	✓	✓		✓		✓	✓			✓	✓	✓	
Change in stock types				✓		✓		✓		✓						✓		✓			✓	✓				✓

✓ = Mitigations that can be used in conjunction with one another.

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