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Hot topic

Methane production by ruminant animals: current and future technologies

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There is considerable international effort to develop and introduce technologies to reduce methane emissions from agriculture involving ruminant animals in Aotearoa New Zealand, given the sector's importance to our economy and the percentage of our total emissions from ruminant animals, playing a significant role. This has been led by research and funding organisations and consortia such as the Pastoral Green House Gas Research Consortium, New Zealand Agricultural Green House Gas Research Centre, AgResearch, AgriZero, the Centre for Climate Action on Agricultural Emissions and New Zealand's universities.

In 2018, a report to the Biological Emissions Reference Group, a partnership between New Zealand's Agricultural sector and Government, the New Zealand Agricultural Greenhouse Gas Research Centre looked at the potential impact of options to reduce on-farm emissions of greenhouse gasses.[1] This Explainer looks at some of the technologies that could be used to reduce methane emissions.

Contents

Introduction to methane

Methane is part of the natural biological carbon cycle of animal growth and decay.[3] Plants absorb carbon as carbon dioxide from the atmosphere, which is converted into sugars via photosynthesis. Most of these sugars are converted into compounds for energy storage, such as starch, and structural components, such as fibre, of the plants. When animals eat plant material, the digestive system converts it into components the animal can absorb by digestion. Some of the gut microbes, known as methanogens, are involved in digestion and produce methane as a by-product of digestion. Carbon compounds like methane are released into the atmosphere at the end of the digestion process. Other processes, such as respiration and decomposition after death, release carbon as carbon dioxide into the atmosphere and close the loop of the carbon cycle.

Methane is also produced when organic matter rots, or ferments, in an anaerobic (without oxygen or little oxygen) environment that favours the growth of methanogens. This includes animal manure, particularly when stored in effluent ponds, vital to protect waterways, but also when deposited or spread on pastures.

About half the methane released into the atmosphere will decay into carbon dioxide in 10-11 years. This is known as methane's half-life. After a period of 100 years or more, the decay of methane means the process has not added more greenhouse gasses to the atmosphere. However, while it is in the atmosphere, methane has a much greater warming potential than carbon dioxide, around 80 times that of carbon dioxide over its first 20 years, so cutting methane emissions is the fastest way to reduce global warming in the short term.[4]

Context: methane production by ruminant animals

Methane emissions from ruminant animals (livestock such as cattle, deer, goats, and sheep) make up a significant proportion (37.5% in 2021) of New Zealand's total greenhouse gas emissions (as carbon dioxide equivalents).[2] To meet the country's international obligations to reduce emissions, and satisfy demands for lower emission products from international markets for our agricultural produce, growers are actively seeking ways to reduce methane emissions from livestock.

Methane production is an inherent part of pasture-based agriculture. Animals can't readily digest the fibre component of plants on their own. Animals, including humans and ruminant animals, that consume plants for food rely on a symbiotic relationship with microbes in the gut to break down the large complex molecules such as celluloses, hemicelluloses, and lignins that make up non-digestible fibre into small molecules that can be absorbed and used as a source of energy.

Ruminant animals have evolved to thrive on leafy diets that are relatively low in energy sources that the animal can digest itself, such as starch, and relatively high in celluloses and hemicelluloses that need to be broken down by microbes. This involves passing their food through a four-chambered stomach, where some of the chambers are specifically adapted to host complex communities of microbes that that break down the fibrous components of the feed. This process is referred to as 'microbial fermentation.' Other chambers behave more like the human single chambered stomach.

The digestion process of ruminant animals requires regurgitation of the contents from the front chamber of the stomach, the rumen, where most of the fermentation happens. The content is chewed again to break it up and mixed with saliva to help with the process. This is known as rumination or 'chewing the cud'.

Some of the gut microbes involved are methanogens, that mostly operate in anaerobic (oxygen limited) environments found in the rumen, and produce methane as the final product of digestion. The methane produced cannot be absorbed by animals, and it is released, contrary to popular imagination, primarily as burps (see figure 1). The vast majority of methane released by New Zealand sheep and cattle comes from fermentation in the rumen, but there is also a small but significant amount of methane from break down of manure.[5]

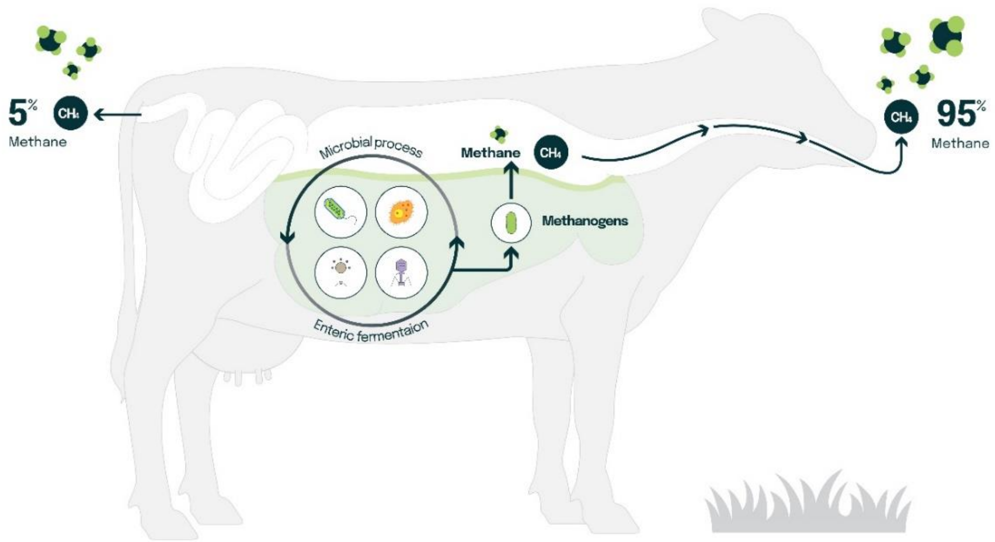


Figure 1: Diagram showing how methane is produced in the rumen. Image credit: NZAGRC.[5]

Methanogens are an essential part of ruminant digestion because they help control the level of acid produced during fermentation. The digestion process has been refined by evolution over the last 50 to 60 million years so ruminant animals use food sources for energy in grassland and shrubland areas where most other herbivores cannot get enough energy from the available food. Humans have exploited this by hunting or, more recently, domesticating ruminant animals to provide food. This has allowed New Zealand to develop a very efficient and productive pastoral agricultural sector, however there are greenhouse gas emissions also to consider as well as economics. Reducing methane emissions from ruminant digestion while maintaining animal health and productivity presents a challenge as the interventions required are not straightforward.

In the following sections, we give a brief description of the technologies that will most likely be available in the near term to mitigate methane emissions from agriculture, as well as their potential impact.

Breeding lower emission stock

Sheep and cattle can be genetically selected to emit less methane than those currently farmed in Aotearoa. Animals, within a species, vary naturally in the amount of methane they produce with the same intake of the same diet, and this trait has been shown to be heritable. This means that farmers can use traditional breeding techniques to select for ruminant animals that produce less methane.

Potential reductions

There is potential for daily emissions reduction by an estimated 10-20% between high-emitting and low-emitting animals in 10-15 years. By combining this trait with productivity improvement traits (e.g. milk quality), methane emissions/kg meat or milk could be reduced by up to 25% by 2050 through genetics alone.[6] However, overweighting selection on methane reducing traits at the expense of other desirable traits is likely to reduce the overall fitness of the animals, so such gains may not be made in practice.

Technology and research

Research is well underway for both cattle and sheep.[7]

For sheep, genomic breeding values are being estimated by Beef + Lamb New Zealand for the low-emission trait.[8] The breeding value for the trait has been incorporated into the Sheep Improvement Limited database (nProve).[9] There is ongoing funding of research in this area through NZAGRC.

Work on breeding cattle is at an earlier stage. Pilot trials have been conducted in Aotearoa, and in 2021 a bull testing trial began. A full scale trial is underway within existing Livestock Improvement Corporation (LIC) and CRV Ambreed sire-proving schemes.[10]

There is also research to develop proxies for identifying low-emitting cows (e.g. gut microbes, milk, blood plasma), which are needed for a full-scale national methane breeding programme. New Zealand company, LIC, expects that if current trials are successful, methane breeding values for all their artificial breeding bulls will be available in the 2026 season allowing selection for low-emission cattle.[11] Once research is completed, outcomes will be able to be rapidly adopted by industry through traditional breeding methods and genomic selection.

So far there is little research undertaken regarding breeding strategies in either deer or goats, but it is anticipated that the same genetic variation and heritability apply. Therefore, progress can be made in the future.

Barriers

The most significant barrier is the cost of methane monitoring equipment, such as enclosed chambers and wearable methane monitors, which means trials are conducted on a relatively small number of animals. However, as genetic markers are identified, breeding to reduce methane emissions can be carried out without the need to monitor every animal.

Timeline

Beef + Lamb New Zealand Genetics made research emissions breeding values available to selected sheep farmers in Aotearoa in 2019. The programme is being expanded with the prediction that emissions per animal can be reduced by 2-3% per year.[6,12] The LIC emissions breeding values for dairy cattle are expected to be available in 2026.

Methane inhibitors

Methane inhibitors are chemical compounds that can reduce the production of methane in the stomachs of ruminants. Inhibitors work by blocking or re-routing enzymatic and chemical pathways in methanogens and prevents the methanogens from proliferating and/or disrupting methane production.[13]

Potential reductions

Methane inhibitors could potentially reduce methane emissions by 30% or more. However, most inhibitors are suited when raising ruminant animals in feedlots or sheds. Where, the inhibitor can be routinely mixed with food, as opposed to New Zealand's pasture-based systems.

Technology and research

Several technologies have been developed or are in development, with most activity happening offshore rather than in Aotearoa:

- 3-NOP[*] or Bovaer® is a feed additive produced by global chemicals company, DSM, that has demonstrated its ability to reduce methane emissions from ruminant animals in many countries.[14] It has been approved for import into New Zealand by the Environmental Protection Agency[15] but DSM has yet to register it for commercial use in the country. Internationally, most trials have been on animals fed Total Mixed Ration diets rather than the pasture-fed animals which dominate New Zealand livestock farming. Bovaer® is designed to be fed daily with every mouthful of food, making it practically challenging to use in New Zealand livestock farming.

- Bromoform (tribromomethane) is a representative of a number of low molecular weight iodine, bromine, and chlorine containing (halogenated) molecules that prevent methane production by methanogens.[16] They also have the advantage that methane production is diverted to other small soluble molecules that the animal can absorb which improves feed utilisation. Bromoform and related compounds are also relatively cheap. However, their presence at moderate to high concentration in meat or milk raises health concerns.[17] The use of bolus[†] technologies to deliver constant low doses in the rumen could solve both the health issue and the need to regularly include the inhibitors in the animal's feed.

[*] 3-nitrooxypropanol, also known commercially as Bovaer®
[†] A controlled slow-release capsule that sits in the cow's rumen for up to six months.

- A number of seaweeds have been shown to reduce methane emissions when fed to ruminants.[18] Most of the activity has been ascribed to the low molecular weight halogenated molecules such as bromoform (discussed above), which are naturally abundant in seaweeds, but other components have also been implicated.[19] The seaweed, therefore, provides a natural source of halogenated compounds at suitable levels, along with other compounds that have antimicrobial activity. Work has focussed on developing supplements from particular red seaweeds, principally asparagopsis species, that have high levels of bromoform and related compounds and that grow in Australia and Aotearoa. Barriers to their use include the amount of seaweed that is available naturally, or alternatively the cost of aquaculture and the using the supplements in New Zealand's pasture-based farming systems.[20] In Australia, the Commonwealth Scientific and Industrial Research Organisation is working to develop an asparagopsis based supplement,[21] while the international company CH4 Global is developing a tank-based aquaculture system for asparagopsis in New Zealand.[22]

The use of some probiotics might also reduce methane production by affecting gut bacteria that create methane in the rumen.[23] Although probiotics are not strictly 'inhibitors' because they are live bacteria fed to animals rather than chemical compounds. The mechanism of action is not clear; probiotic bacteria could work by outcompeting methanogens so there are fewer of them, encouraging the growth of existing non-methanogenic bacteria in the rumen, or by providing alternative reaction pathways that do not result in methane production. Initial trials by Fonterra of bacteria from their culture collection have shown up to a 20% reduction in methane emissions from calves fed probiotics.

Barriers

There are several barriers to the effective use of methane inhibitors in Aotearoa including cost, impacts on production, animal welfare, potential human health impacts of residues,[24,25] and availability of the inhibitors. However, the key issue is that our mainly pasture-based farming systems provides a challenge to any feed additive that must be fully mixed in with the feed to be effective. Slow-release capsules could potentially be used to deliver inhibitors slowly and continuously, solving this issue, particularly for additives that work at low doses.

New Zealand solutions

The New Zealand company, Ruminant Bio Tech, is developing a bolus technology for methane inhibitors in animals that may overcome some barriers to inhibitor dosing in New Zealand pastoral systems.[26] The Australian/US company, Rumin8, is developing inhibitors in solid and liquid form for adding to feed and as a bolus for use in pasture fed animals.[27]

Synthetic biology can also provide a technology to overcome barriers to the use of methane inhibitors. Endophytic fungi have a symbiotic relationship with grasses in Aotearoa pastures there is proof-of-concept that it is possible to bioengineer methane inhibitors into grass endophyte, and further research is being undertaken to develop this idea.[28] The Australian company number8bio (started by a New Zealander from the Waikato) is using synthetic biology to engineer yeast strains to produce methane inhibitors. The yeast broth can then be dried and fed to the animals as an easily scalable, cost effective supplement.[29]

Timeline

Adoption of methane inhibitors is likely to take between 2-10 years depending on the technology. DSM's inhibitor Bovaer® and CH4 Global's seaweed derived supplement are available internationally but have not been made suitable for Aotearoa pastoral systems. Ruminant Biotech expect to launch their bolus supplement in 2025. Synthetic biology solutions will take longer to bring to market.

Methane vaccines

A methane vaccine is targeted at triggering the immune system to generate antibodies secreted in the animals' saliva that suppress methanogens in the rumen. The suppression of methanogens results in less methane being generated.[30]

Potential reductions

Researchers believe that a methane vaccine could potentially reduce methane emissions by 30% although this still remains very uncertain.[31]

Technology and research

Methane vaccines remain in development and not a usable solution for ruminant animals at this stage .[31] However, all the major components of a possible vaccine have been demonstrated to be feasible and in vitro trials are promising. There is evidence for methane reduction in pure methanogen cultures,[30] and the production of antibodies in sheep against methanogens.

The New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) and AgriZero are currently supporting work ($4 million in 2023-24) to develop a prototype vaccine.

Current research focusses on identifying the right antigen(s) against which to raise antibodies that will inhibit the growth and function of the broadest range of methanogens in animals.

Barriers

A methane vaccine could be practical and cost-effective in New Zealand's pastoral farming systems and if used globally, would a significantly reduce the amount methane emitted into the atmosphere. Vaccines are widely used by farmers, primarily for animal diseases, facilitating easy uptake. However, significant research is still needed before vaccine adoption.

Discovering the right antigen(s) that will generate effective antibodies against the range of methanogens found in the rumen still poses major challenges.[32] Once an effective vaccine has been developed, it is likely that the methanogens will develop resistance to it, so the work will continue. The potentially large impact and ease of use in a broad range of farming systems of vaccines makes them an attractive research area despite the barriers.

Timeline

Vaccine research has been ongoing in Aotearoa for around 20 years, and techniques and knowledge of the methanogens' genomes, which will make generating vaccines much easier, has improved vastly over that time. It is still uncertain when a prototype vaccine will be developed and once it is demonstrated to be effective in animals it will likely still take 7-10 years before a vaccine would be commercially available.[31]

Low methane emission feeds

Most New Zealand farming systems are pasture-based, meaning the livestock mostly graze grass and legume pasture. The type of feed consumed, either primarily or as a supplementary feed, can impact other emissions other than methane. For example, alternative feeds, such as plantain, aim to reduce nitrogen in urine to prevent water pollution from excess nitrogen in the soil and are not considered here.

While there is a strong relationship between the amount of feed consumed and methane emissions, feeds with higher levels of readily fermentable carbohydrates, such as starch or sugars, and less non-digestible fibre, or that contain higher levels of fats or oils, reduce methane emissions.

Potential reductions

Low-emissions feed may reduce methane emissions by around 20-30% if fed at high levels in the diet. However, many of the alternative feeds are only seasonally available. Low emission feed's impact on overall methane emission is compromised as feed availability cannot be maintained all year.

Technology and research

A number of feeds that potentially lower methane emissions have been trialled including:

- Forage rape, when used as a sole feed, reduces methane emissions by around 30% but is only available over a relatively short season.[33] Fodder beet supplementation (20%) of a mainly pasture diet can reduce the amount of methane produced by 16% per unit of milk production compared to pasture feed alone.[33]
- Maize, widely used overseas for feedlot and barn raised animals along with other grains, and maize silage have high levels of digestible carbohydrates and so reduce methane emissions. Grains are relatively low in nitrogen and minerals. Research is ongoing on the proportion of diet required for methane reductions and quantifying reductions.[34]

There is also potential for genetic modification of current pasture species in ways that cannot be achieved by traditional breeding to provide advances in this area. Researchers have already developed a genetically modified ryegrass that has a higher lipid content which directs rumen digestion away from methane production. Modelling and testing in vitro has demonstrated there could be a potential reduction in methane emissions, though research is still at an early stage.[35]

Another potential target for genetic modification is raising condensed tannin levels in white clover. Condensed tannins affect rumen digestion to lower nitrogen in urine and reduce bloat, as well as to reduce methane emissions. Efforts are being made to produce a clover species with sufficiently high condensed tannin levels in sufficiently large quantities to undertake feeding trials.[36]

Barriers

While currently available low methane feeds are being used as part of New Zealand farming systems issues of year round availability, cost, impact on production, and potential to increase nitrogen leaching mean they are unlikely to have a huge impact on overall methane emissions.

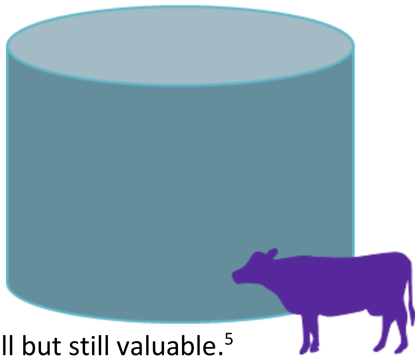
The incorporation of methane reducing genetic traits into pasture species by genetic modification would solve many of these issues, however, any modified feed would need to demonstrate efficacy and meet regulatory approval.

Timeline

Some low methane emission feeds are available now. Genetic modification techniques are improving and the regulatory environment for genetically modified organisms is changing but it is unlikely that any modified pasture species will be widely available in less than 10 years.

Manure storage and management

Manure is a small but still significant source of methane. Decomposition of manure in anaerobic environments, such as in large piles or effluent storage ponds without an adequate supply of air produces carbon dioxide.



The majority of New Zealand dairy farms (more than 90%) have effluent storage ponds, used to reduce water pollution from soil run off, which are potential sources of methane. After storage the effluent is typically applied to land where it decomposes to produce carbon dioxide.[37]

Potential reductions

Around 97% of methane emissions from ruminants comes from microbial fermentation in the rumen, so methane reductions from better manure management and storage are likely to be small but still valuable.[5]

Technology and research

There are a number of technologies that are available or in development, which aim to remove the methane that is produced or capture and use it as an energy source where the scale is sufficient to make it worthwhile.[38] These include:

- Biofiltration - passing the gasses released from effluent ponds through a support containing microorganisms that oxidise methane to carbon dioxide (proven in concept).
- Covered anaerobic in-ground ponds and digester tanks (proven but expensive, so only viable for large systems or when manure is combined with other sources of waste).
- Surface-aerated ponds (not yet proven).
- Additives that inhibit methane formation (adding iron sulphate to effluent as it enters the pond has been shown to reduce methane emissions by 95% in on-farm trials.[39])

Barriers

Many of these systems are common in Europe and the US but they are not widely used in Aotearoa. While many are well established in principle, they are not generally economically viable under New Zealand farming conditions.

Timeline

These systems are available now, but further work is required to see greater adoption in New Zealand by making the technology more affordable.

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