Carbon-Kai Ltd

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Confidential Scientific Review Document

1. WHAT IS CARBON-KAI?

Carbon-Kai is a proprietary second-generation biochar formulation developed by Carbon-Kai Ltd. Unlike standard biochar (usually produced by pyrolysing a single organic feedstock in a low-oxygen environment), Carbon-Kai incorporates a purposeful blend of minerals into the biomass feedstock prior to the pyrolysis process. This pre-blending step, carried out at high temperature, produces a carbon-mineral composite material with a targeted physicochemical profile rather than a conventional porous carbon product.

The specific mineral composition and processing conditions constitute proprietary intellectual property and are not disclosed in this document. Carbon-Kai is a material with surface chemistry and porosity which are purposefully engineered toward specific rumen and digestive outcomes in dairy cattle. Carbon-Kai is intended to function across multiple biological domains, rumen function, gut health, soil biology, and multiple sources of GHG emissions within a farm ecosystem.

> How Carbon-Kai differs from first-generation biochar
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> Standard biochar is produced from a single carbon feedstock and is not optimised for rumen-specific function. Carbon-Kai is co-formulated with minerals at the feedstock stage before pyrolysis, which modifies the resulting material's surface chemistry and internal pore architecture in ways that target rumen methanogenesis and digestive performance. This distinguishes it from both standard biochar and post-production activated carbon products, including those used in peer-reviewed livestock trials to date.

1a. Scientific Context: Biochar & Activated Carbon

Biochar is a carbon-rich material produced by the thermal decomposition of organic biomass in a low-oxygen environment. These thermal processes (pyrolysis, charring, and carbonisation) occur typically at 350–1,000°C and produce a porous black solid. When subjected to further activation, a biochar or charcoal can be converted into activated carbon. Following a thermal or chemical activation process, an activated carbon material will have significantly enlarged surface area and enhanced adsorptive capacity.

When produced under certain conditions both biochars and activated carbons are non-toxic, stable materials which are electrically conductive. Biochars can have measured surface areas around 300 m²/g and activated carbons are typically around 1000 m²/g. The exact surface areas and properties of biochars and activated carbons depend greatly on the processing conditions used in their manufacture, and to a lesser extent biomass feedstock.

Wildfire charcoals have long been a part of ecosystems and are naturally found in many different soils. Although, biochars and activated carbons are intentionally manufactured products they often overlap with wildfire charcoals in terms of physically and chemically properties. This mitigates risks and concerns associated with synthetic products that would be novel in to farmland or natural ecosystems.

2. ANIMAL HEALTH: EVIDENCE SUMMARY

2a. Gut Health & Toxin Adsorption

One of the most consistently documented properties of biochars and activated carbons in animal nutrition research is its capacity to bind harmful substances within the digestive tract before systemic absorption occurs.

Certain biochars and activated carbons have been reported to:

- Adsorb mycotoxins, bacterial toxins, ammonia, heavy metals, dioxins, glyphosate, pesticides, and polycyclic aromatic hydrocarbons (PAHs) [1][2][3].
- Reduce bioavailability of these substances, protecting liver, kidney, and immune function [1][2][3].
- Shift gut microbial populations away from disease causing species such as Clostridium botulinum, Escherichia coli, Salmonella enterica, Campylobacter jejuni when various animals are feed biochar-supplemented diets [1][2][3].

2b. Internal Parasite Burden

- Biochar has been associated with reductions in internal parasites, with evidence of reduced worm burden in treated animals with a few publications [1] and many anecdotal accounts.
- Reducing the need for chemical worming treatments has on-farm economic benefits and regulatory benefits, being relevant to NZ's clean-green export positioning.

2c. Feed Efficiency & Improved Weight Gains

- Improved body weight gains have been recorded across cattle, pigs, goats, sheep, and poultry in controlled biochar supplementation trials [1][2][3].

> Scientific caveat on feed efficiency
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> Improved feed conversion efficiency is more often observed in situations where diet quality is impacted by plant toxins or mycotoxin contamination. A study in Switzerland with Holstein dairy cows found no significant effect on milk yield or methane at 1% DM biochar inclusion [4]. This underscores that biochar's rumen benefits are most pronounced under pasture-based or nutritionally variable conditions (the dominant NZ grazing context) rather than in optimised feedlot scenarios which use considerable concentrate feed (such as in the Swiss study).

3. RUMEN FUNCTION: METHANE REDUCTION & MILK PRODUCTIVITY

Enteric fermentation is New Zealand's single largest source of agricultural greenhouse gas emissions. It is also the same biological process that determines how much energy a cow captures from feed for milk synthesis. Methane reduction and milk productivity are therefore linked through the same rumen chemistry. This is the scientific foundation for Carbon-Kai's dual value proposition in the NZ dairy sector.

3a. How the Rumen Produces Methane — and Wastes Energy

During rumen fermentation, plant carbohydrates are broken down by microbial communities into volatile fatty acids (VFAs) such as acetate, propionate, and butyrate which are taken up by the animal. Hydrogen gas (H2) is also generated due to a need by some microbes to jettison excess electron and hydrogen from their metabolic processes. Carbon dioxide (CO2) is also created as a waste product of the fermentation process. Methanogens (microbes such as Methanogenic archaea species) consume the hydrogen dissolved in the rumen fluid and combine it with CO2 to produce methane (CH4), which is expelled via eructation.

This methanogenesis process is considered to serve no productive purpose for the animal. It represents a net energy loss of approximately 2–12% of gross energy intake [5], energy that could otherwise contribute to milk fat, milk protein, or milk volume. Reducing methanogenesis is therefore simultaneously an emissions reduction goal and a production efficiency goal.

> The core rumen problem
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> Every litre of methane expelled by a dairy cow represents a waste of energy which could have instead been converted by fermentation into fatty acids (such as propionate) and utilised as a metabolic energy source by the cow to produce milk or grow muscle for meat. Suppressing methanogenesis is considered an opportunity to redirect this energy back into productive pathways.

3b. How Carbon-Kai Modulates Rumen Chemistry & Biology

An early hypothesis that these porous carbon additives simply collect the methane on their surfaces to reduce methane emissions was quickly dismisses as unrealistic (and unhelpful if the methane is later released from the manure).

The scientific literature identifies multiple distinct mechanisms by which biochars, activated carbons, and mineral-enriched biochar materials alter rumen chemistry to reduce methane output and improve fermentation efficiency.

Carbon-Kai's second-generation mineral-biochar formulation is designed to engage several of these pathways simultaneously.

Mechanism 1: Electron Storage & Transfer

Biochar's porous carbon matrix has documented electron-mediating properties in biological redox reactions [6][7][8]. Within the rumen, this enables the conductive carbon surfaces on biochars to function as an alternative electron acceptor and medium for transferring electrons to other electron acceptors.

This functionality provides alternative pathways for electrons and potentially hydrogen. Catalytic and redox functionality of mineral additives can aid these alternative pathways, either biochemically or through abiotic chemistry.

In 2022, researchers highlighted the importance of electron flow and electron acceptors in the quest to reduce methane emissions from ruminal digestion [9]. Those researchers also drew contrasts and comparisons between the rumen fermentation and other anaerobic fermentation environments.

Conductive carbons have been investigated in other anaerobic environments such are peat soil [8], reactors [10], and waste digesters [11]. Those investigations have found evidences of conductive carbon materials facilitating direct electron transfer and mediating redox reactions. In the peat soil study, methane production was suppressed through biochars providing capacitive electron storage and conductive electron transfer mechanisms. These mechanisms function by facilitating or catalysing alternative biochemical pathways which enable microbes to access more terminal electron acceptors.

Ultimately, a product such as Carbon-Kai should catalyse and enable metabolic pathways within the rumen ecology that outcompete the methane production pathway.

Mechanism 2: Alternative Sinks for Electrons and Hydrogen

The complicated ecology of the rumen can be viewed in terms of the metabolic flows of electrons [9] and hydrogen [5].

From the electron flow viewpoint methane production is how the rumen ecology disposes of electrons, with some researchers predicting that 2/3 of the electrons generated by ruminal fermentation go to methane as the terminal electron acceptor [9]. Diverting electron flow away from the methane-creating pathway towards other electron acceptors (and preferably products of nutritional benefit to the animal) is a strategic aim for those researching approaches for methane reduction.

Other researchers view the situation and focus on the metabolic flows of hydrogen with the production of methane being the main sink for hydrogen. Alternative pathways which redirect hydrogen to the production of more volatile fatty acids and less methane are a key aim in efforts to reduce unwanted emissions and increase animal productivity [5]. Simply inhibiting methanogenesis many increase the concentration of dissolved H_2 (dihydrogen) or other metabolites, and too high concentrations can cause metabolic issues. If dissolved dihydrogen is an electron carrier, promoting alternative electron carriers can reduce these issues. Other microbial pathways can consume dihydrogen and not produce methane and certain additives can act as alternative electron acceptors avoiding the need for dihydrogen production.

Mineral additives in Carbon-Kai formulations have been selected to offer alternative sinks for electrons and enable redox activity. Some Carbon-Kai components many act as terminal acceptors. However, the preference is for regenerative capabilities, where beneficial microbes can utilise excess electrons (or sorbed metabolites) to create products which have nutritional value to the animal.

Ideally microbes would ultilise both electrons and hydrogen to form metabolic products other than methane. Preferably more products such as volatile fatty acids would be created and taken up by the animal to boost the production of milk and meat.

Mechanism 3: Altering Microbial Communities

Carbon-Kai provides both physical structure and chemical functionality to act in a catalytic role. Microbes in the rumen are needed to do the metabolic work and utilise the Carbon-Kai to improve their metabolic effiency.

Biochars are known to provide porous structure and colonisable surfaces. Carbon-Kai surfaces are engineered to be conductive in order to facilitate electron transfer between species and onto mineral components. Microbial colonisation of conductive carbon surfaces has been previously reported in anaerobic digester studies [10].

The other three mechanisms discussed in this section can be combined to create a habitat within and around a Carbon-Kai particle for the benefit of certain microbes.

The scientific literature contains many examples of biochars and activated carbons being associated with changes in microbial communities in animal digestive systems, including the suppression of pathogenic bacteria species [1]. A published trial on feeding activated carbon to dairy cows in Queensland reported that carbon supplementation reduced the population of methanogenic flora by 30% on average, with a corresponding relative increase in non-methanogenic microbial species according RNA sequencing [12]. This microbiome-level shift represents a significant alteration in fermentation ecology, not merely a transient chemical effect.

Mechanism 4: Chemical Concentration Modulation

The high surface areas of biochars may adsorb hydrogen and other metabolites, buffering their concentrations within the rumen fluid. This mechanism could modulate local concentrations of metabolites, reducing fluctuations and the extremes of shortages or excesses. More moderate levels of feedstocks and metabolites could lead to more efficient metabolic processes and improve overall ruminal function.

The surfaces of biochars and activated carbons could also sorb inhibitors and toxins which would otherwise cause inefficiencies in ruminant digestion and suppress the activity of beneficial microbes.

Carbon-Kai surfaces have been modified through mineral additions, so that Carbon-Kai formulations will also sorb chemical compounds which do not have affinity with typical biochars.

4. EVIDENCE BASE: PUBLISHED TRIALS & CARBON-KAI INTERNAL DATA

4a. The Brymaroo, Queensland In Vivo Trial — Al-Azzawi et al. (2021)

The most directly relevant peer-reviewed in vivo evidence for activated carbon's effect on dairy cattle methane emissions and milk productivity comes from a trial conducted at Brymaroo, Queensland, Australia, published in the journal Sustainability [12]. This research originated from the University of Southern Queensland.

- A herd of approximately 180 dairy cattle cycled between the diets with and without activated carbon. Powdered activated carbon (PAC) was added at 0.5% of diet dry matter intake (DMI).
- The animals spent 6-weeks on each diet with a 2-week adjustment period on the new diet followed by 4-weeks of measurements. This pattern was repeated over the 22-week trial.
- Methane emissions were measured for the herd at a whole barn level with methane produced from eructation during milking and from manure deposits.
- 16S rRNA gene sequencing performed to characterise the community of bacteria and archaea populations in the manure from both treated and control animals.

> Published Results — Al-Azzawi et al. (2021) [12]
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> CH_4 emissions reduced by 30–40% (based on milking shed measurements), CO_2 emissions reduced by 10%, methanogenic flora reduced by 30% (estimated from RNA sequencing), daily milk production increased by 3.43%, milk protein increased by 2.63%, and milk fat increased by 6.32%.

4b. The Townsville, Queensland In Vivo Trial — Martinez-Fernandez et al. (2024)

This publication [6] reports on two in vivo Australian cattle trials with two different biochar-mineral formulations.

The first trial was feeding 12 steers in methane collection chambers. They reported methane reductions of 9.5% (with biochar @ ~0.6% of DMI) and 12% (with biochar @ ~2.4% of DMI) for their better performing biochar-mineral formulation.

However, a second outdoor trial on 45 heifers produced no statistically significant effects on recorded methane emissions. The differences between the trials involved a change of diet, a switch to voluntary supplement intake, and a change of methane monitoring equipment.

The better performing biochar-mineral formulation in this trial contained potassium nitrate.

Adding nitrates to Carbon-Kai formulations is an approach deliberately avoided to minimise concerns about elevated levels of non-protein nitrogen in milk, meat or blood.

Both biochar-mineral formulations used in these Townsville, Queensland trial fall outside the propriety formulation design-envelope which Carbon-Kai has been developing.

4c. Carbon-Kai — Internal Laboratory Data

Carbon-Kai has conducted in vitro rumen fluid fermentation trials using its proprietary mineral co-formulated products, with comparisons to controls and other carbon-based additives. The in vitro trial methodology is based on other trials [13], and this approach allows quick screening without needing to access fistulated cattle.

In a direct comparative in vitro evaluation, Carbon-Kai also tested the activated carbon product supplied by the University of Southern Queensland. That is same material used in the Brymaroo, Queensland field trial test alongside Carbon-Kai's most promising formulation under identical in vitro fermentation conditions.

> Carbon-Kai Internal In Vitro Results (2025)
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> A top-performing Carbon-Kai formulation resulted in 9.3% (steer ruminal sample) and 25% (bull ruminal sample) less methane production when directly compared to the reference activated carbon used in the University of Southern Queensland trials [12]. In those previous Queensland trials the activated carbon resulted in up to 62% reductions in methane production in vitro [13] and up to 40% reductions in vivo [8]. This indicates top-performing Carbon-Kai formulations offer scope to exceed some of the most substantial methane reductions in the scientific literature for activated carbon and biochar feed trials. Note: Carbon-Kai's internal laboratory findings are from in vitro screening trials designed to guide formulation development (relative comparisons between different treatments rather than absolute values for methane reductions). Independent in vitro and/or in vivo trials will be required. Formal in vivo validation trials are planned for September 2026.

Carbon-Kai's internal in vitro trials have involved comparisons of a range of formulation variants along with other biochar and activated carbon products. This has been used to select promising formulations for future trials and identify potential dead-ends where formations lose effectiveness from excessive mineral additions or the lack of important properties (this is work towards understanding a design-envelope for engineering effective biochar-mineral formulations).

Results from in vitro systems cannot be directly extrapolated to in vivo performance. Controlled animal trials are required and Carbon-Kai is working towards a September 2026 start for well-designed animal trial.

5. SOIL & PASTURE: CASCADING BENEFITS

5a. Carbon Sequestration via the Feed-Through Pathway

A recently published peer-reviewed study provides direct quantification of biochar's fate following ingestion by dairy cattle [14].

- 70–90% of ingested biochar was recovered intact in manure samples across dairy cow feeding trials.
- Recovered material retained condensed aromatic carbon structures consistent with long-term chemical stability, indicating that highly durable biochar survives the digestive process in cattle.
- The authors conclude that the majority of biochar passes through the digestive system with minimal decomposition and they identify the application of manure to soil as a means for sequestering CO_2 as stable biochar.

5b. Soil Fertility, Water Retention & Nitrate Leaching

- Biochar increases soil cation exchange capacity (CEC), aeration/structure, nutrient retention, water-holding capacity, and microbial diversity [1][2][15].
- Biochar has recently been trialled by Manaaki Whenua (Landcare Research). The biochar was applied to a NZ dairy farm soil at a high application rate which resulted in a major increase in soil carbon levels and significantly reduced topsoil nitrate-N concentrations [16]. Nitrate leaching is a primary driver of stream and groundwater contamination.

6. WHOLE-FARM GREENHOUSE GAS PROFILE

Carbon-Kai has potential to address the three major gas which New Zealand's agricultural emissions; CH_4, N_2O, and CO_2.

6a. Nitrous Oxide (N_2O)

Nitrous oxide carries a 100-year global warming potential of 273× that of CO_2 (IPCC AR6) [17]. NZ pastoral soils, when saturated with ruminant urine nitrogen, are a significant N_2O source.

- Meta-analysis supports a link between biochar additions and N_2O emission reductions across a range of soil types and geographies [18][19], though repeated applications may be required.
- Biochar addition has been found to increase the prevalence of the nosZ-gene in soil microbial communities which is responsible for the terminal reduction of N_2O to inert N_2 [20].
- Published research has reported that biochars can suppress N_2O arising from ruminant urine patches, which are a significant emission source in NZ [21].

6b. Ammonia (NH_3) — Manure Management

- An acid-activated biochar has be investigated as a floading cover for manure ponds with reports of 37–51% NH_3 reduction in first month and 25–28% over four months [22].
- A related study of floating biochar covers over liquid manure lagoons reported a 72–80% reduction in headspace NH_3 when using biochar produced from pyrolysis at 600°C [23]. Result for both these studies appeared to be biochar-type specific with other types of biochars showing minimal performance.

6c. The Cascading Benefits Pathway

Carbon-Kai's feed-through model creates a sequential on-farm benefit chain:

- Carbon-Kai manufacturing diverts radiata pine biomass from fates where it decays or burns → carbon is locked in the solid form of a stable biochar instead of being returned to the atmosphere as CO_2.
- Carbon-Kai is fed to cows → modulates rumen fermentation, reducing enteric CH_4 emission by an estimated 20–47% (in vitro trial indications with in vivo validation trials planned for September 2026).
- Carbon-Kai transits the digestive system → adsorbs toxins and parasites during passage.
- Carbon-Kai in manure → reduces NH_3 and N_2O losses during storage and field application.
- Carbon-Kai in pasture soil via manure → sequesters carbon long-term; improves fertility; reduces nitrate leaching.

7. POSITIONING FOR SPROUT ACCELERATOR ENGAGEMENT

- Carbon-Kai's mineral co-formulation is a second-generation product architecture which is distinguishable from standard biochars and activated carbons. Carbon-Kai is an engineered solid which combines feed-safe ingredients to provide large surfaces and catalytic functionality with the aim of improving rumen function.

- Unlike single-mode methane inhibitors currently being commericalised, Carbon-Kai has potential co-benefits across a whole-farm GHG profile through the cascading benefits pathway to ultimately increase stable soil carbon.

- The feed-through carbon sequestration model involves durable solid carbon passing from the ruminant's digestive system into manure and then applied to pasture. Cascading environmental and economic benefits can be achieved as the biochar carbon moves towards soil sequestration.

- In vitro trial data indicates that the most promising Carbon-Kai formulation can achieve better methane reductions than the activated carbon use in a recently published University of Southern Queensland trial. That Australian trial reported 30–40% lower methane emissions with the addition of activated carbon when compared to the control herd, the highest reported for an in vivo study on dairy cattle with biochar or activated carbon feeding.

- Milk productivity gains (additional volume, fat, and protein) were observed in vivo in that University of Southern Queensland trial with activated carbon addition. This provides the basis for anticipating production benefits from feeding Carbon-Kai to dairy cattle. This will need to be investigated and validated with well-designed in vivo trials under New Zealand conditions.

- Carbon-Kai does not involve halogenated organic compounds or added nitrate compounds. This avoids any concerns about animal toxicity or the contamination of meat, milk, or aquifers [24][25].

- Manaaki Whenua — Landcare Research has conducted NZ-specific soil N_2O and nitrate leaching trials, providing a local scientific evidence base for MPI and Sprout Accelerator engagement [16].

- Carbon-Kai's formal in vivo scientific trial (planned for September 2026) will generate NZ-specific dairy data to transition internal findings to peer-validated evidence.

Carbon-Kai: Evidence Summary Table

Compiled from Carbon-Kai Scientific Evidence Review, May 2026 | Sources cited correspond to document reference list

ENTERIC METHANE REDUCTION				
Enteric methane reduction	Activated carbon provides high surface area for microbes, more efficient redox reactions via direct electron transfer.	Al-Azzawi (2021) [13] Activated carbon at 0.5%, 1%, and 2% in vitro, fermentation of ruminal fluid from cattle.	Up to 62% reductions in methane production	PhD thesis In vitro
Enteric methane reduction	As above + suppression of methanogenic archaea	Al-Azzawi et al. (2021) [12] Activated carbon at 0.5% DMI, 180-head dairy herd, Queensland. Barn-level methane monitoring during milking	30–40% reduction in CH_4 (milking shed measurements)	Peer-reviewed in vivo
Enteric methane reduction	Not clear: Biofilm formation, altering rumen fermentation, microbial community, methane absorption, increased methanotrophs, alternative hydrogen sinks discussed	Martinez-Fernandez et al. (2024) [6] — 12 steers in methane collection chambers, two biochar-mineral formulations dosed at different levels up to ~2.4% DMI	9.5% and 12% reduction at ~0.6% and ~2.4% DMI (controlled chamber trial); no significant effect in outdoor herd trial	Peer-reviewed in vivo
Enteric methane reduction	Conductive surfaces for microbes, more efficient redox reactions via direct electron transfer. Additional surfaces, redox functionality, and potential acceptors of electrons/hydrogen from mineral additions and processing.	Carbon-Kai internal in vitro fermentation trials (2025) Carbon-Kai mineral co-formulation vs. reference activated carbon (USQ material)	9.3% (steer sample) and 25% (bull sample) less CH_4 vs. reference activated carbon; reference AC achieved up to 62% reduction vs. control in vitro [13]	Internal in vitro
Methanogen population reduction	Shift in rumen/manure microbial community away from methanogenic archaea	Al-Azzawi et al. (2021) [12] — 16S rRNA gene sequencing of manure from dairy herd given activated carbon at 0.5% DMI.	~30% reduction in methanogenic flora; relative increase in non-methanogenic species; significant increase in species richness and abundance	Peer-reviewed in vivo
MILK PRODUCTIVITY				
Milk volume increase	Rumen energy reallocation — methane energy redirected to more productive pathways	Al-Azzawi et al. (2021) [12] Al-Azzawi (2021) [13]	+3.43% daily milk production	Peer-reviewed in vivo / PhD thesis In vitro
Milk protein increase	Improved rumen fermentation efficiency	Al-Azzawi et al. (2021) [12]	+2.63% milk protein	Peer-reviewed in vivo
Milk fat increase	Improved rumen fermentation efficiency	Al-Azzawi et al. (2021) [12]	+6.32% milk fat	Peer-reviewed in vivo
Body weight / feed efficiency gains	Toxin adsorption; improved gut health; more efficient digestion; more efficient redox reactions via direct electron transfer; biofilm formation	Multiple biochar supplementation trials across cattle, pigs, goats, sheep, poultry [1][2][3]	Improved weight gains reported; effect most pronounced where diet quality is variable or toxin-impacted	Peer-reviewed (review) multiple species in vivo
ANIMAL HEALTH				
Gut health & toxin adsorption	High surface area adsorbs mycotoxins, bacterial toxins, ammonia, heavy metals, pesticides, PAHs in digestive tract	Schmidt et al. (2019) [1]; Kalus et al. (2019) [2]; Kazemi (2025) [3]	Reduced bioavailability of harmful substances; liver, kidney and immune protection reported	Peer-reviewed (review) multiple species

Pathogen suppression	Shift in gut microbiome away from disease-causing species	Schmidt et al. (2019) [1]; Kalus et al. (2019) [2]; Kazemi (2025) [3]	Suppression of C. botulinum, E. coli, Salmonella enterica, Campylobacter jejuni reported across multiple animal species	Peer-reviewed (review) multiple species in vivo
Internal parasite reduction	Mechanism not clear; adsorption proposed	Schmidt et al. (2019) [1]; anecdotal accounts	Reduced worm burden in treated animals reported in a small number of publications; many anecdotal accounts	Limited peer-reviewed + anecdotal
SOIL & PASTURE				
Soil carbon sequestration	Feed-through pathway — biochar passes intact through digestive system into manure, applied to pasture.	Walz, Dittmann & Leifeld (2026) [14] — dairy cow feeding trials with biochar recovery analysis; cascading approach also summarised by Schmidt et al. (2019) [1]	70–90% of ingested biochar recovered intact in manure; condensed aromatic carbon structures confirm long-term stability	Peer-reviewed in vivo / Peer-reviewed (review)
Soil fertility & nitrate leaching reduction	Biochar increases CEC, water retention, nutrient retention, microbial diversity; adsorbs nitrate	Manaaki Whenua Landcare Research (2025) [16] — NZ dairy farm soil trial; Borchard et al. (2019) [18]; cascading approach summarised by Schmidt et al. (2019) [1]	Major increase in soil carbon; significant reduction in topsoil nitrate-N concentrations at high application rate (NZ field trial)	Peer-reviewed (NZ field) / Peer-reviewed (review)
WHOLE-FARM GREENHOUSE GAS				
Nitrous oxide (N_2O) reduction	Biochar increases nosZ-gene prevalence in soil microbiome — terminal reduction of N_2O to inert N_2; biochars provide porosity, surface areas, cation exchange capacity and increase pH.	Taghizadeh-Toosi et al. (2011) [21]; Harter et al. (2014) [20]; Borchard et al. (2019) [18]; Zhong et al. (2025) [19] Global meta-analyses support N_2O reductions across soil types	Nitrous oxide flux from ruminant urine patch reduced by >50% (NZ pasture context). Meta-analyses: N2O emissions reduction was 19%–38%, though one meta analysis concluded that this can decline rapidly after first year.	Peer-reviewed in situ / Peer-reviewed (meta)
Ammonia (NH_3) reduction — manure storage	Biochar cover adsorbs NH_3 from manure surface; acid-activated biochar enhances effect	Baral et al. (2023) [22] — acid-activated biochar floating cover; Dougherty et al. (2017) [23] — biochar covers over manure lagoons; additional evidence reviewed in Schmidt et al. (2019) [1]	37–51% NH_3 reduction (first month), 25–28% over 4 months [22]; 72–80% headspace NH_3 reduction with 600°C biochar addition [23]. Effect is biochar-type specific.	Peer-reviewed in situ / Peer-reviewed (review)

REFERENCES

[1] Schmidt, H.-P.; Hagemann, N.; Draper, K.; Kammann, C., The use of biochar in animal feeding. PeerJ, 2019, 7, e7373.

[2] Kalus, K.; Koziel, A. J.; Opaliński, S., A Review of Biochar Properties and Their Utilization in Crop Agriculture and Livestock Production. Applied Sciences 2019, 9, (17).

[3] Kazemi M. Biochar in Animal Agriculture: Enhancing Health, Efficiency and Environmental Sustainability. Veterinary medicine and science, 2025, 11(6), e70629. https://doi.org/10.1002/vms3.70629

[4] Dittmann et al. The effect of biochar supplementation on feed utilization, milk production and methane emission in lactating dairy cows. Animal Feed Science and Technology. 2024, 318, 116127, https://doi.org/10.1016/j.anifeedsci.2024.116127.

[5] Ungerfeld, E.M. Metabolic Hydrogen Flows in Rumen Fermentation: Principles and Possibilities of Interventions. Frontiers in microbiology, 2020, 11, 589. https://doi.org/10.3389/fmicb.2020.00589.

[6] Martinez-Fernandez, G.; Kinley, R.D.; Smith, W.J.M,; Simington J.; Joseph, S.; Tahery, S.; Durmic, Z.; and Vercoe, P. Effect of fit-for-purpose biochars on rumen fermentation, microbial communities, and methane production in cattle. Frontiers in Microbiology. 2024, 15:1463817. doi: 10.3389/fmicb.2024.1463817.

[7] Tahery, S.; Parra, M.C.; Munroe, P. et al. Developing an activated biochar-mineral supplement for reducing methane formation in anaerobic fermentation. Biochar 7, (26), 2025. https://doi.org/10.1007/s42773-024-00403-5.

[8] Sun, T.; Guzman, J. J. L.; Seward, J. D.; Enders, A., Yavitt, J. B.; Lehmann, J.; & Angenent, L. T. Suppressing peatland methane production by electron snorkeling through pyrogenic carbon in controlled laboratory incubations. Nature communications, 2021, 12(1), 4119. https://doi.org/10.1038/s41467-021-24350-y.

[9] Leahy, S. C.; Janssen, P. H.; Attwood, G. T.; Mackie, R. I.; McAllister, T. A.; & Kelly, W. J. (2022). Electron flow: key to mitigating ruminant methanogenesis. Trends in microbiology, 30(3), 209–212. https://doi.org/10.1016/j.tim.2021.12.005

[10] Chen, S., Rotaru, A. E., Shrestha, P. M., Malvankar, N. S., Liu, F., Fan, W., Nevin, K. P., & Lovley, D. R. (2014). Promoting interspecies electron transfer with biochar. Scientific reports, 4, 5019. https://doi.org/10.1038/srep05019.

[11] Zhang, K., Deng, Y., Liu, Z., Feng, Y., Hu, C., & Wang, Z. (2023). Biochar Facilitated Direct Interspecies Electron Transfer in Anaerobic Digestion to Alleviate Antibiotics Inhibition and Enhance Methanogenesis: A Review. International journal of environmental research and public health, 20(3), 2296. https://doi.org/10.3390/ijerph20032296.

[12] Al-Azzawi, M.; Bowtell, L.; Hancock, K.; Preston, S., Addition of Activated Carbon into a Cattle Diet to Mitigate GHG Emissions and Improve Production. Sustainability 2021, 13, (15), 8254.

[13] Al-Azzawi, M. S. Addition of Activated Carbon in a Cattle Diet to Mitigate GHG Emissions and Ameliorate Ingested Toxins, 2021, PhD Thesis at the University of Southern Queensland.

[14] Walz, I.L.; Dittmann, M.; & Leifeld, J. Recovery and composition of biochar after feeding to cattle, 2026, Biochar 8, 13. https://doi.org/10.1007/s42773-025-00507-6.

[15] Pandian K., Vijayakumar S., Mustaffa MRAF, Subramanian P., and Chitraputhirapillai S. (2024) Biochar – a sustainable soil conditioner for improving soil health, crop production and environment under changing climate: a review. Front. Soil Sci. 4:1376159. doi: 10.3389/fsoil.2024.1376159

[16] Manaaki Whenua Landcare Research Group. Biochar incorporation into soils: initial effects and challenges. https://www.landcareresearch.co.nz/publications/soil-horizons/soil-horizons-articles/biochar-incorporation-into-soils-initial-effects-and-challenges. 2025.

[17] https://www.epa.gov/ghgemissions/understanding-global-warming-potentials.

[18] Borchard, N.; Schirrmann, M.; Cayuela, M. L.; Kammann, C.; Wrage-Mönnig, N.; Estavillo, J. M.; Fuertes-Mendizábal, T., Sigua, G.; Spokas, K.; Ippolito, J. A.; & Novak, J. Biochar, soil and land-use interactions that reduce nitrate leaching and N2O emissions: A meta-analysis. The Science of the Total Environment, 2019, 651(Pt 2), 2354–2364. https://doi.org/10.1016/j.scitotenv.2018.10.060.

[19] Zhong, L.; Wang, P.; Gu, Z. et al. Biochar reduces N2O emission from fertilized cropland soils: a meta-analysis. Carbon Research, 2025, 4, 31. https://doi.org/10.1007/s44246-025-00198-5

[20] Harter, J.; Krause, H. M.; Schuettler, S.; Ruser, R.; Fromme, M.; Scholten, T.; Kappler, A.; & Behrens, S. Linking N2O emissions from biochar-amended soil to the structure and function of the N-cycling microbial community, 2014, The ISME Journal, 8(3), 660–674. https://doi.org/10.1038/ismej.2013.160.

[21] Taghizadeh-Toosi, A.; Clough, T. J.; Condron, L. M.; Sherlock, R. R.; Anderson, C. R.; & Craigie, R. A. Biochar incorporation into pasture soil suppresses in situ nitrous oxide emissions from ruminant urine patches. 2011, Journal of environmental quality, 40(2), 468–476. https://doi.org/10.2134/jeq2010.0419.

[22] Baral, K. R.; McIlroy, J.; Lyons, G.; & Johnston, C. The effect of biochar and acid activated biochar on ammonia emissions during manure storage, Environmental pollution, 2023, 317, 120815. https://doi.org/10.1016/j.envpol.2022.120815.

[23] Dougherty, B.; Gray, M.; Johnson, M. G.; & Kleber, M. Can Biochar Covers Reduce Emissions from Manure Lagoons While Capturing Nutrients?. Journal of environmental quality, 2017, 46(3), 659–666. https://doi.org/10.2134/jeq2016.12.0478.

[24] Biesterbos, J.W.H., den Braver, M.W. and Sijm, D.T.H.M. (2025), Risks of bromoform by adding seaweed of the genus Asparagopsis to feed for ruminants. Food Risk Assess Europe, 3: 0072E. https://doi.org/10.2903/fr.efsa.2025.FR-0072

[25] Malyugina, S.; Holik, S.; and Horky, P.; Mitigation strategies for methane emissions in ruminant livestock: a comprehensive review of current approaches and future perspectives. 2025, Frontiers in Animal Science, 6:1610376. https://doi.org/10.3389/fanim.2025.1610376.

Re: Carbon-Kai Scientific Review

PL

Condron, Leo <Leo.Condron@lincoln.ac.nz>
To Raymond Dobbe

Reply | Reply All | Forward | ...

Mon 8/06/2026 10:42 am

You replied to this message on 8/06/2026 11:32 am.
If there are problems with how this message is displayed, click here to view it in a web browser.

Dear Raymond:
As requested, I have reviewed the document you sent through on "Carbon-Kai in Livestock Systems".

The report provides a concise account of specific studies on the actual and potential beneficial impacts of including biochar in the diet of cattle with respect to its effects on rumen function and subsequent productivity and methane emissions. Clearly there is opportunity and potential to investigate the specific impacts of carbon-kai inputs on these processes, together with the subsequent effects on soil processes (carbon sequestration, nitrous oxide emission) following excretion. It is, however, very important that this research should include detailed investigation of the mechanisms responsible for any measured significant impacts.

I am happy to assist your company further but only in the capacity as a Research Advisor - in this regard I would be happy to assist in the development and implementation of appropriate research.

Regards
Leo Condron

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