Produção de metano ruminal e estratégias de mitigação

Luciano Cabral, Julia Carvalho, Emerson Miranda

UFMT

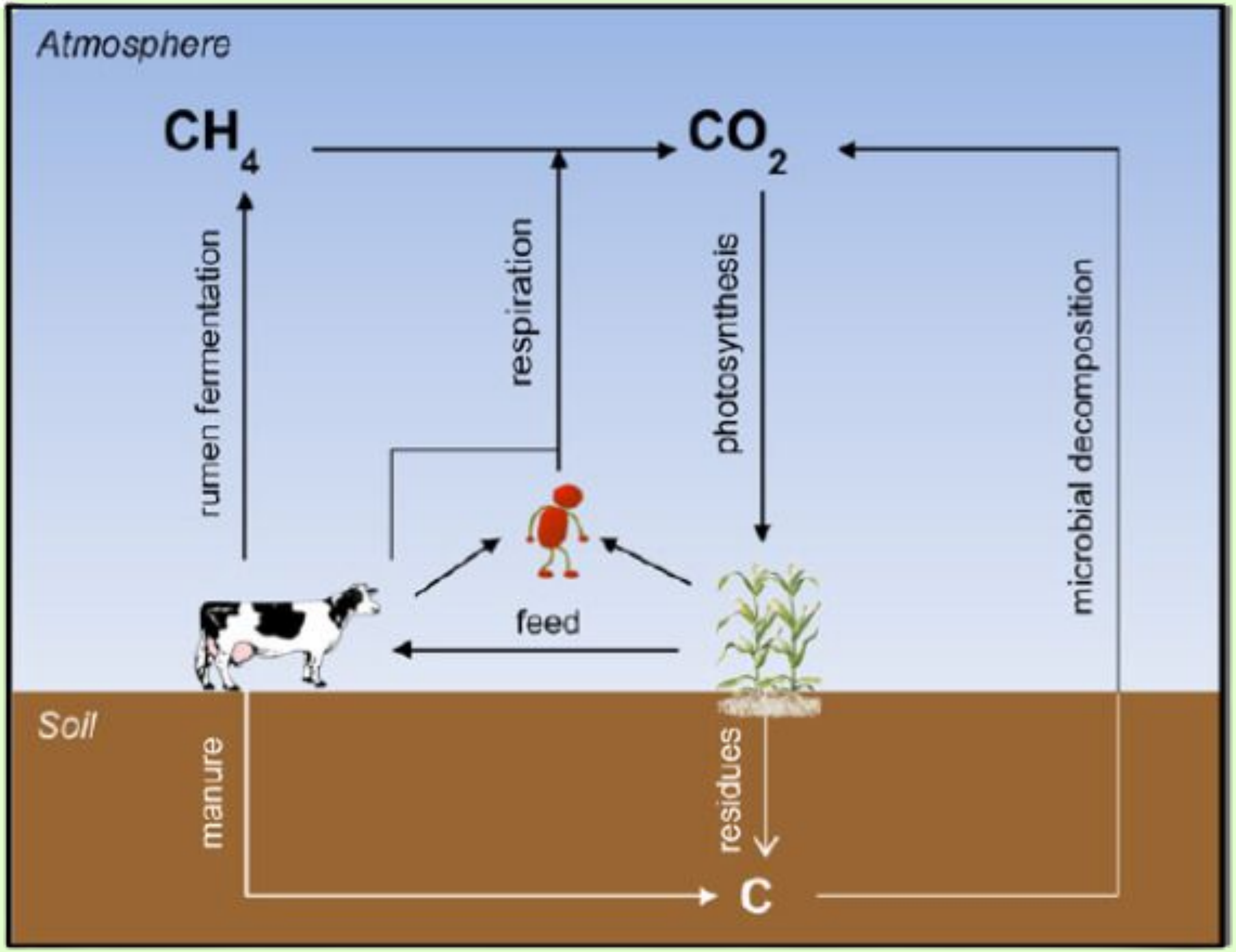
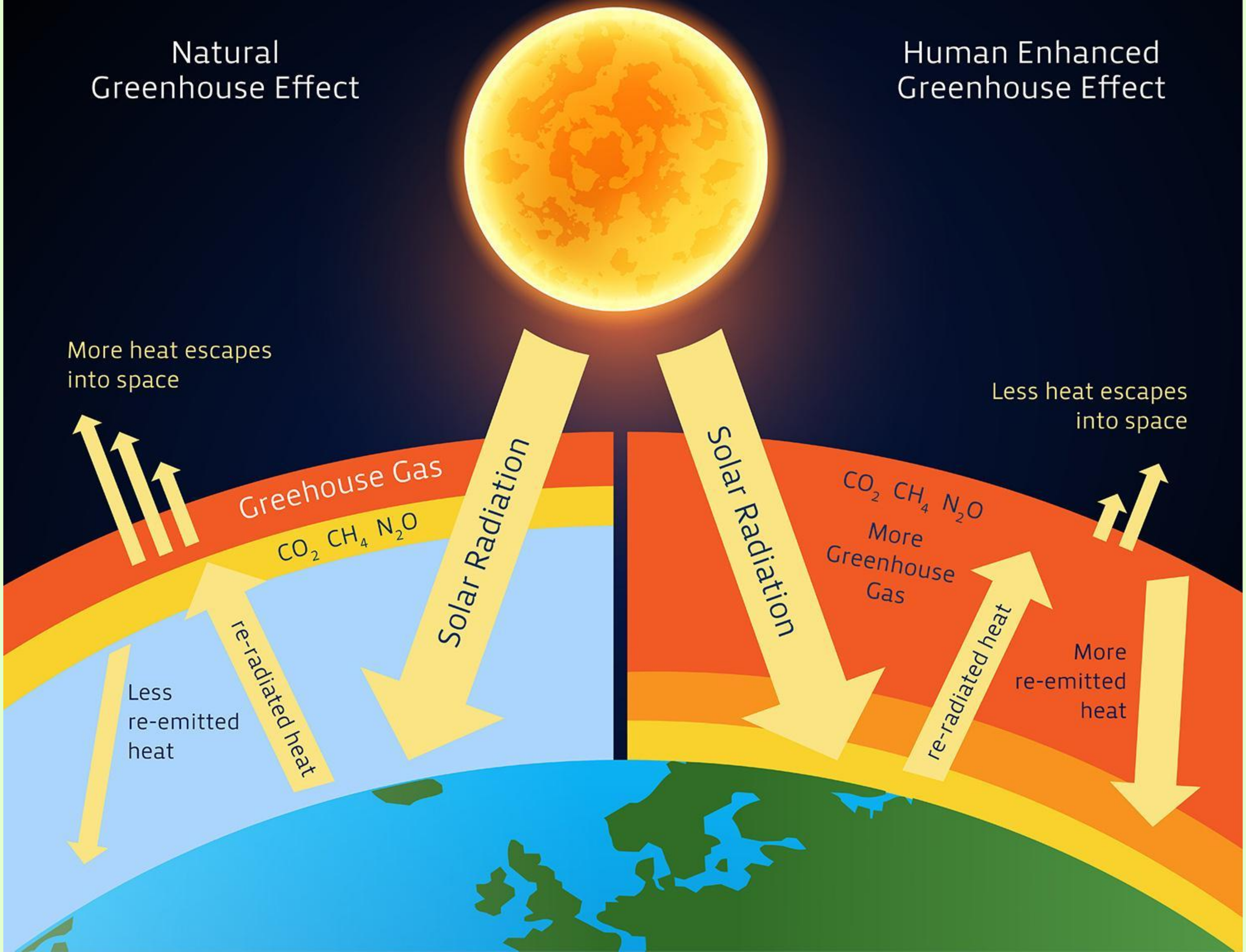
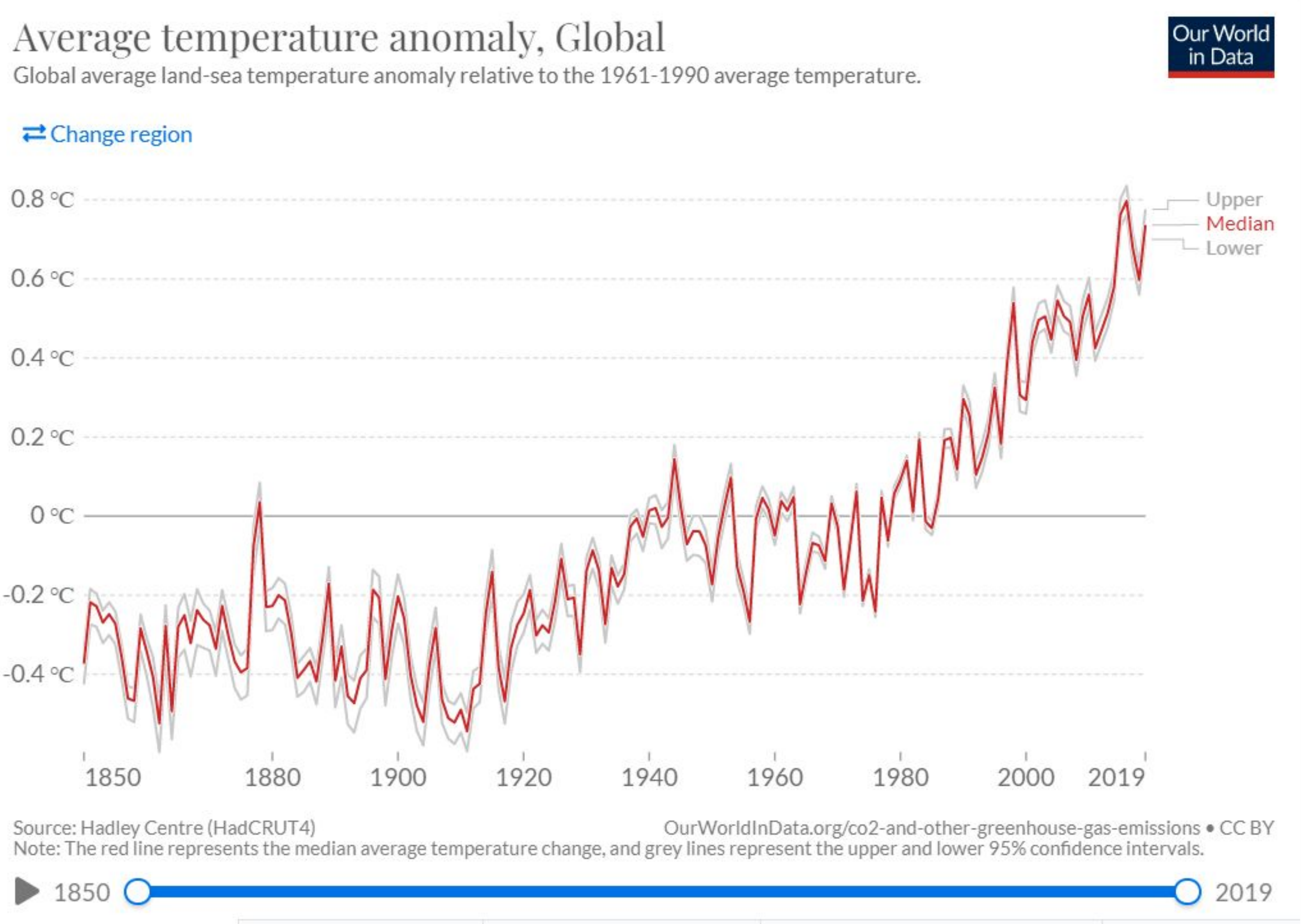


Figure 1. Conceptual illustration of C flows in an agroecosystem. Plants capture atmospheric CO2 in biomass, via photosynthesis. Some of his C is harvested and exported; the rest is returned to the soil as


Natural Greenhouse Effect
Human Enhanced Greenhouse Effect
More heat escapes into space
Greehouse Gas
CO$_2$ CH$_4$ N$_2$O
Solar Radiation
re-radiated heat
Less re-emitted heat
Solar Radiation
Less heat escapes into space
CO$_2$ CH$_4$ N$_2$O
More Greenhouse Gas
re-radiated heat
More re-emitted heat



Average temperature anomaly, Global

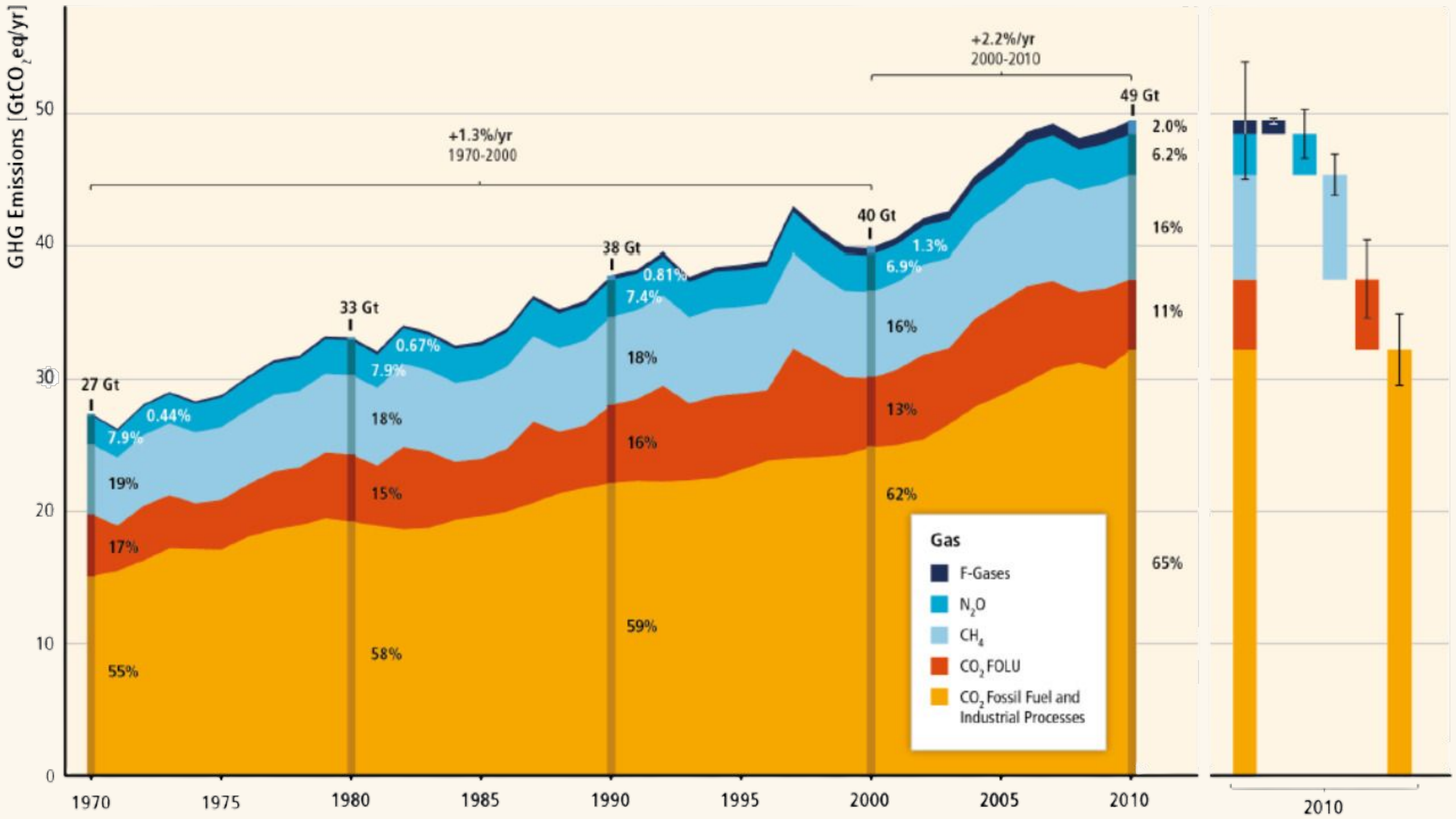
Global average land-sea temperature anomaly relative to the 1961-1990 average temperature.

Source: Hadley Centre (HadCRUT4)

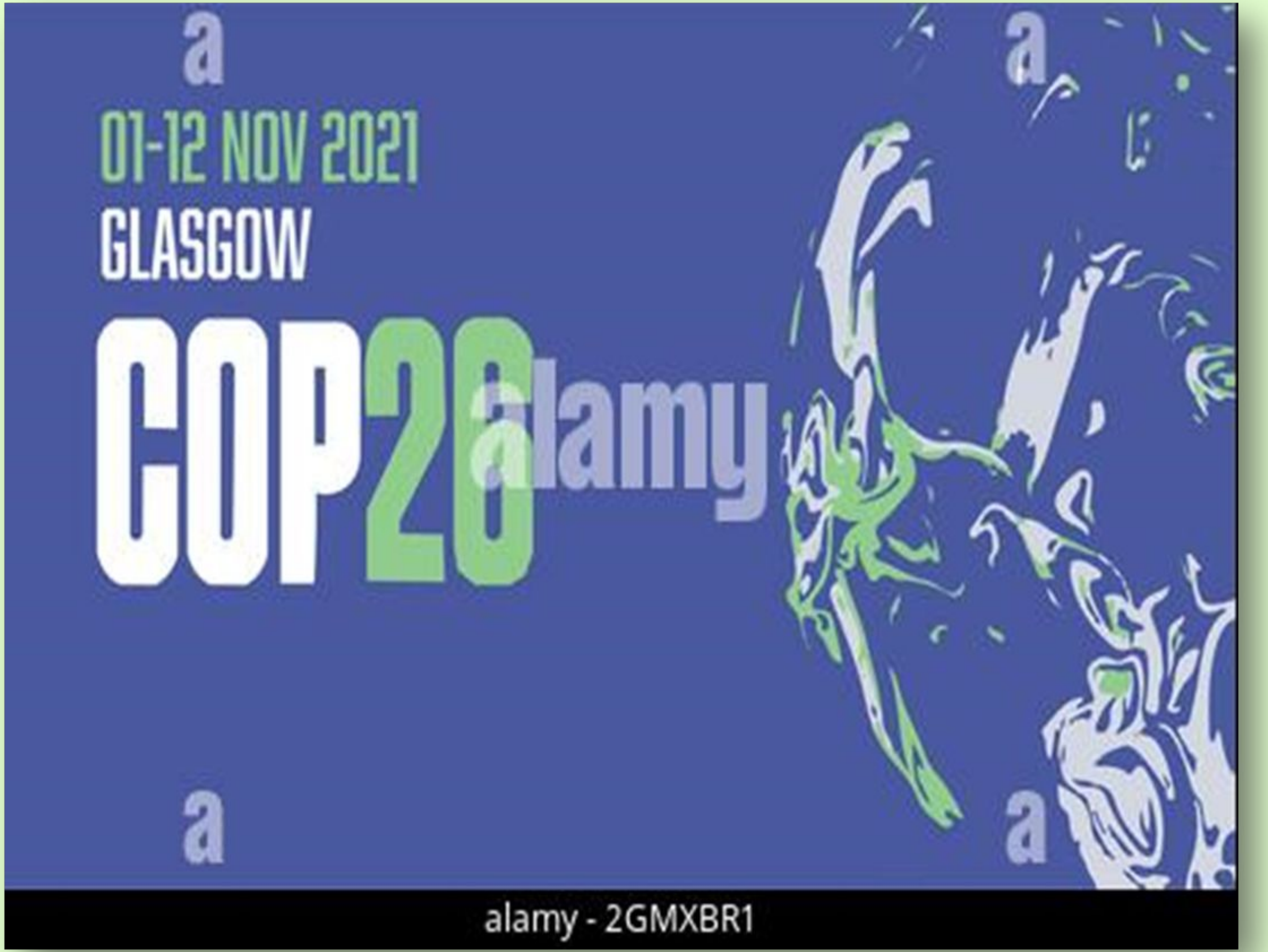
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

Note: The red line represents the median average temperature change, and grey lines represent the upper and lower 95% confidence intervals.

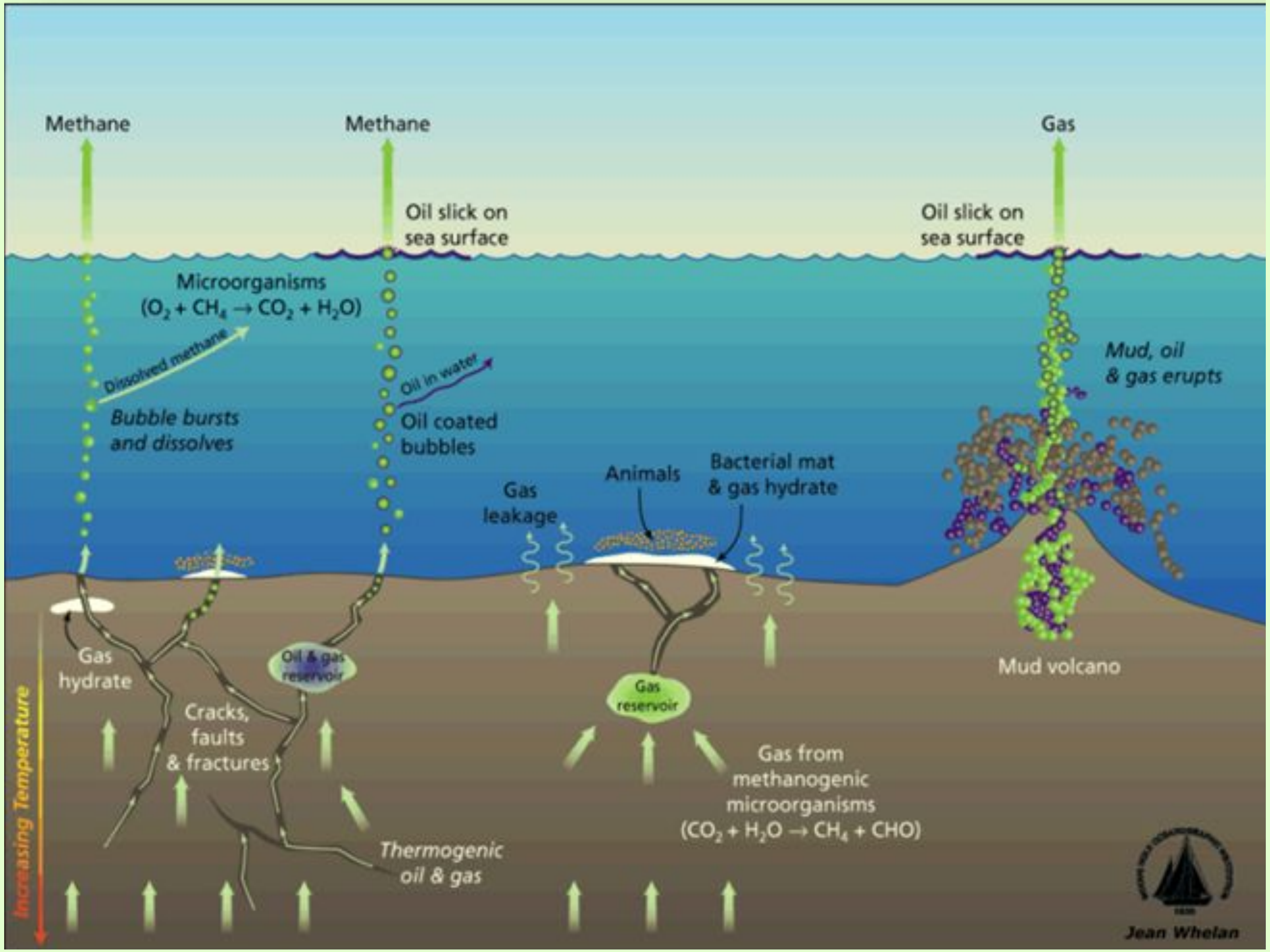
Total Annual Anthropogenic GHG Emissions by Groups of Gases 1970-2010



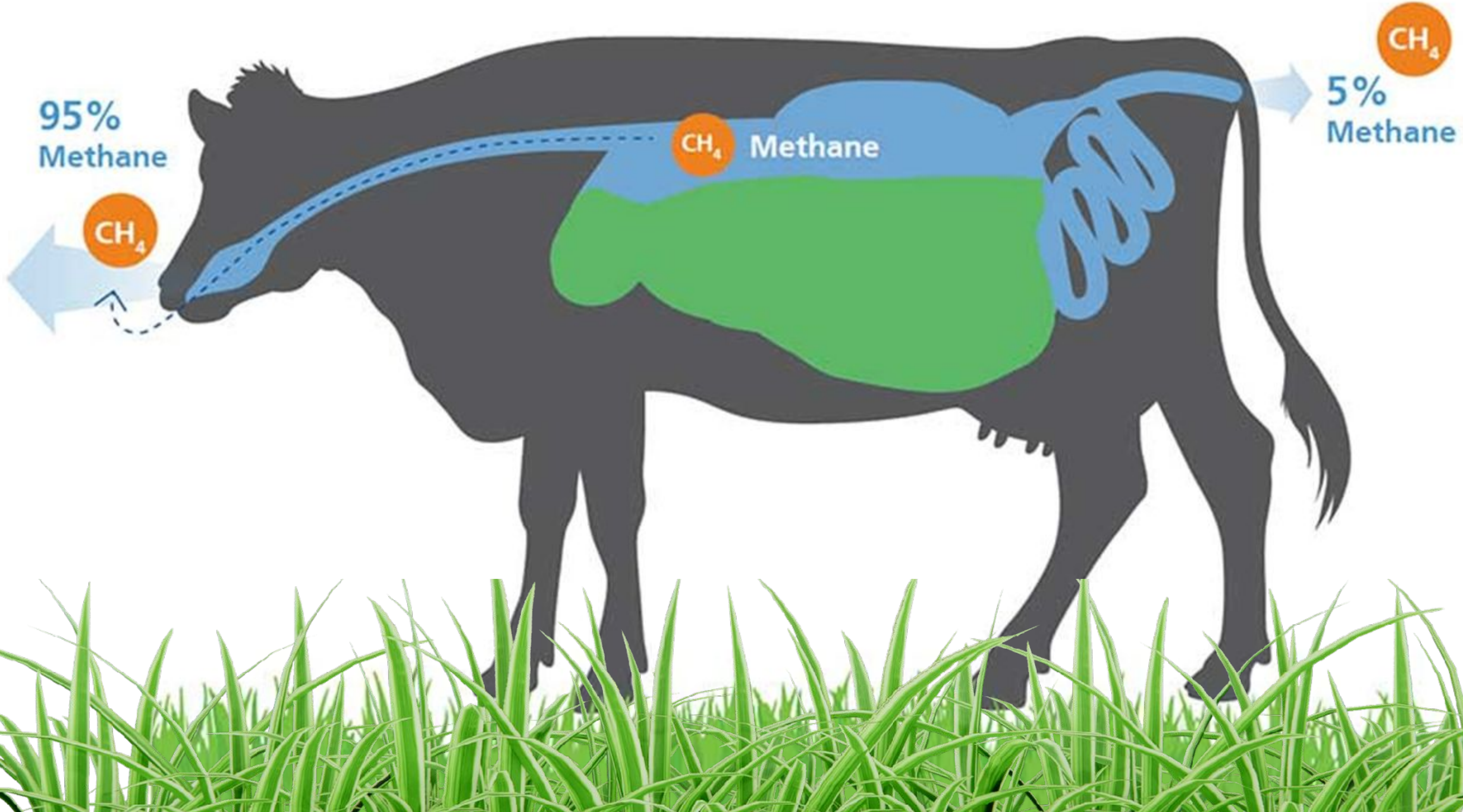
Edenhofer *et al.* (2014) – IPCC WGIII AR5


01-12 NOV 2021
GLASGOW
COP26
alamy
alamy - 2GMXBR1

ORIGEM DE METANO NO PLANETA



Rumen function diagram



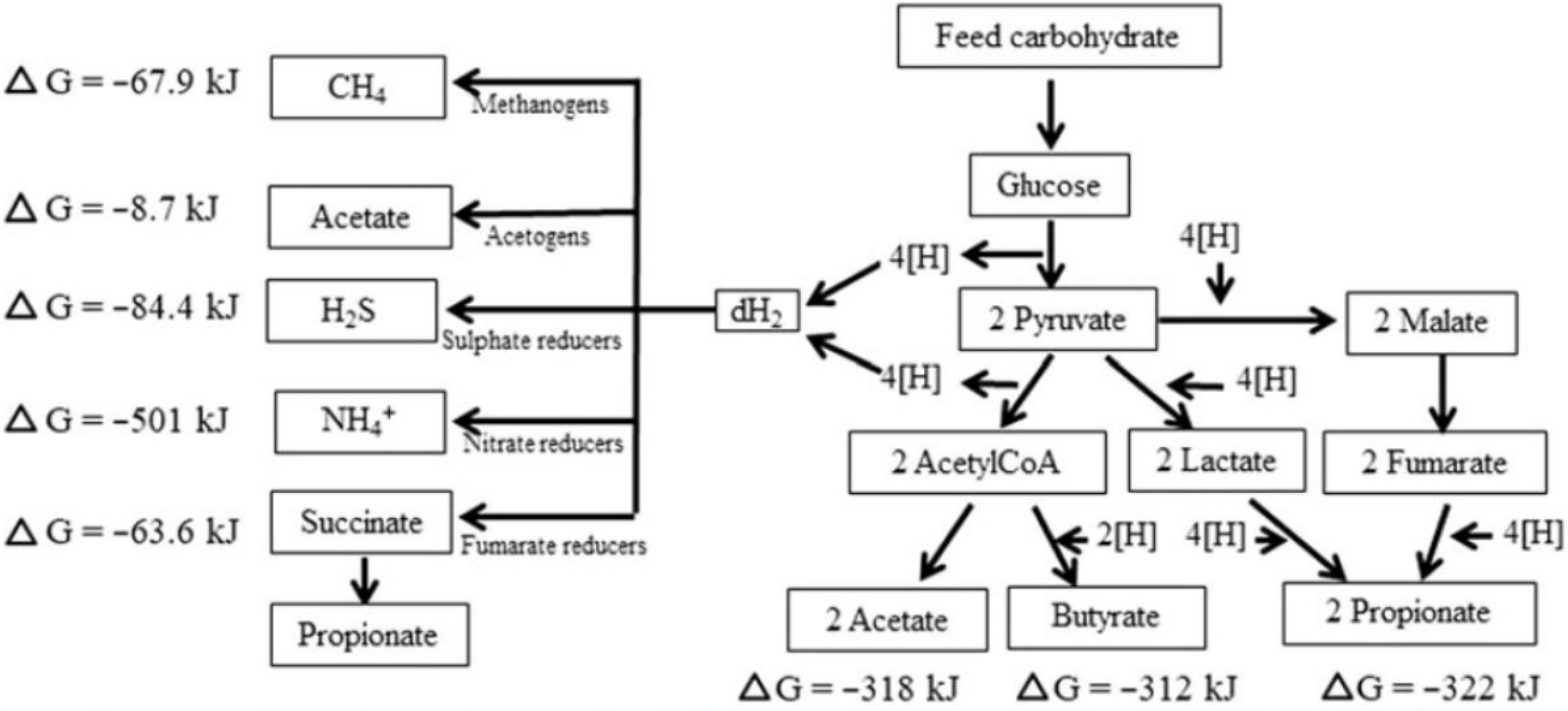


Figure 2 Scheme of the major pathways of rumen fermentation including generation and incorporation of metabolic hydrogen ([H]) and dihydrogen (H_2). Estimated Gibbs energy changes are based on Kohn and Boston (2000) and Ungerfeld and Kohn (2006) without considering ATP generation. Generation and incorporation of [H] are estimated based on 1 mol of glucose fermentation according to the following reactions: $C_6H_{12}O_6$ (glucose)→2 $C_3H_4O_3$ (pyruvate) + 2 [2H]; 2 $C_3H_4O_3$ + 2 HSCoA (non-esterified coenzyme A) → 2 C_2H_3OSCoA (acetyl coenzyme A) + 2 CO_2 + 4 [2H]; C_2H_3OSCoA + H_2O (water) →→ $C_2H_4O_2$ (acetate) + HSCoA; 2 C_2H_3OSCoA + 2 [2H] → $C_4H_8O_2$ (butyrate) + 2 HSCoA; 2 $C_3H_4O_3$ + 2 [2H] → 2 $C_3H_6O_3$ (lactate); 2 $C_3H_6O_3$ + 2 [2H] → 2 $C_3H_6O_2$ (propionate) + 2 H_2O; 2 $C_3H_4O_3$ + 2 [2H] + 2 CO_2 (carbon dioxide) → 2 $C_4H_6O_5$ (malate); 2 $C_4H_4O_4$ (fumarate) + 2 [2H] →→ 2 $C_3H_6O_2$ + 2 CO_2.

Animal (2020), **14:S1**, pp s2–s16 © Her Majesty the Queen in Right of Canada, as represented by the Minister of Agriculture and Agri-Food Canada 2020
doi:10.1017/S1751731119003100

animal

Review: Fifty years of research on rumen methanogenesis: lessons learned and future challenges for mitigation

K. A. Beauchemin[1†], E. M. Ungerfeld[2], R. J. Eckard[3] and M. Wang[4]

[1]Lethbridge Research and Development Centre, Agriculture and Agri-Food Canada, 5403 1st Avenue South, Lethbridge, Alberta, Canada, T1J 4B1; [2]Instituto de Investigaciones Agropecuarias INIA, Camino Cajón a Vilcún s/n km 10, Temuco, Chile; [3]Faculty of Veterinary and Agricultural Sciences, University of Melbourne, Melbourne, VIC 3010, Australia; [4]CAS Key Laboratory for Agro-Ecological Processes in Subtropical Region, National Engineering Laboratory for Pollution Control and Waste Utilization in Livestock and Poultry Production, Institute of Subtropical Agriculture, Chinese Academy of Sciences, Changsha, Hunan 410125, P. R. China

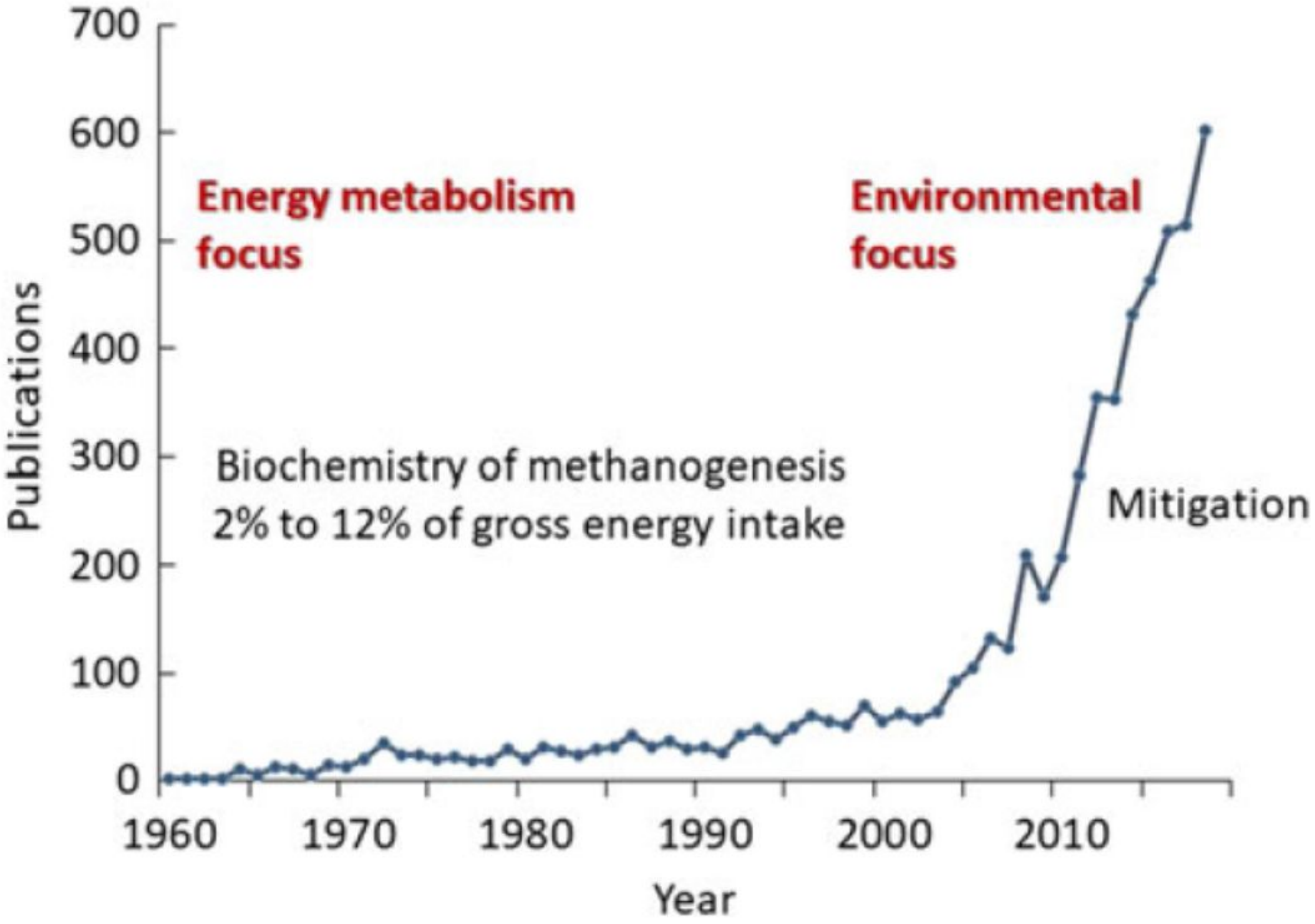
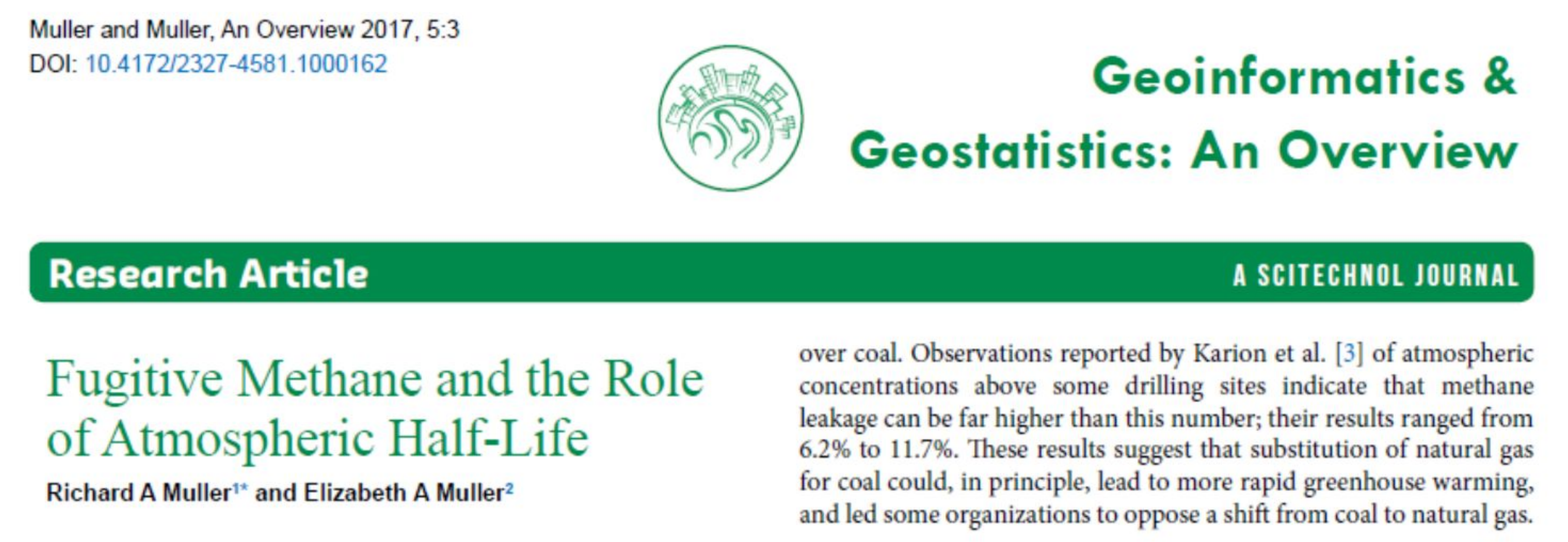


Figure 1 (colour online) Number of published papers related to enteric methanogenesis (Scopus search keywords: methane OR methanogenesis AND cow OR cattle OR sheep OR lamb OR rumen (total = 5845). A shift in research focus from energy metabolism to environment occurred in the early 2000s, indicating significant recent investment in CH_4 mitigation research.

2% a 12% da energia bruta consumida é convertida em CH4 entérico durante a digestão ruminal;

As emissões globais totais de GEE da pecuária (animais, esterco, produção de ração e expansão de terras em áreas florestais) são estimadas em 14,5% do total de emissões antropogênicas (Gerber et al., 2013);

O CH4 entérico de ruminantes contribui com aproximadamente 6% das emissões antropogênicas globais de GEE



Muller and Muller, An Overview 2017, 5:3
DOI: 10.4172/2327-4581.1000162

Geoinformatics &
Geostatistics: An Overview

Research Article A SCITECHNOL JOURNAL

Fugitive Methane and the Role of Atmospheric Half-Life

Richard A Muller[1*] and Elizabeth A Muller[2]

over coal. Observations reported by Karion et al. [3] of atmospheric concentrations above some drilling sites indicate that methane leakage can be far higher than this number; their results ranged from 6.2% to 11.7%. These results suggest that substitution of natural gas for coal could, in principle, lead to more rapid greenhouse warming, and led some organizations to oppose a shift from coal to natural gas.

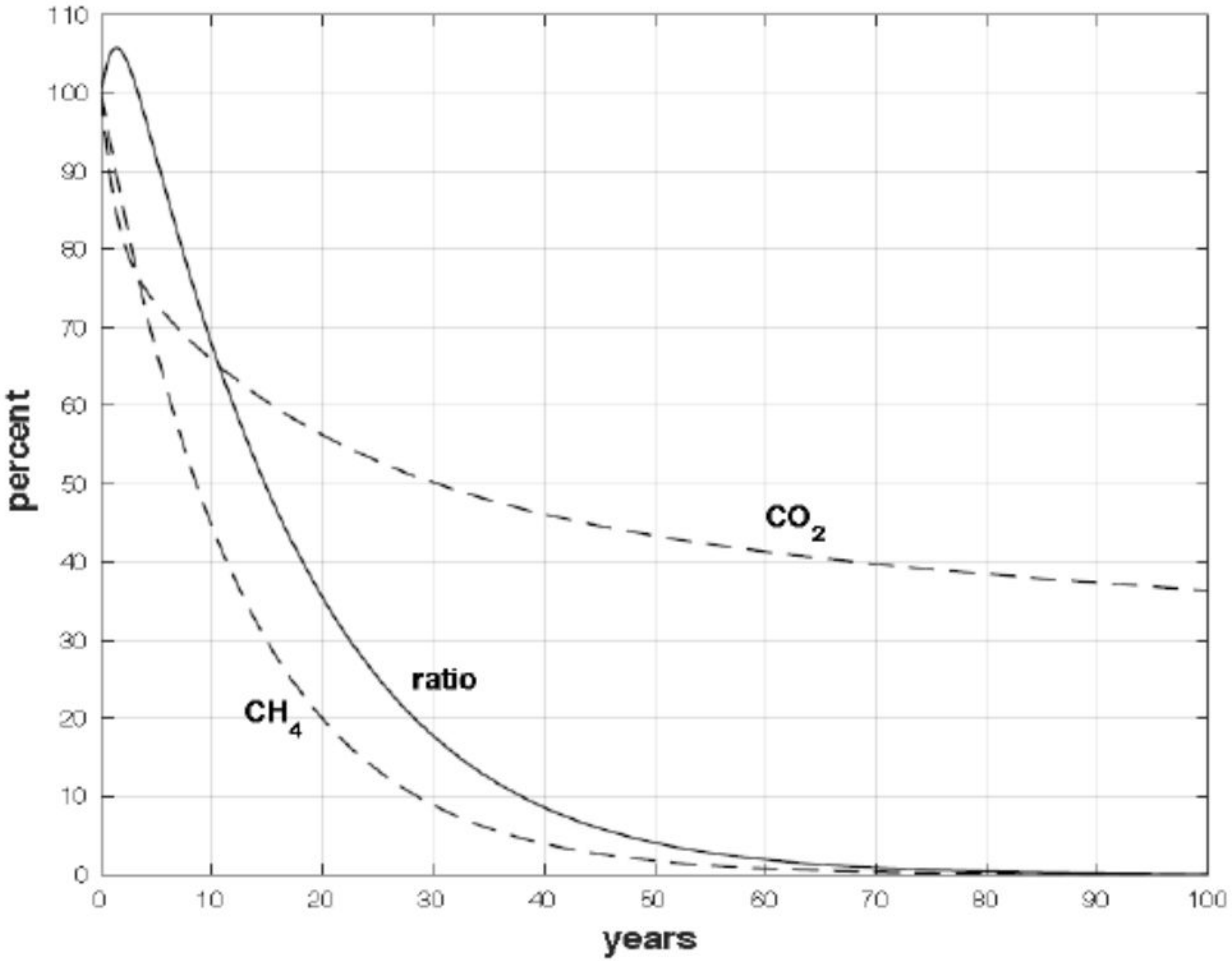
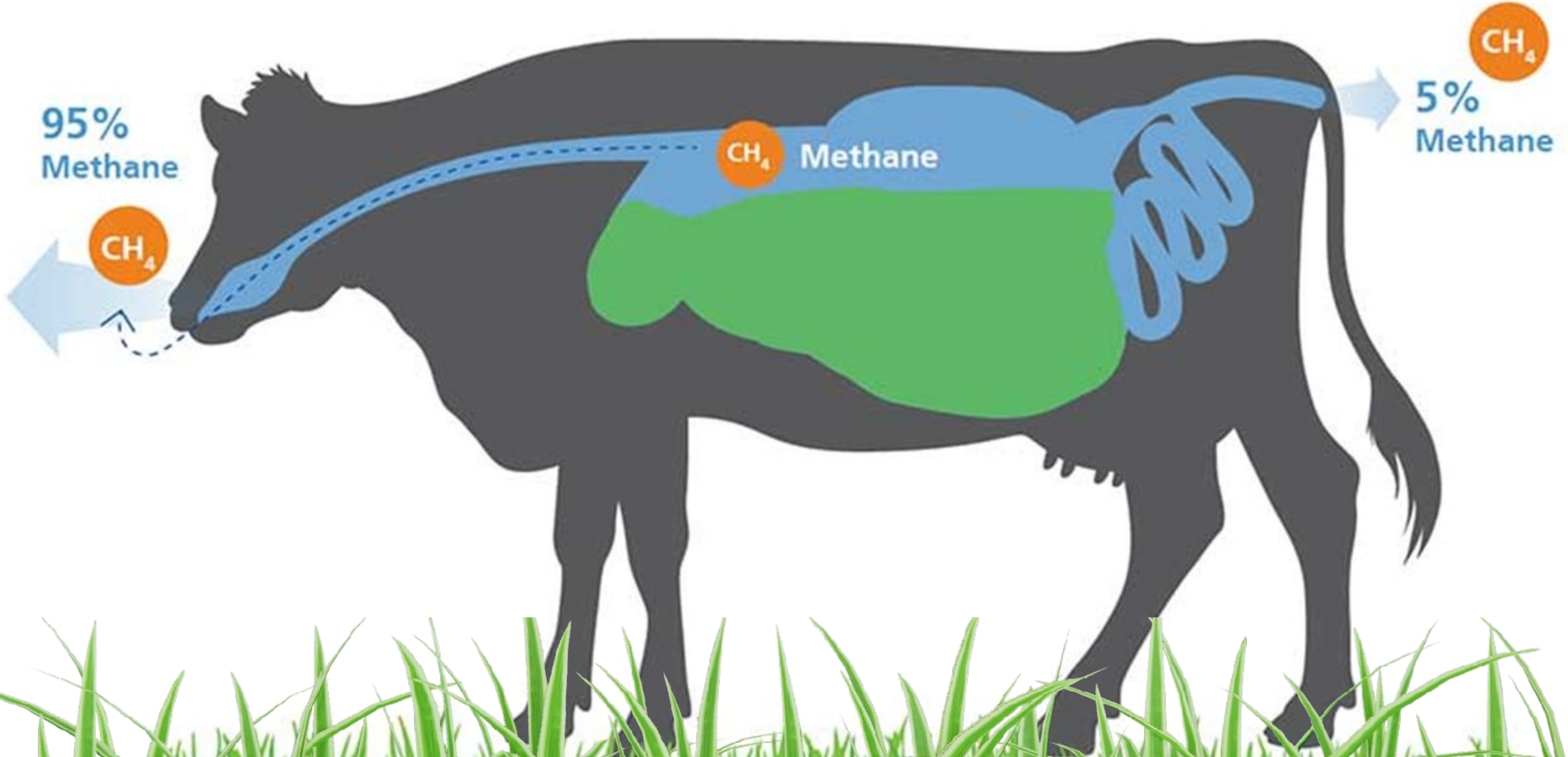


Figure 1: The persistence of carbon dioxide and methane in the atmosphere as a function of time. The chart begins when a pulse of the gas is injected into the atmosphere. The legacy effect of methane is miniscule compared to that of carbon dioxide.

Rumen function diagram



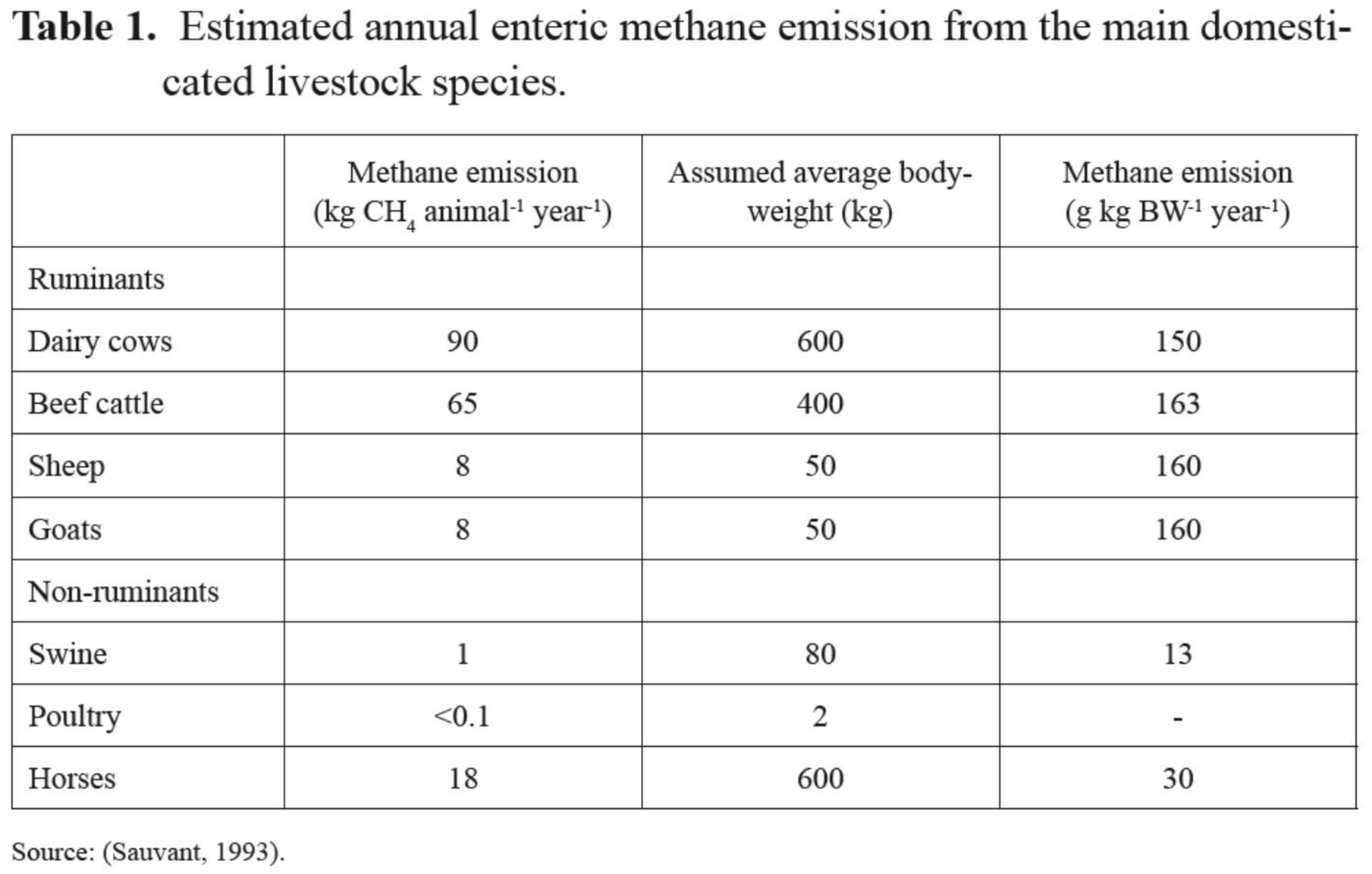
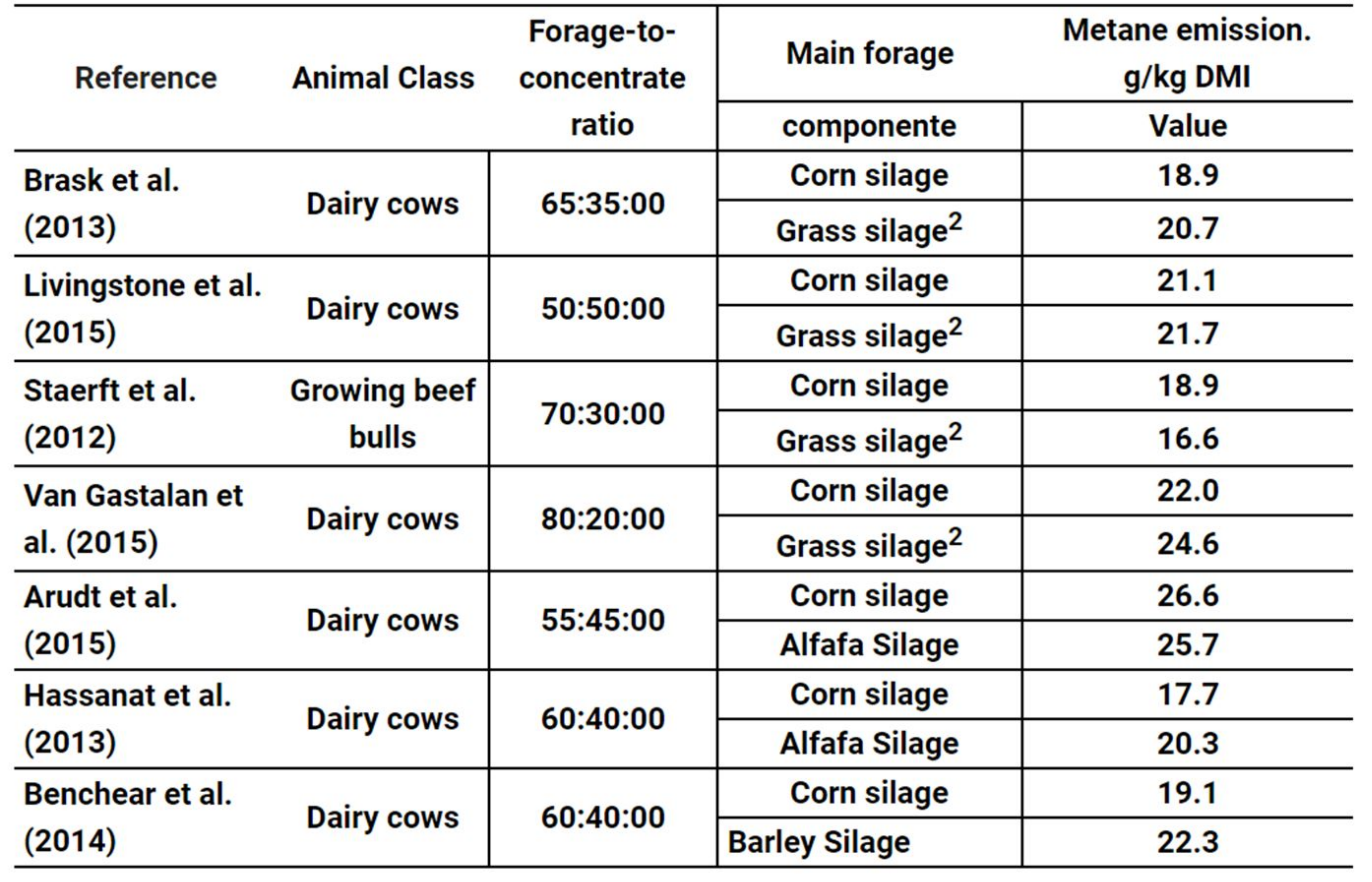


Table 1. Estimated annual enteric methane emission from the main domesticated livestock species.

	Methane emission (kg CH_4 animal^{-1} year^{-1})	Assumed average body-weight (kg)	Methane emission (g kg BW^{-1} year^{-1})
Ruminants			
Dairy cows	90	600	150
Beef cattle	65	400	163
Sheep	8	50	160
Goats	8	50	160
Non-ruminants			
Swine	1	80	13
Poultry	<0.1	2	-
Horses	18	600	30

Source: (Sauvant, 1993).



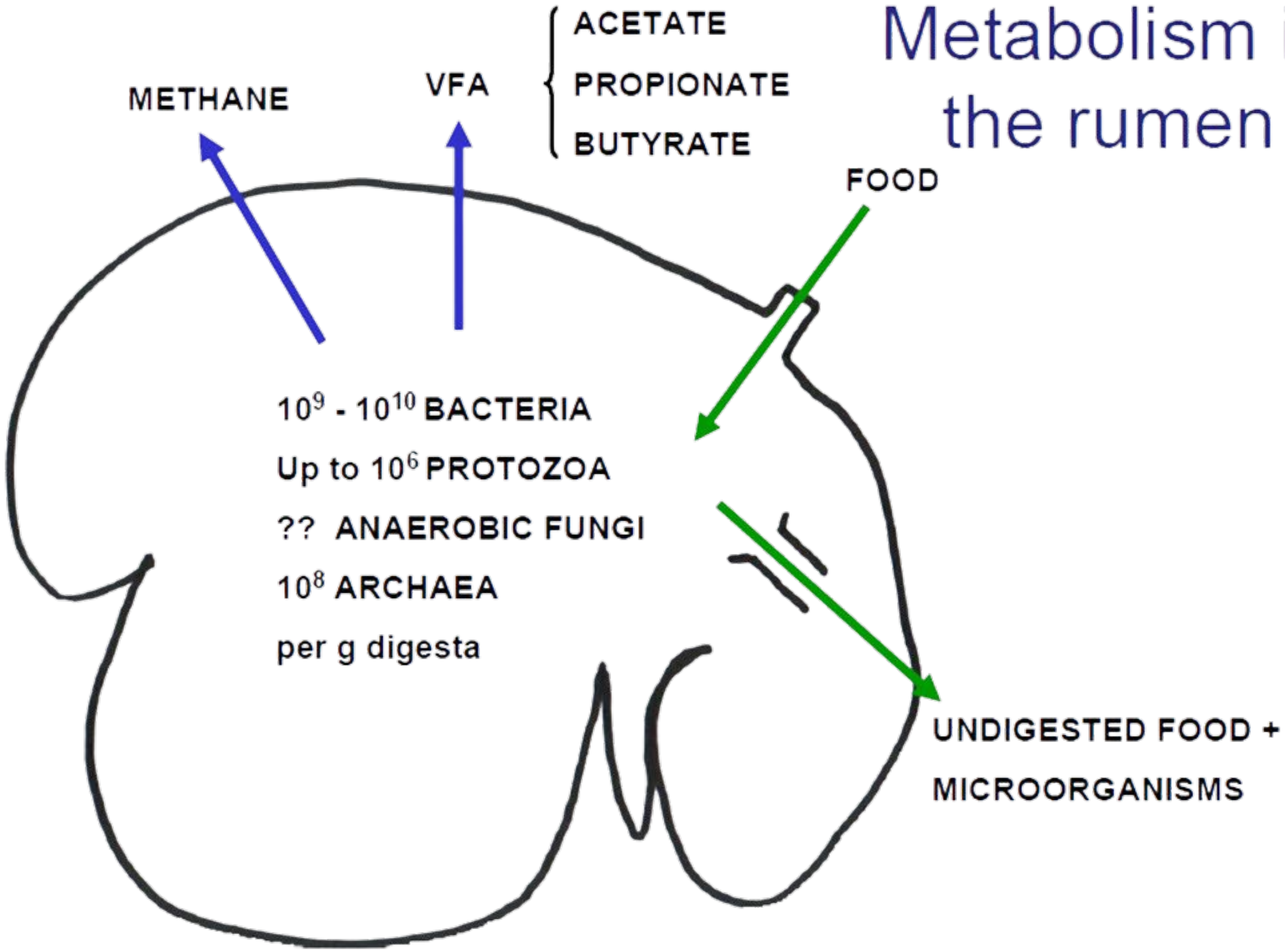
Reference	Animal Class	Forage-to-concentrate ratio	Main forage	Metane emission. g/kg DMI
			componente	Value
Brask et al. (2013)	Dairy cows	65:35:00	Corn silage	18.9
			Grass silage^2	20.7
Livingstone et al. (2015)	Dairy cows	50:50:00	Corn silage	21.1
			Grass silage^2	21.7
Staerft et al. (2012)	Growing beef bulls	70:30:00	Corn silage	18.9
			Grass silage^2	16.6
Van Gastalan et al. (2015)	Dairy cows	80:20:00	Corn silage	22.0
			Grass silage^2	24.6
Arudt et al. (2015)	Dairy cows	55:45:00	Corn silage	26.6
			Alfafa Silage	25.7
Hassanat et al. (2013)	Dairy cows	60:40:00	Corn silage	17.7
			Alfafa Silage	20.3
Benchear et al. (2014)	Dairy cows	60:40:00	Corn silage	19.1
			Barley Silage	22.3

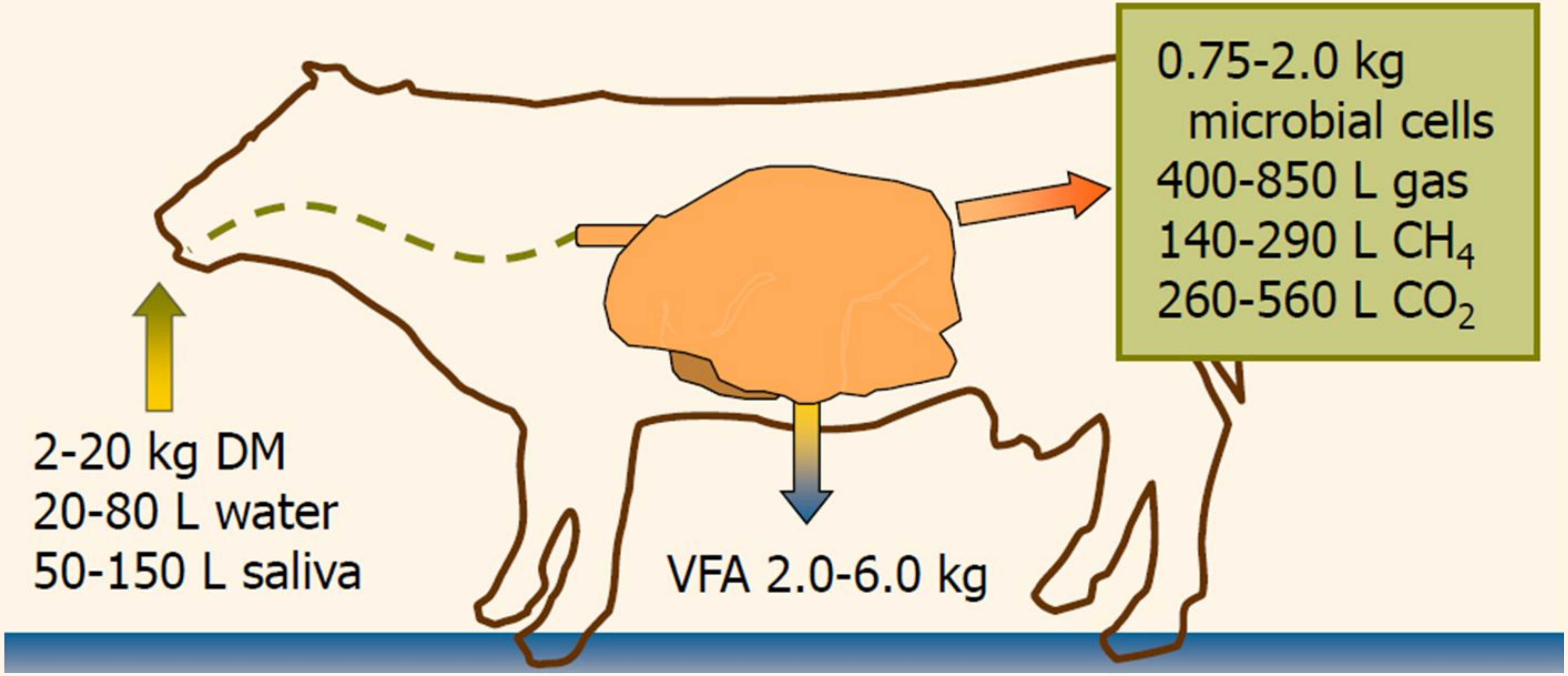
IPCC

Emissão total de CH4:
kg/animal/ano;

Intensidade de emissão de CH4: g/kg de produto;

Metabolism in the rumen





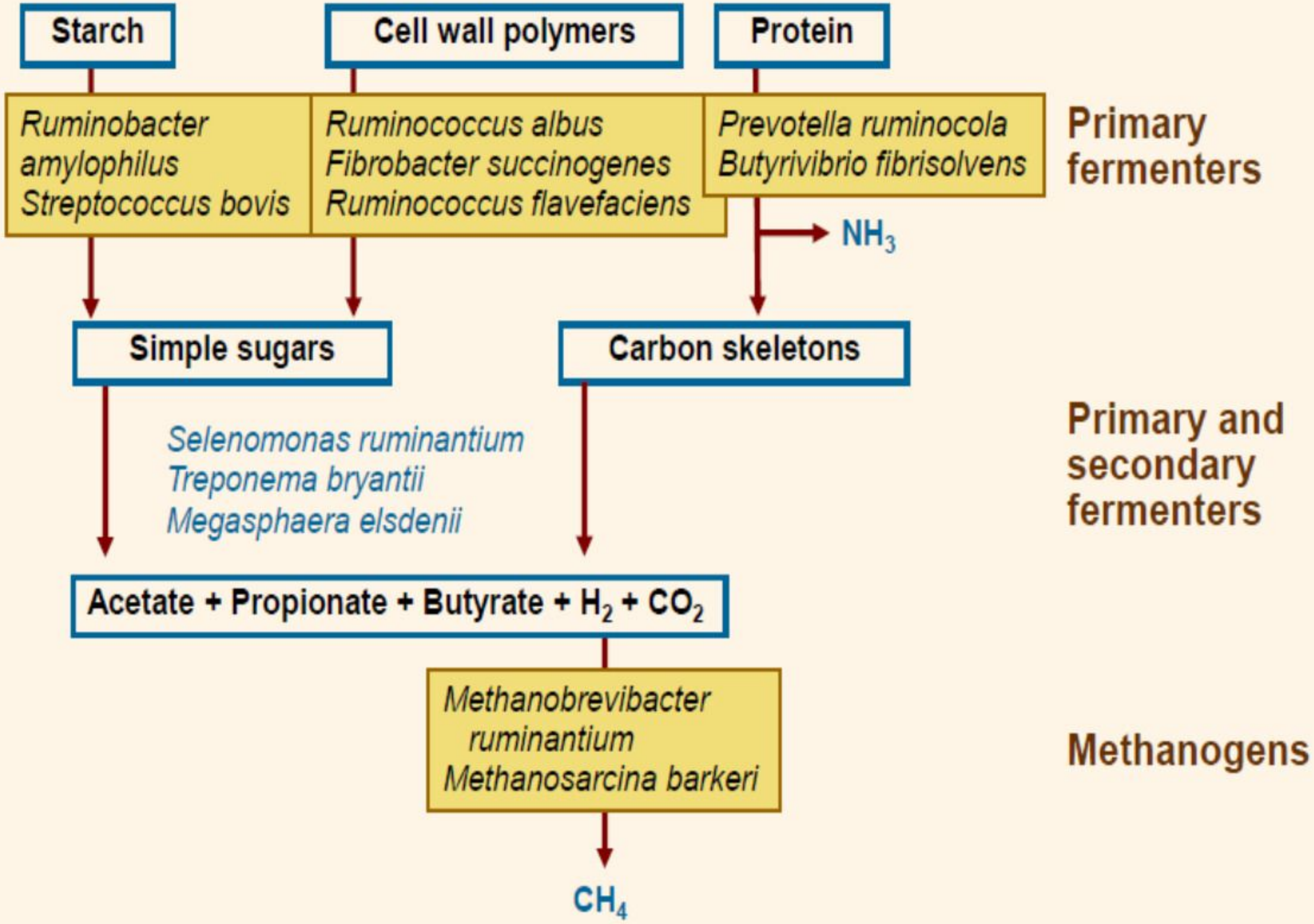
0.75-2.0 kg microbial cells
400-850 L gas
140-290 L CH_4
260-560 L CO_2

2-20 kg DM
20-80 L water
50-150 L saliva

VFA 2.0-6.0 kg

- CMS = 10 kg/a/d
- CH4 = 21g/kg MS
- CH4/d = 21*10 = 210 g CH4/dia
- L?

- CNTP = 1 mol gás = 22,4 L
- 1 Mol de CH4 = 16 g;
- Moles de CH4 = 210/16 = 13 moles de CH4
- L de CH4 = 13*22,4 = 291 L de CH4



Starch

Ruminobacter amylophilus
Streptococcus bovis

Cell wall polymers

Ruminococcus albus
Fibrobacter succinogenes
Ruminococcus flavefaciens

Protein

Prevotella ruminocola
Butyrivibrio fibrisolvens

Primary fermenters

NH_3

Simple sugars

Carbon skeletons

Selenomonas ruminantium
Treponema bryantii
Megasphaera elsdenii

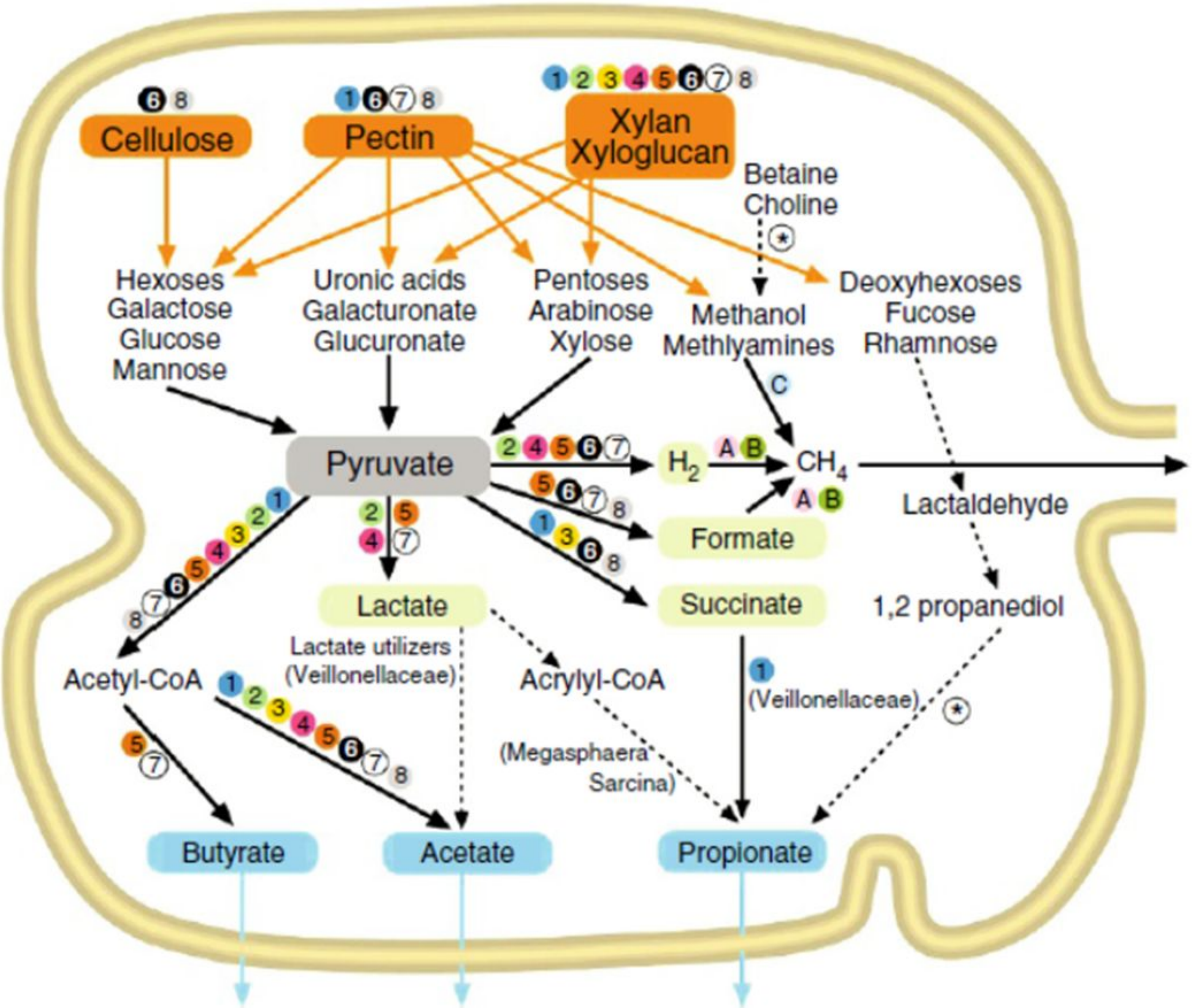
Primary and secondary fermenters

Acetate + Propionate + Butyrate + H_2 + CO_2

Methanobrevibacter ruminantium
Methanosarcina barkeri

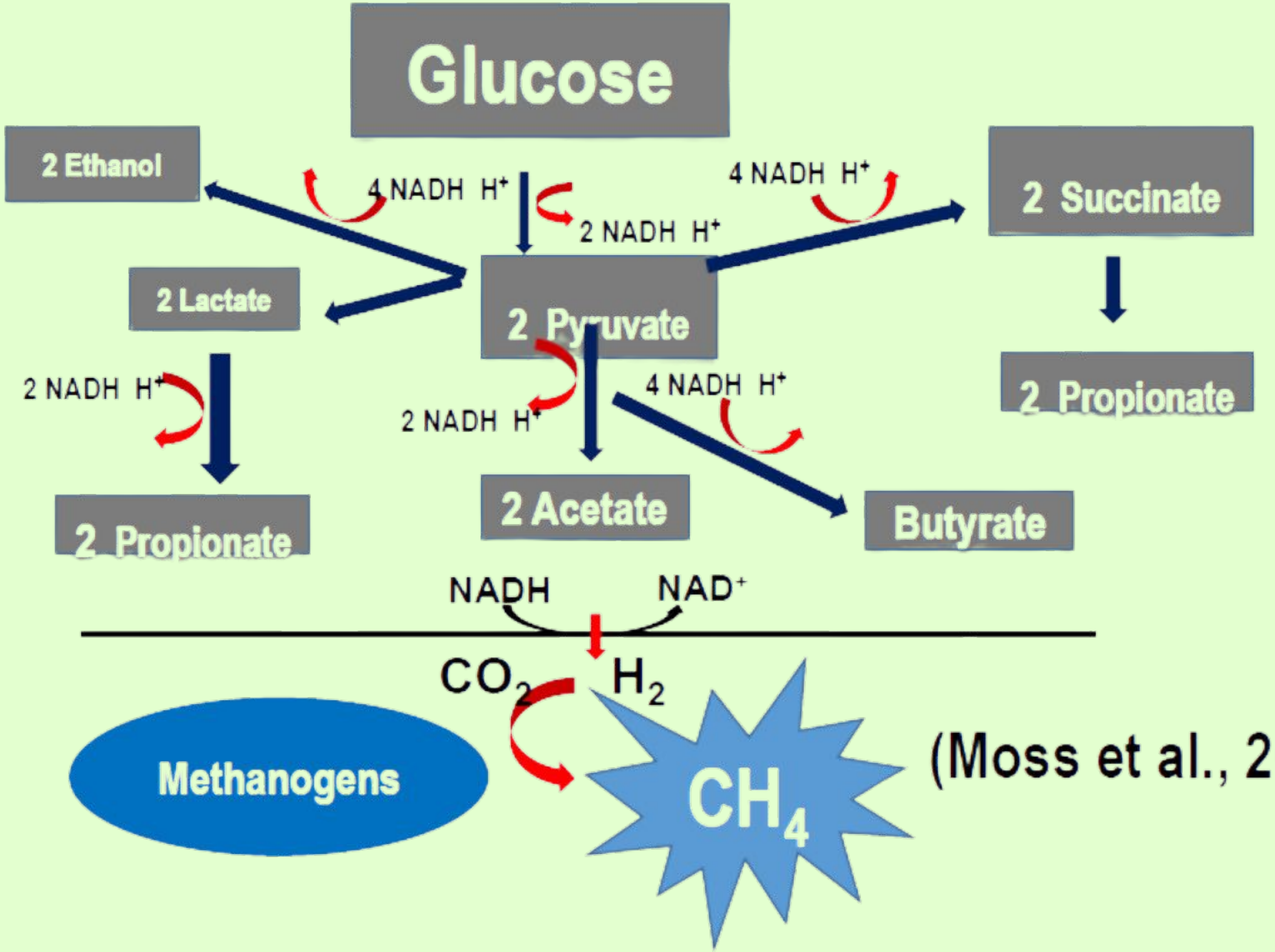
Methanogens

CH_4



⑥ ⑧
Cellulose
① ⑥ ⑦ ⑧
Pectin
① ② ③ ④ ⑤ ⑥ ⑦ ⑧
Xylan
Xyloglucan
Betaine
Choline
(*)
Hexoses
Galactose
Glucose
Mannose
Uronic acids
Galacturonate
Glucuronate
Pentoses
Arabinose
Xylose
Methanol
Methlyamines
Deoxyhexoses
Fucose
Rhamnose
C
Pyruvate
② ④ ⑤ ⑥ ⑦
H_2
A B
CH_4
⑤ ⑥ ⑦ ⑧
Formate
A B
① ③ ⑥ ⑧
Succinate
Lactaldehyde
1,2 propanediol
① ② ③ ④ ⑤ ⑥ ⑦ ⑧
Acetyl-CoA
② ⑤ ④ ⑦
Lactate
Lactate utilizers
(Veillonellaceae)
Acrylyl-CoA
①
(Veillonellaceae)
(*)
(Megasphaera
Sarcina)
⑤ ⑦
① ② ③ ④ ⑤ ⑥ ⑦ ⑧
Butyrate
Acetate
Propionate

Rumen Fermentation and Methane Production



(Moss et al., 2000)

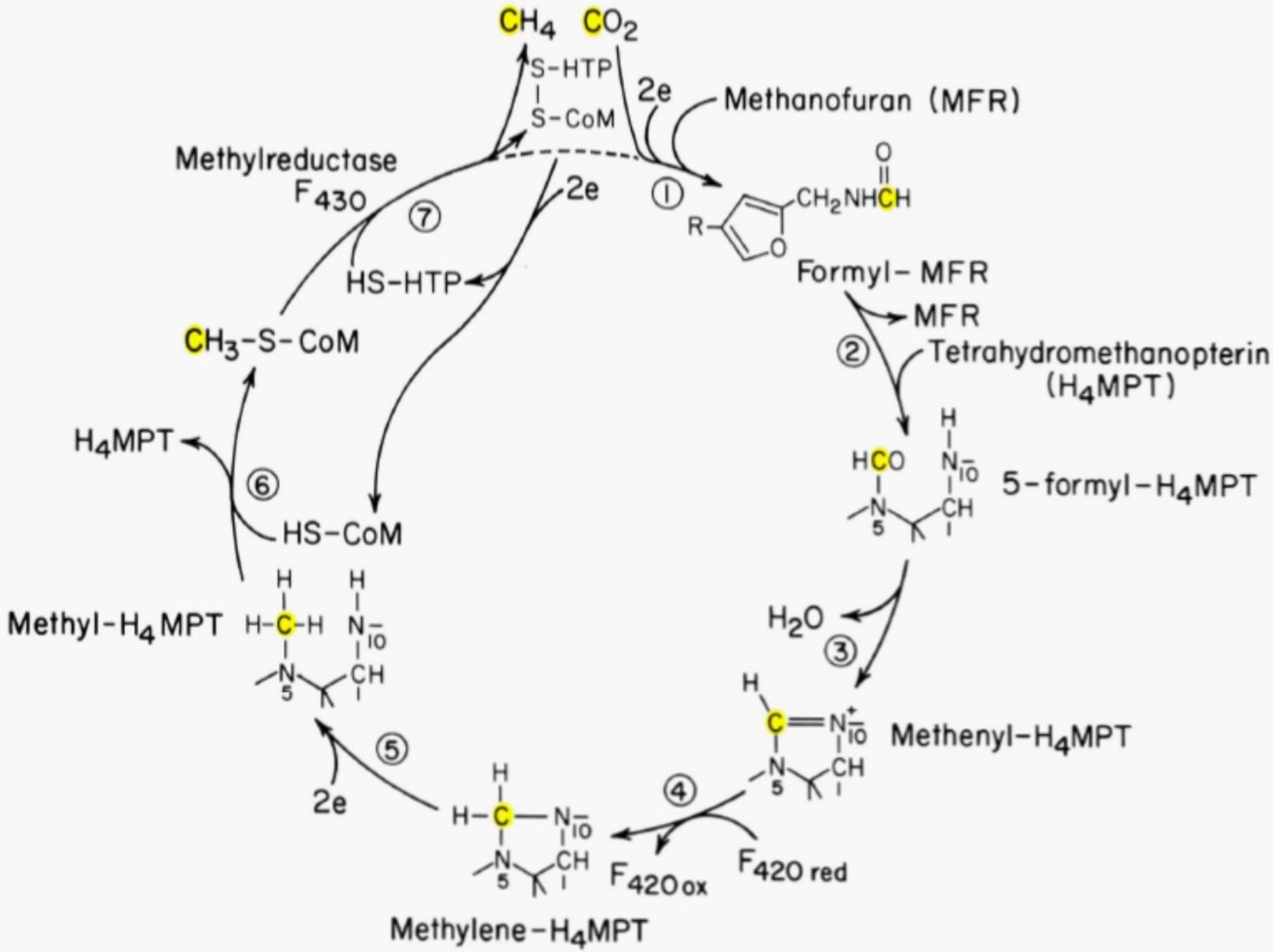


FIG. 2. **Proposed cycle for the reduction of CO_2 to CH_4.** The C_1 unit indicated by the *yellow dot* is sequentially modified, reduced, and transferred in "bucket brigade" fashion bound to coenzymes. Only that portion of the molecule involved in C_1 attachment is shown for methanofuran and tetrahydromethanopterin. The heterodisulfide couples in an unknown manner Reaction *7* to Reaction *1*.

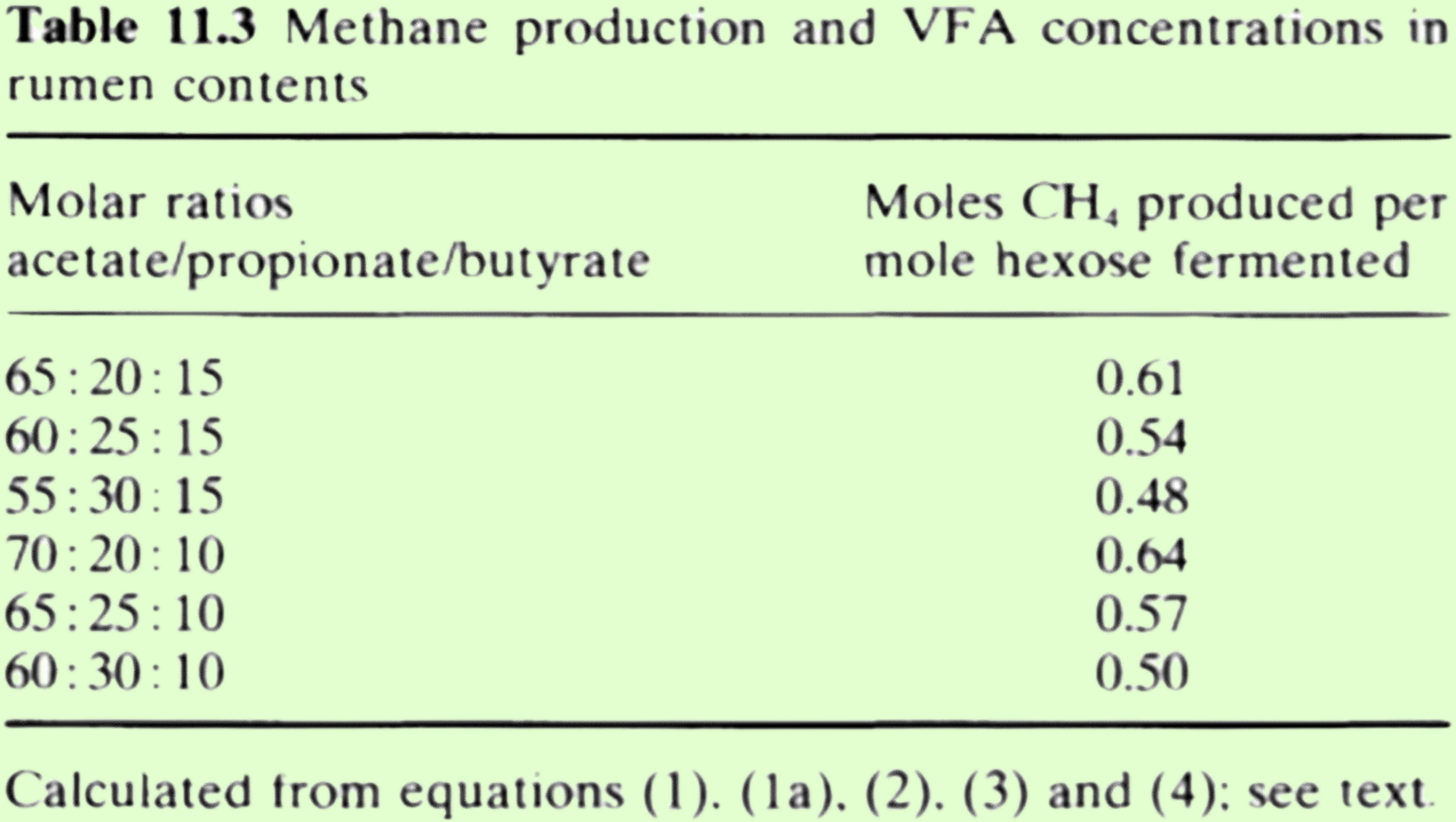
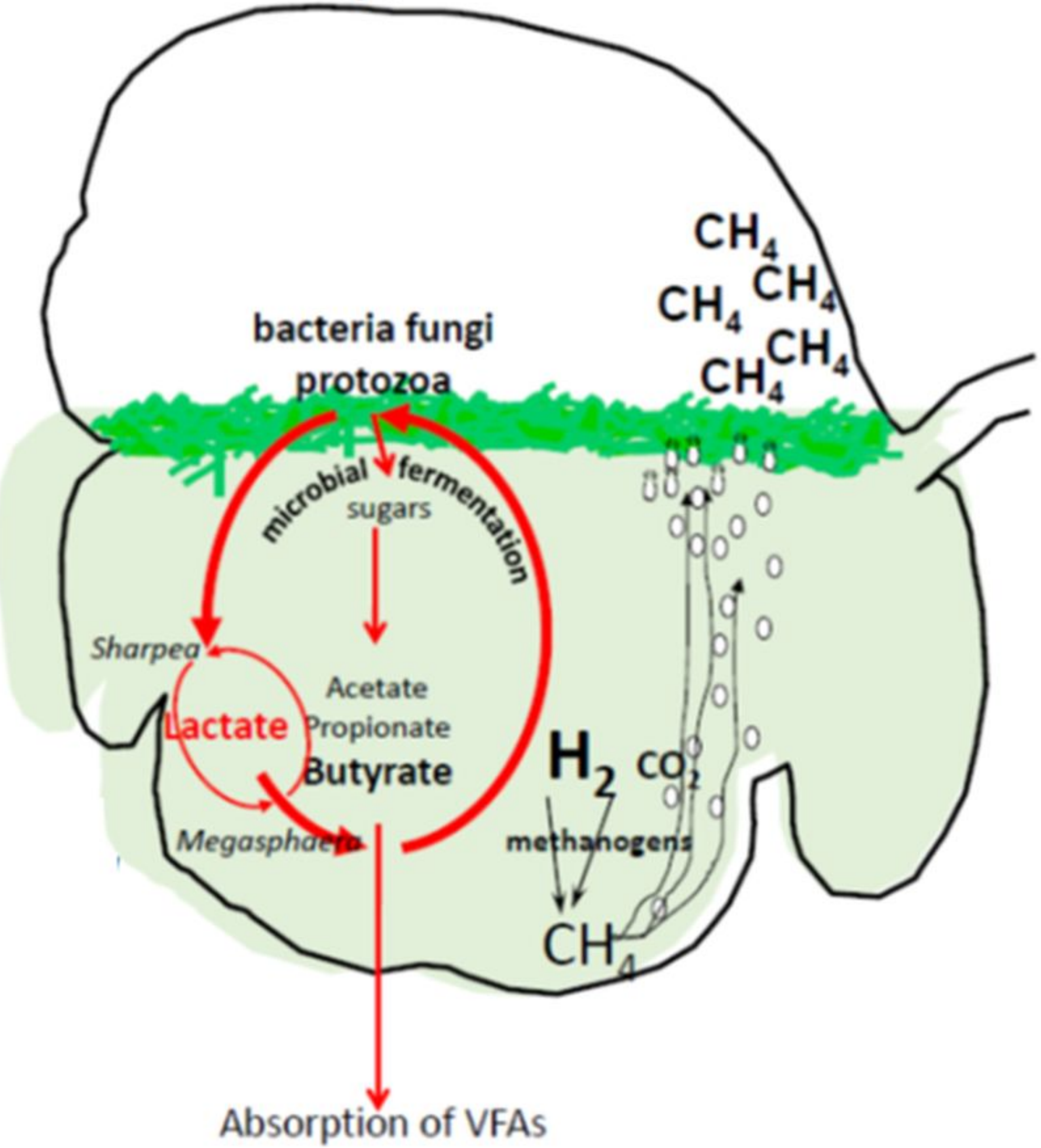


Table 11.3 Methane production and VFA concentrations in rumen contents

Molar ratios acetate/propionate/butyrate	Moles CH_4 produced per mole hexose fermented
65 : 20 : 15	0.61
60 : 25 : 15	0.54
55 : 30 : 15	0.48
70 : 20 : 10	0.64
65 : 25 : 10	0.57
60 : 30 : 10	0.50

Calculated from equations (1). (1a). (2). (3) and (4); see text.

Low CH_4 yield rumen



UFMT

PÓS-GRADUAÇÃO
Ciência Animal
UFMT

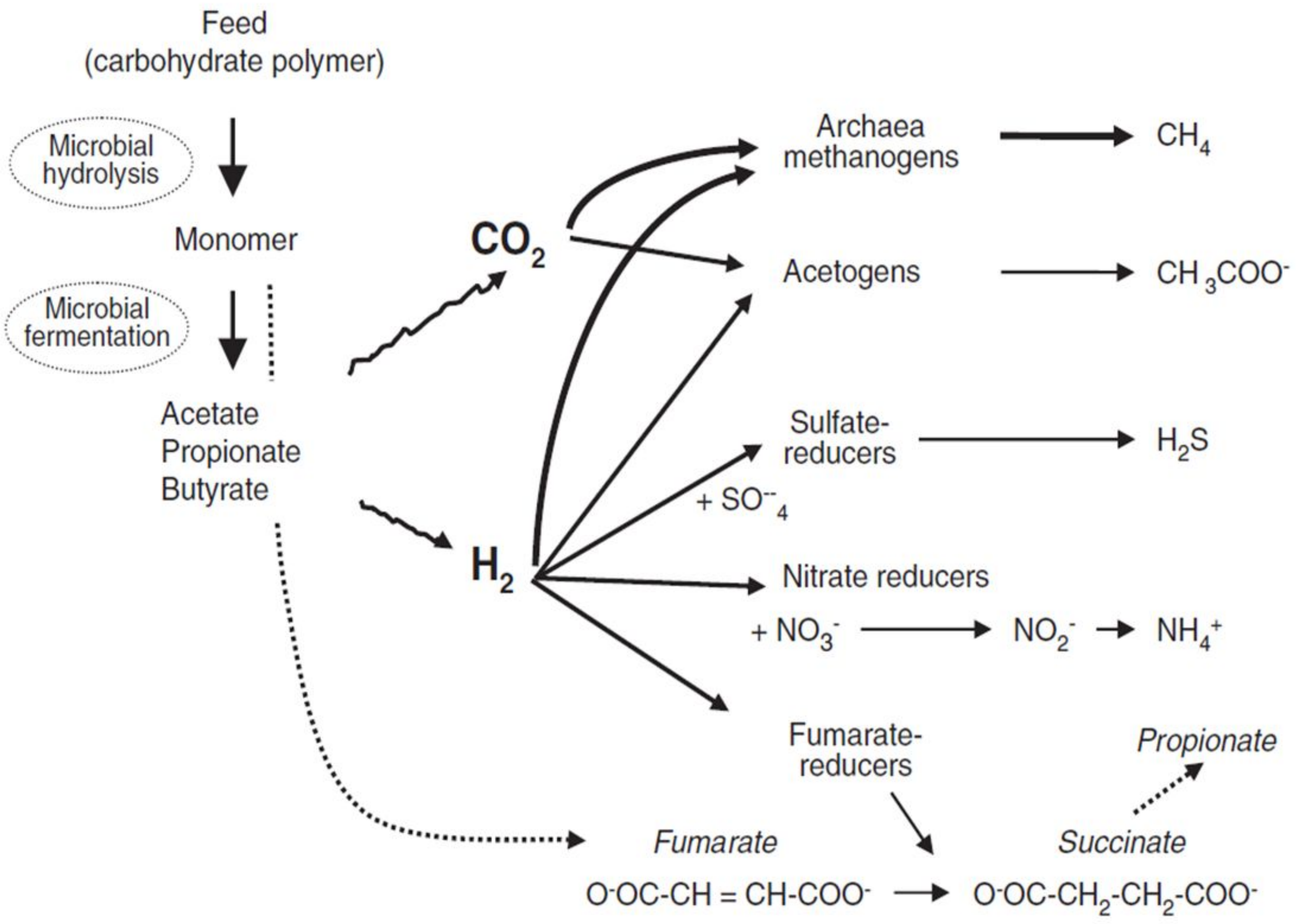


Figure 1 Schematic microbial fermentation of feed polysaccharides and H_2 reduction pathways in the rumen.

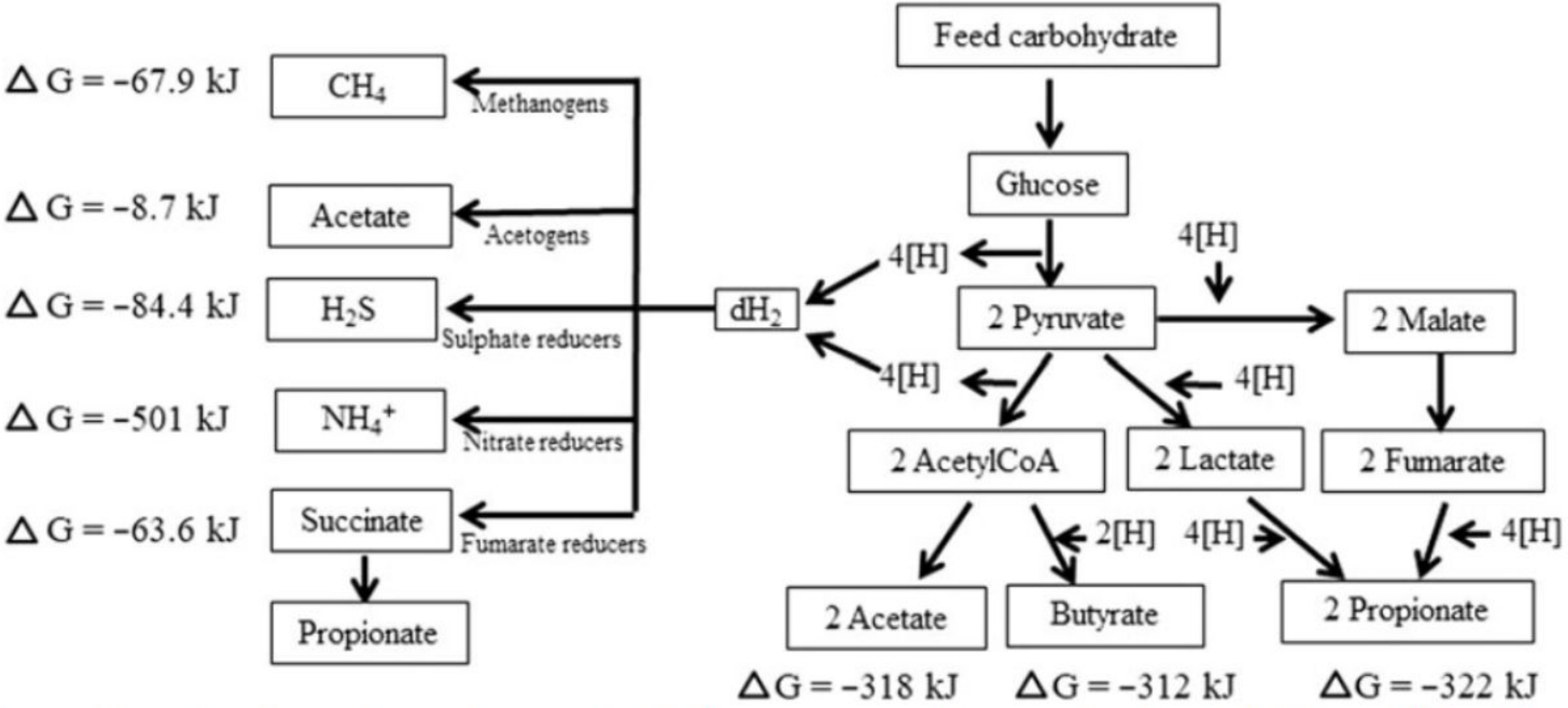


Figure 2 Scheme of the major pathways of rumen fermentation including generation and incorporation of metabolic hydrogen ([H]) and dihydrogen (H_2). Estimated Gibbs energy changes are based on Kohn and Boston (2000) and Ungerfeld and Kohn (2006) without considering ATP generation. Generation and incorporation of [H] are estimated based on 1 mol of glucose fermentation according to the following reactions: $C_6H_{12}O_6$ (glucose)→2 $C_3H_4O_3$ (pyruvate) + 2 [2H]; 2 $C_3H_4O_3$ + 2 HSCoA (non-esterified coenzyme A) → 2 C_2H_3OSCoA (acetyl coenzyme A) + 2 CO_2 + 4 [2H]; C_2H_3OSCoA + H_2O (water) →→ $C_2H_4O_2$ (acetate) + HSCoA; 2 C_2H_3OSCoA + 2 [2H] → $C_4H_8O_2$ (butyrate) + 2 HSCoA; 2 $C_3H_4O_3$ + 2 [2H] → 2 $C_3H_6O_3$ (lactate); 2 $C_3H_6O_3$ + 2 [2H] → 2 $C_3H_6O_2$ (propionate) + 2 H_2O; 2 $C_3H_4O_3$ + 2 [2H] + 2 CO_2 (carbon dioxide) → 2 $C_4H_6O_5$ (malate); 2 $C_4H_4O_4$ (fumarate) + 2 [2H] →→ 2 $C_3H_6O_2$ + 2 CO_2.

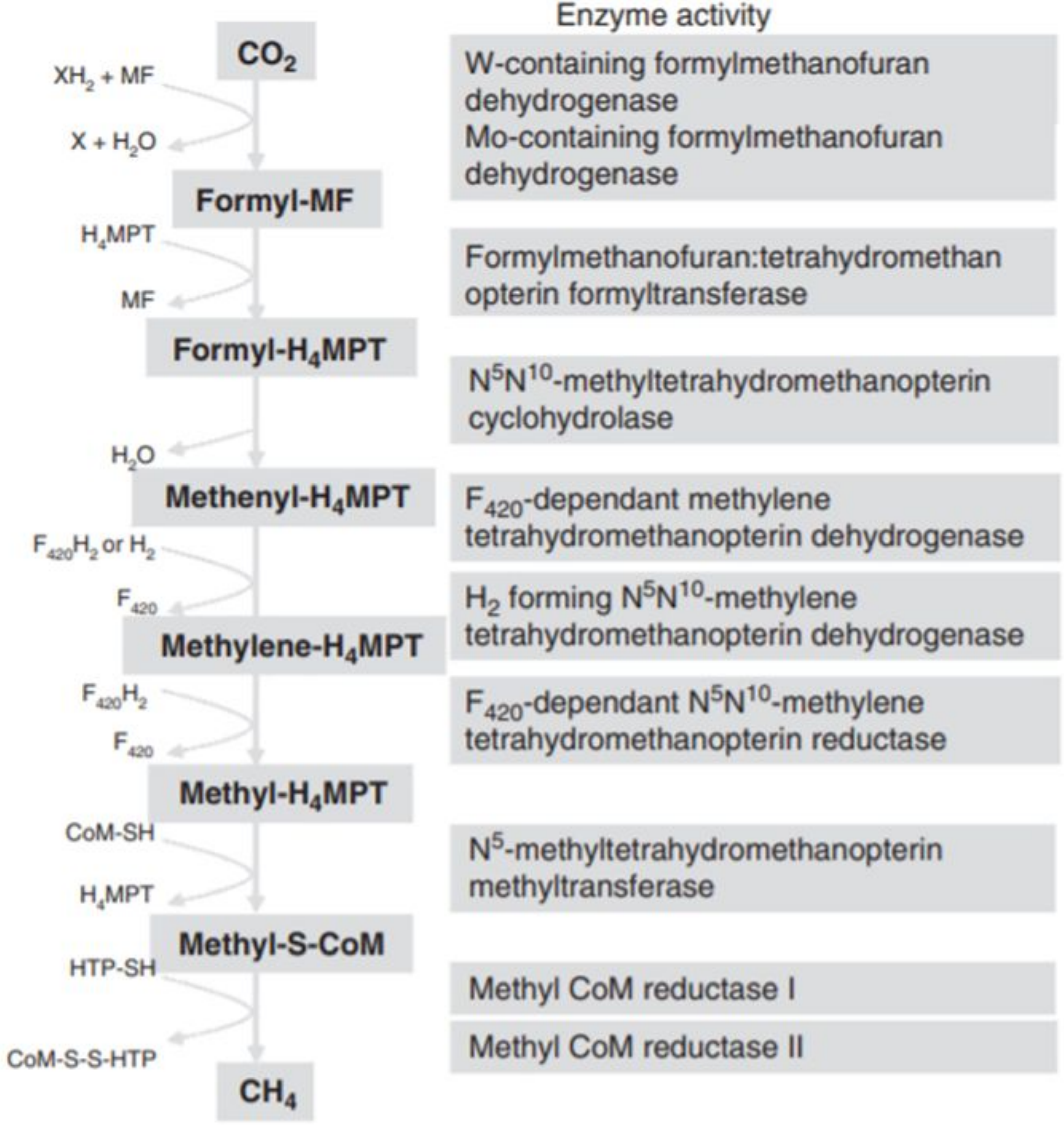


Fig. 1. Methanogenesis pathway from $H_2 + CO_2$. The seven-step enzymatic pathway for the formation of methane in hydrogenotrophic methanogens is shown. Formyl-MF, formylmethanofuran; Formyl-H_4MPT, N^5-formyltetrahydromethanopterin; Methenyl-H_4MPT, N^5, N^{10}-methenyltetrahydromethanopterin; Methylene-H_4MPT, N^5, N^{10}-methylenetetrahydromethanopterin; Methyl-H_4MPT, N^5-methyltetrahydromethanopterin; Methyl-S-CoM, methyl coenzyme M; F_{420}, coenzyme F_{420}; $F_{420}H_2$, reduced coenzyme F_{420}; H_4MPT, methanopterin; H-S-HTP, *N*-7-mercaptohetanoyl-*O*-phospho-L-threonine; X, unidentified electron donor.

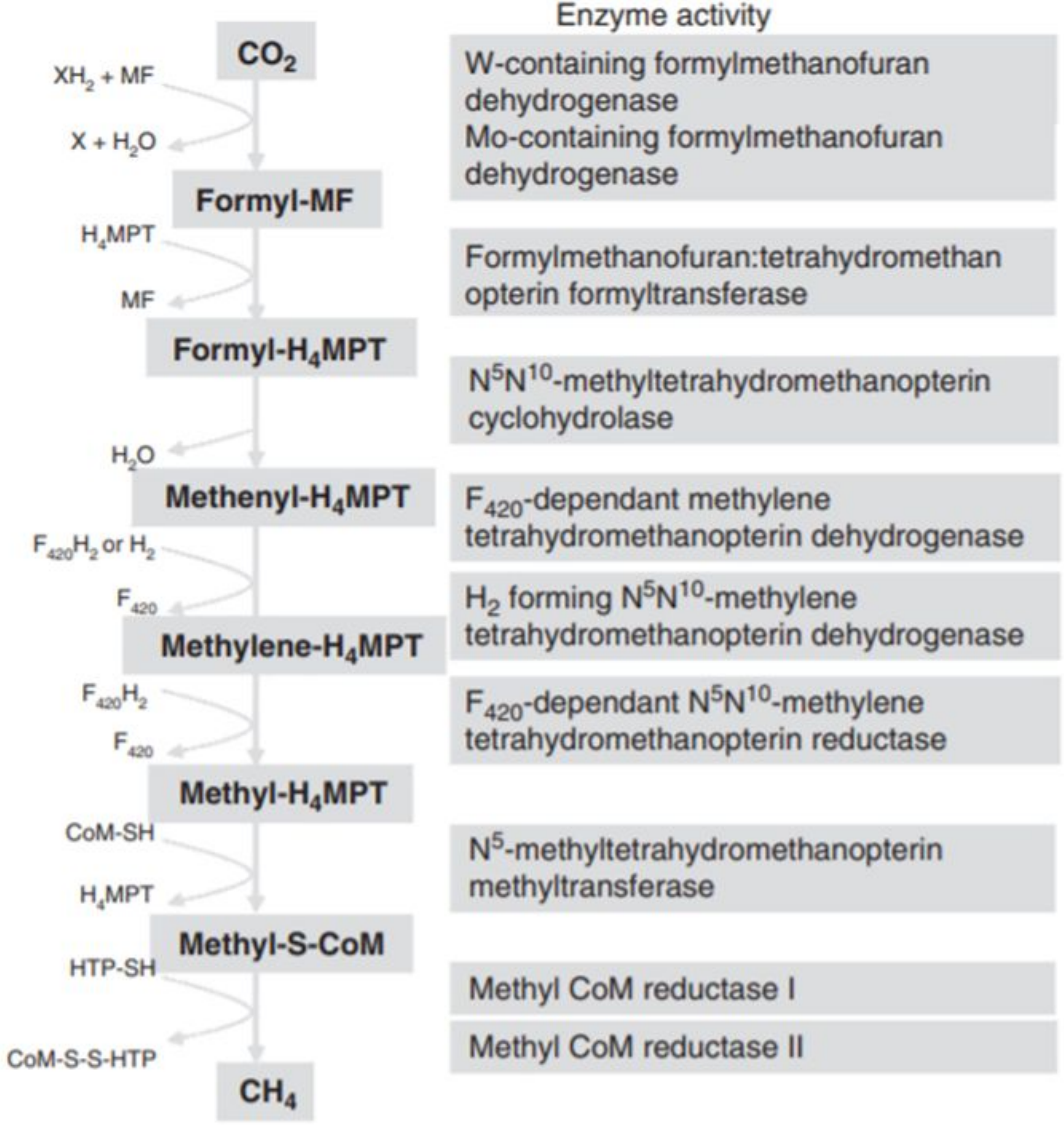


Fig. 1. Methanogenesis pathway from $H_2 + CO_2$. The seven-step enzymatic pathway for the formation of methane in hydrogenotrophic methanogens is shown. Formyl-MF, formylmethanofuran; Formyl-H_4MPT, N^5-formyltetrahydromethanopterin; Methenyl-H_4MPT, N^5, N^{10}-methenyltetrahydromethanopterin; Methylene-H_4MPT, N^5, N^{10}-methylenetetrahydromethanopterin; Methyl-H_4MPT, N^5-methyltetrahydromethanopterin; Methyl-S-CoM, methyl coenzyme M; F_{420}, coenzyme F_{420}; $F_{420}H_2$, reduced coenzyme F_{420}; H_4MPT, methanopterin; H-S-HTP, *N*-7-mercaptohetanoyl-*O*-phospho-L-threonine; X, unidentified electron donor.

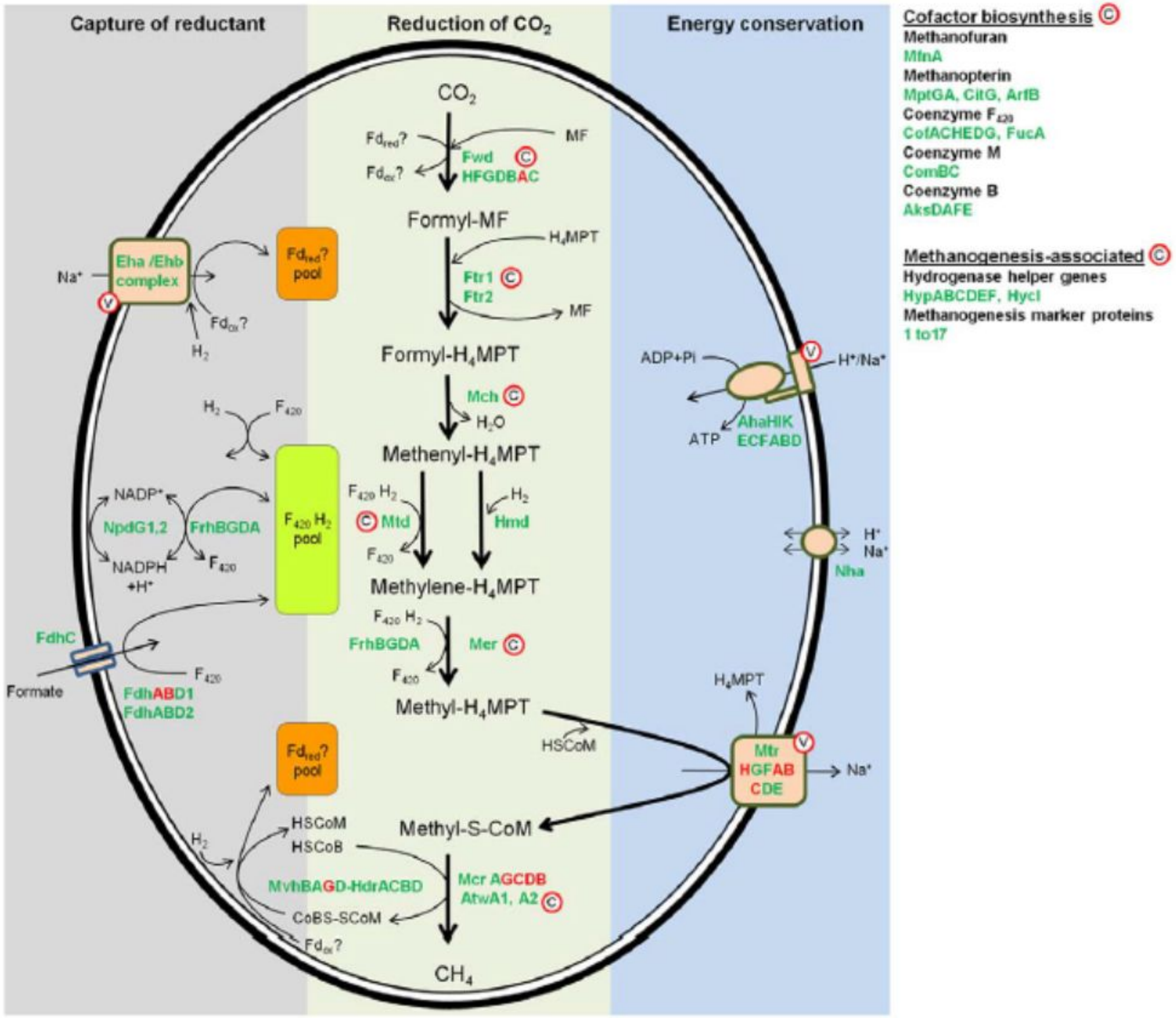
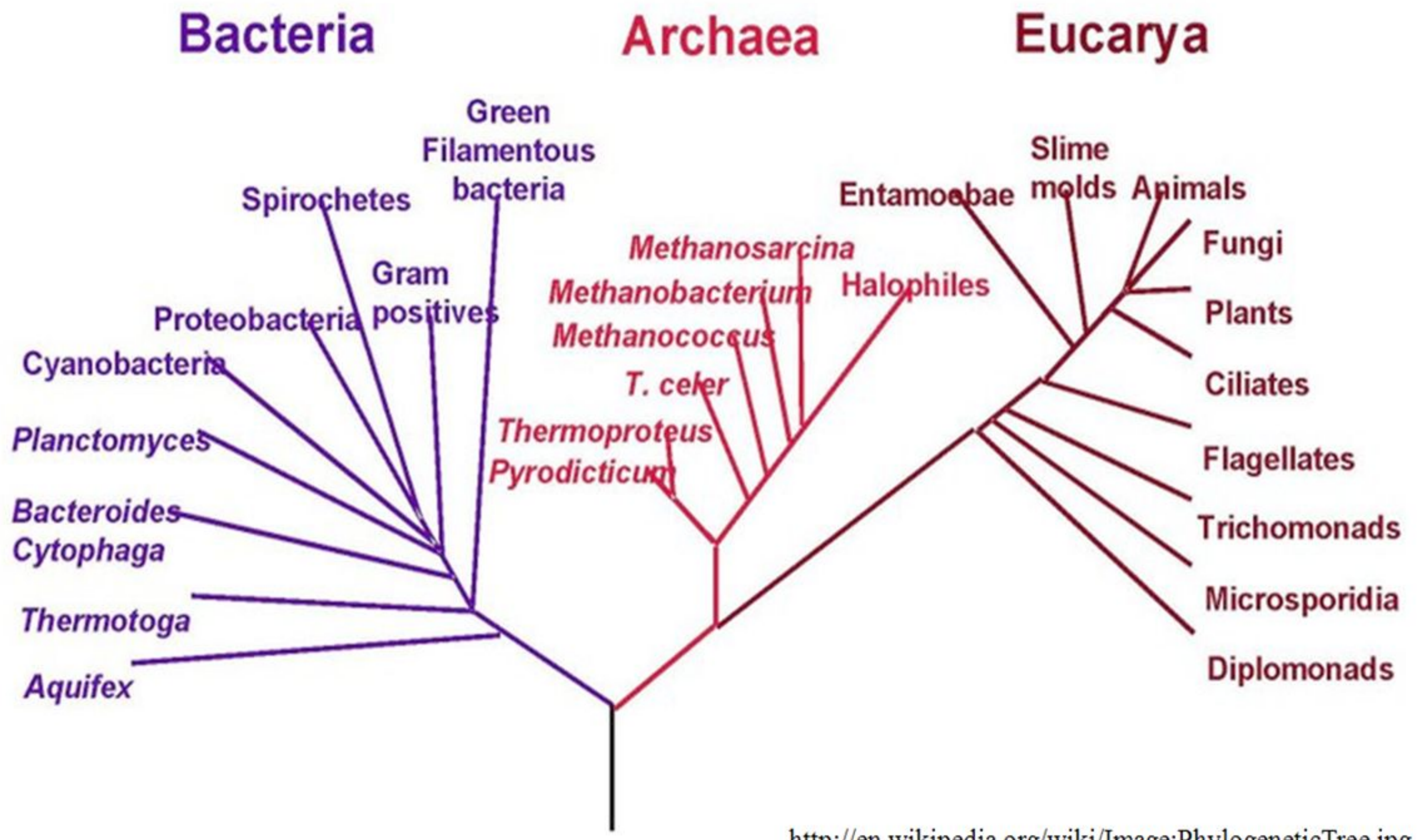


Figure 2. Methanogenesis pathway. The predicted pathway of methane formation in M1 based on the scheme of Thauer *et al.* [15] for methanogens without cytochromes is shown. The diagram is divided into three parts to show the capture of reductant, the reduction of CO_2, and conservation of energy at the methyltransfer step. The main reactions are indicated by thick arrows and enzymes catalysing each step are coloured green. Protein subunits coloured red signify the corresponding genes that were up-regulated during co-culture with *Butyrivibrio proteoclasticus*. Cofactor participation is indicated with thin arrows. For simplicity, protons are not shown and the overall reaction is not balanced. Membrane-located proteins are contained in light brown boxes and potential vaccine and chemogenomic targets are labelled with a circled V or C, respectively. Full gene names and corresponding locus tag numbers can be found in Table S1. H_4MPT; tetrahydromethanopterin; MF, methanofuran; F_{420}, coenzyme F_{420} oxidised; $F_{420}H_2$, coenzyme F_{420} reduced; Fd_{ox}?, unknown oxidised ferredoxin; Fd_{red}?, unknown reduced ferredoxin; HSCoM, reduced coenzyme M; HSCoB, reduced coenzyme B, CoMS-SCoB, coenzyme B-coenzyme M heterodisulphide; $NADP^+$, nicotinamide adenosine dinucleotide phosphate non-reduced; NADPH, nicotinamide adenosine dinucleotide phosphate reduced.

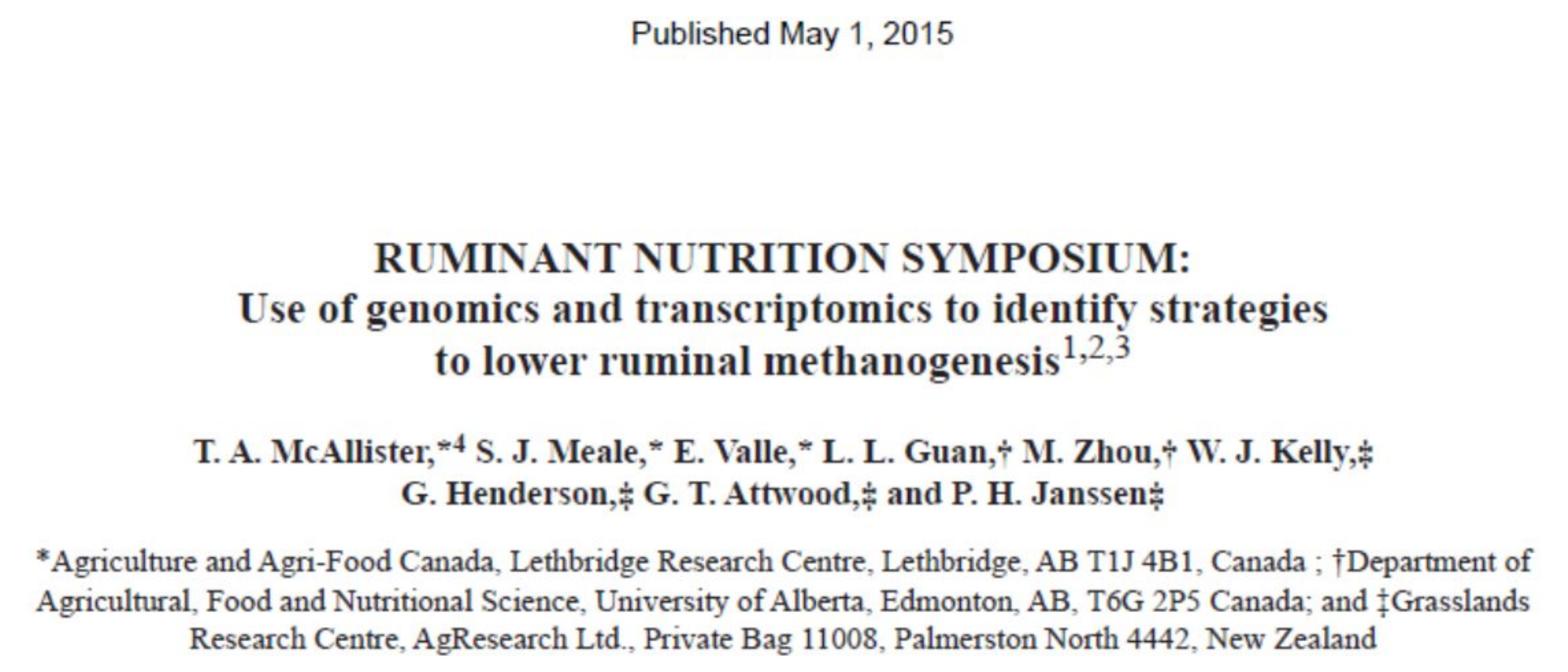
doi:10.1371/journal.pone.0008926.g002

ORGANISMOS METANOGÊNICOS DO RÚMEN

Phylogenetic Tree of Life



http://en.wikipedia.org/wiki/Image:PhylogeneticTree.jpg



RUMINANT NUTRITION SYMPOSIUM: Use of genomics and transcriptomics to identify strategies to lower ruminal methanogenesis[1,2,3]

T. A. McAllister,*[4] S. J. Meale,* E. Valle,* L. L. Guan,† M. Zhou,† W. J. Kelly,‡
G. Henderson,‡ G. T. Attwood,‡ and P. H. Janssen‡

*Agriculture and Agri-Food Canada, Lethbridge Research Centre, Lethbridge, AB T1J 4B1, Canada ; †Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, AB, T6G 2P5 Canada; and ‡Grasslands Research Centre, AgResearch Ltd., Private Bag 11008, Palmerston North 4442, New Zealand

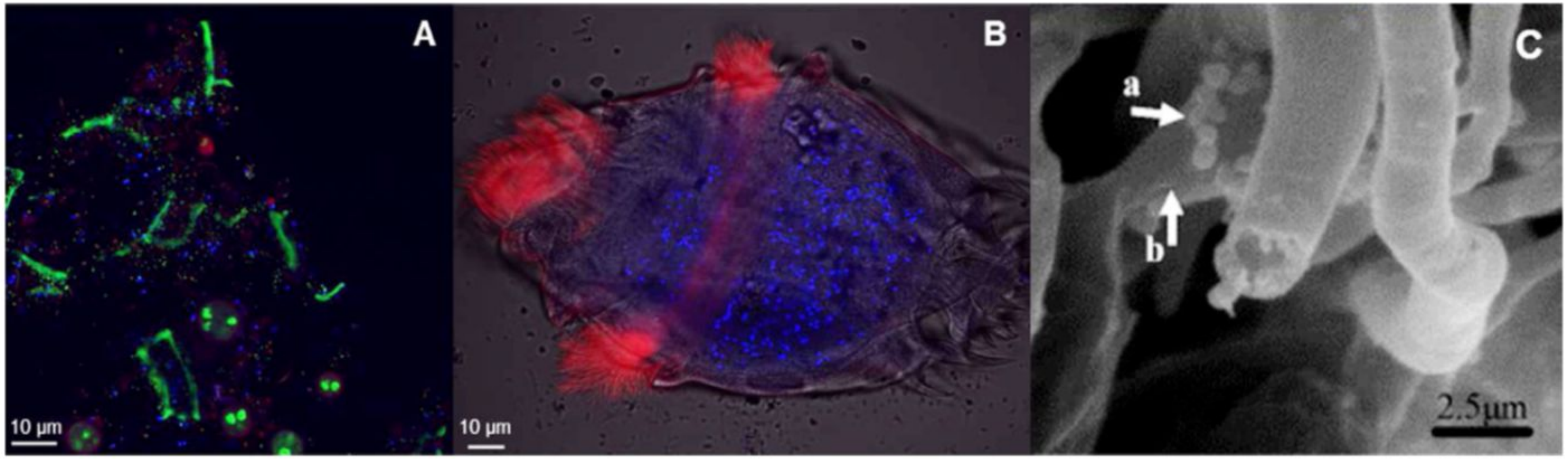


Figure 1. Methanogen interactions documented in different rumen microenvironments using confocal laser scanning microscopy (CLSM) and scanning electron microscopy. Characteristic blue-green autofluorescence of coenzyme F_{420} identified (A) methanogens associated with feed/particles in biofilm and (B) endosymbiotic methanogens associated within an *Ophryoscolex* sp., using CLSM. (C) Scanning electron microscopy image of methanogens (a) attached to fungal rhizoids (b). The physical proximity between hydrogenosomes and methanogens is considered to facilitate H_2 transfer. Adapted from Jin et al. (2011).

- Archaea metanogênica não possui o peptidoglicano encontrado nas paredes celulares das bactérias, mas contém pseudomureína, heteropolissacarídeo ou proteína em suas paredes celulares;

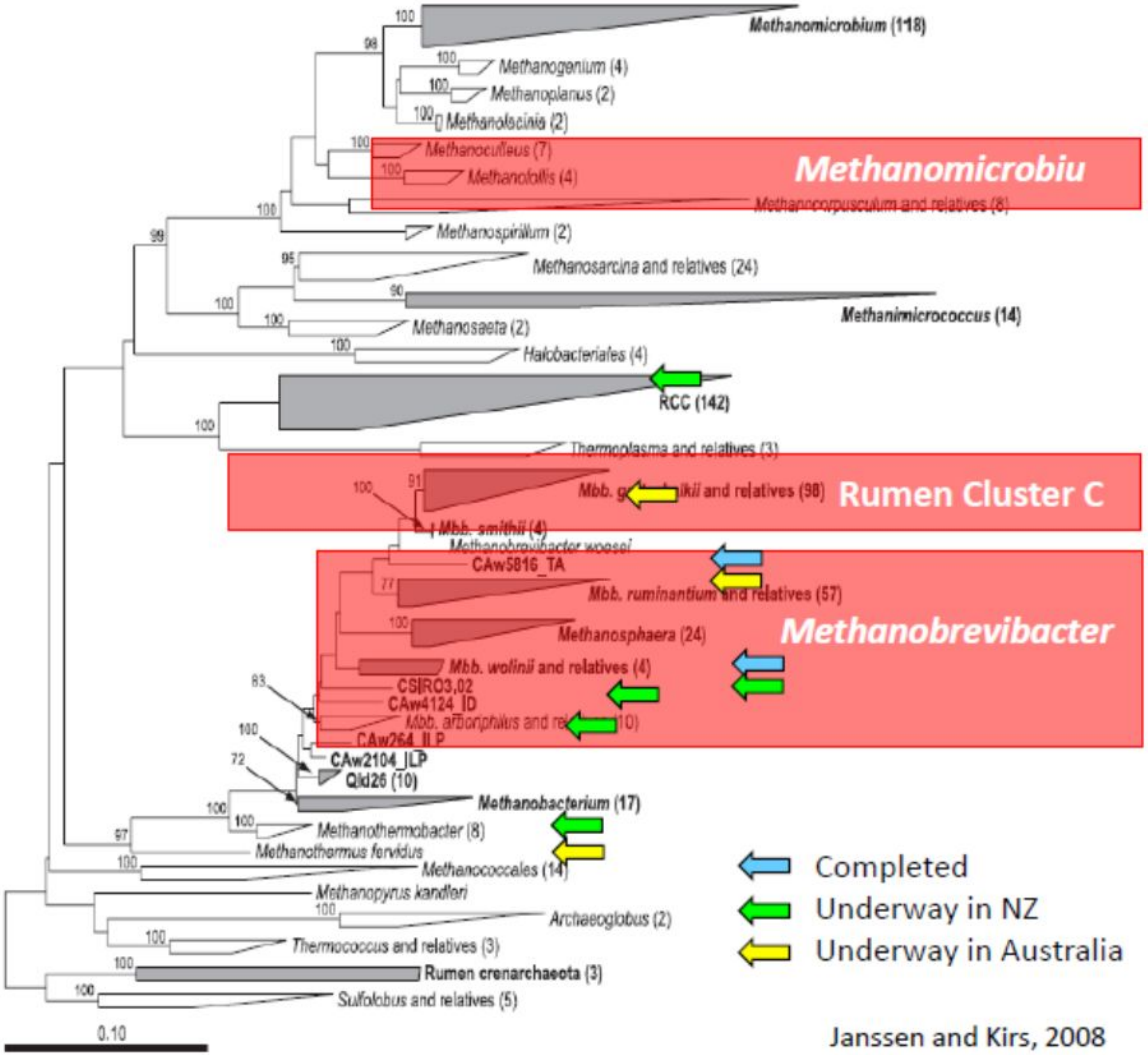
- Membros do domínio Archaea contribuem com cerca de 0,3 a 3,3% da pequena subunidade microbiana (16S e 18S) do rRNA no rúmen;

- Os organismos metanógenos também possuem cofatores distintos, incluindo a coenzima F420, que exibe autofluorescência azul-esverdeada em 470 nm;

Provavelmente haja no rúmen cerca de 120 espécies de metanogênicas representandas em 33 gêneros (Wright e Klieve, 2011);

92,3% das Archaea ruminais são de três gêneros: Methanobrevibacter (61,6%), Methanomicrobium (14,9%) e cluster ruminal C (15,8%);

Rumen methanogen diversity



🡐 Completed
🡐 Underway in NZ
🡐 Underway in Australia

Janssen and Kirs, 2008

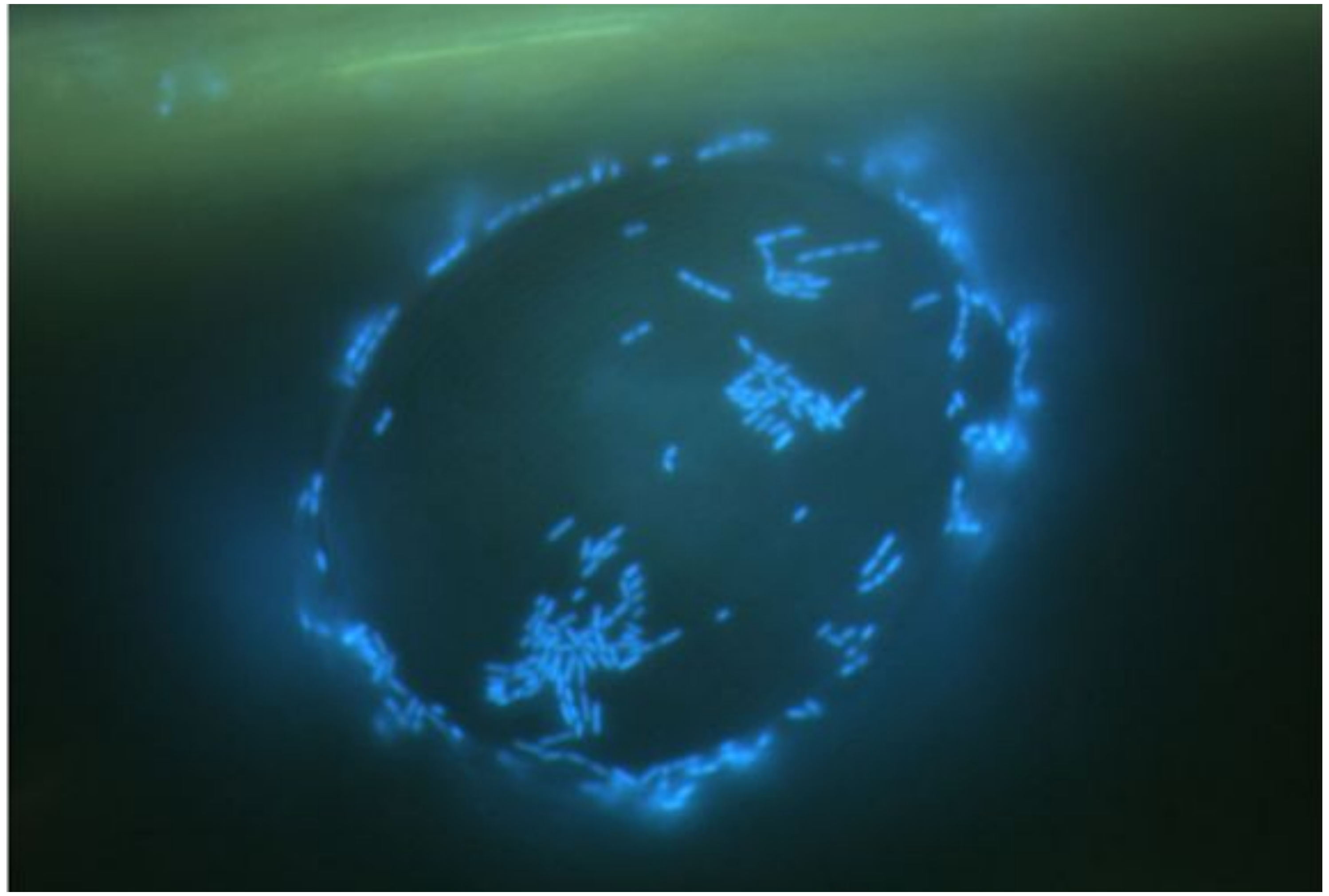
Methanogens (10) isolated from the rumen

Organism	Morphology	Substrate	Reference
Methanosarcina sp.			
Methanosarcina barkeri	Irregular cocci large clusters, immobile, HPS + PR	H_2/methanol methylamines/ acetate	Beijer (1952)
Methanosarcina mazei	Cocci, immobile, HPS	Methanol methylamines/ acetate	Mah (1980)
Methanobacterium formicicum	Long rods and filaments, immobile, PS	H_2/formate	Opperman et al. (1957)
Methanobacterium bryantii	PS	H_2/formate	Joblin et al. (2005)
Methanobrevibacter ruminantium	Short rods, requires CoM, PS, variably motility	H_2/formate	Smith and Hungate (1958)
Methanomicrobium mobile	Short curved rods, motile, PR	H_2/formate/ acetate	Paynter and Hungate (1968)
Methanobrevibacter sp.	Short rods, synthesizes CoM, PS	H_2/formate	Lovley et al. (1984)
Methanobrevibacter millerae			Rae et al. (2007)
Methanobrevibacter olleyae			Rae et al. (2007)
Methanoculleus olentangyi*		H_2/formate/ acetate	Joblin et al. (2005)

*Cultured from cervid rumen

Abbreviations: CoM, Coenzyme M; PC, pseudomurein; HPS, heteropolysaccharide; PR, protein

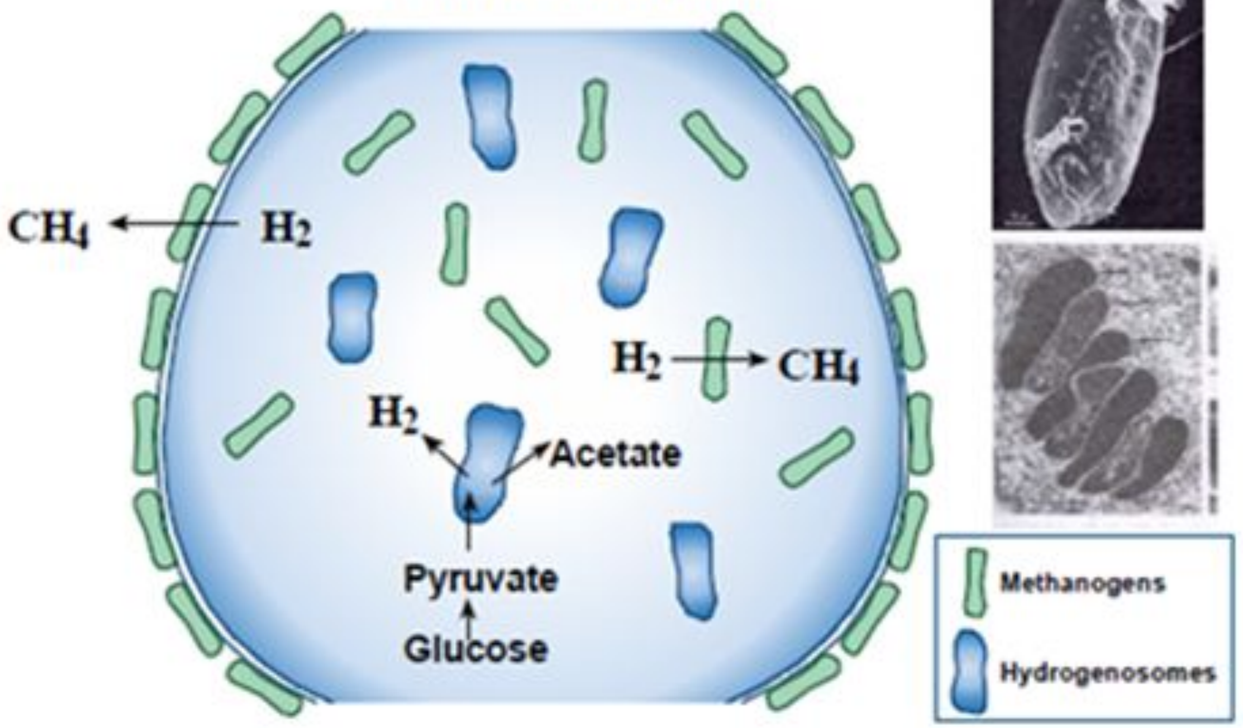
Rumen protozoa are often colonized by methanogens, and the methanogens literally “suck” hydrogen from their “hydrogenosomes.”



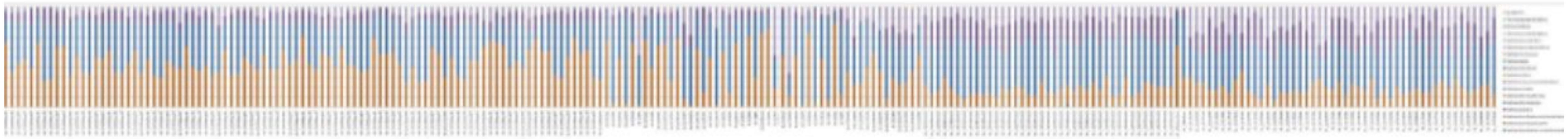
Inhibition of methane formation

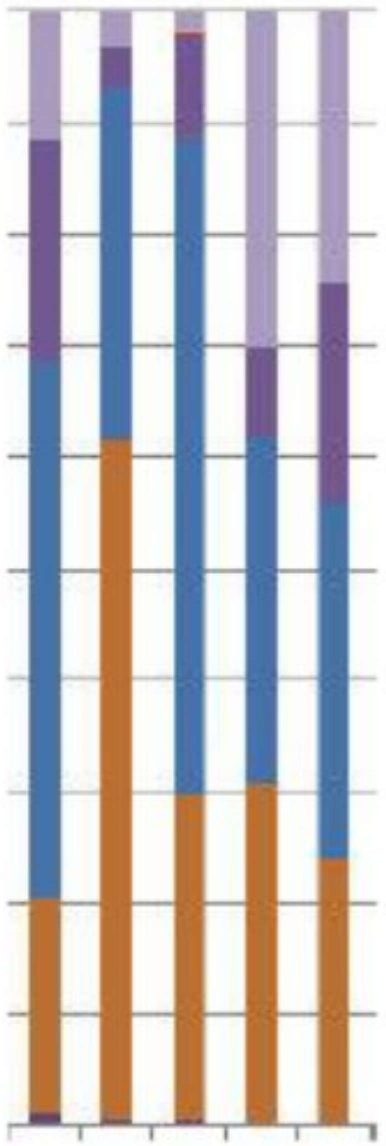
- Defaunation
  - Decreases methane formation by 20%

Intracellular Hydrogen Transfer in Ciliate Protozoa



Variability in rumen methanogens





Methanogen group	Mean	Range
Methanobrevibacter ruminantium group	41.0	6.3 – 90.1
Methanobrevibacter gottschalkii group	33.4	2.0 – 84.2
Methanosphaera	14.9	1.0 – 37.4
Rumen cluster C	10.4	0 – 66.0
Others	0.3	0 – 12.4

From 232 rumen samples from NZ

Data courtesy of Sandra Kittelmann

- Com base nas técnicas de cultivo, M. ruminantium e Methanosarcina spp., foram encontrados no rúmen em populações maiores que 10/mL;

- Dificuldades em cultivar metanógenos ruminais são atribuídas à sua natureza anaeróbica exigente com requisitos de um potencial redox abaixo de -300 mV (Stewart e Bryant, 1988) e condições ótimas de crescimento dentro de um pH de 6,0 a 8,0 (McAllister et al., 1996; Kumar et. al., 2009).

FATORES QUE AFETAM A PRODUÇÃO DE METANO NO RÚMEN

- Composição da dieta: teores de FDN ou amido;
- Consumo de matéria seca;
- Uso de Aditivos;
- Animal;
- Composição do microbioma ruminal (animais jovens);

FERMENTAÇÃO RUMINAL

RELAÇÃO ACETATO:PROPIONATO

Variação na relação V:C;

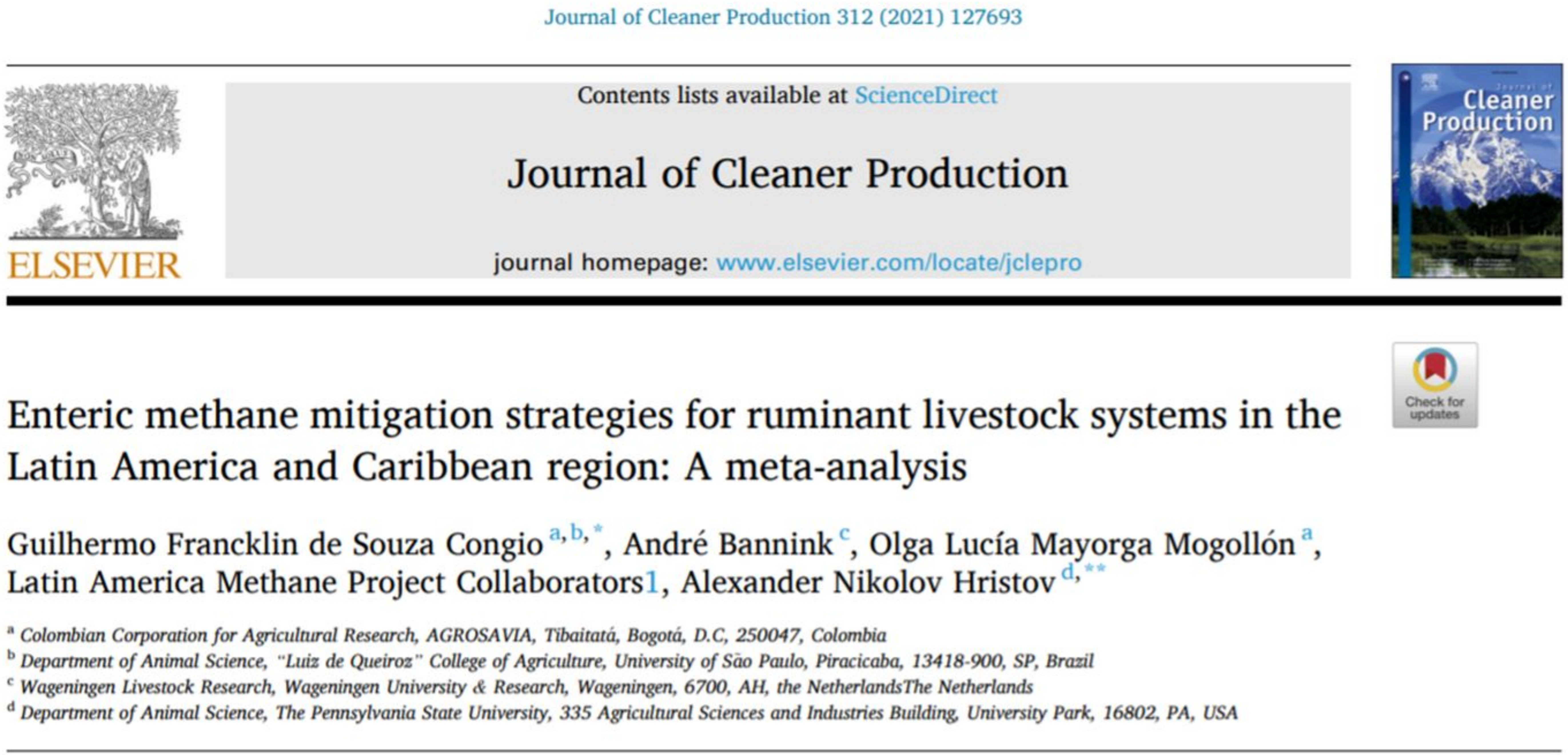
Fibra x amido;

Fibra: mais acetato;

Amido: mais propionato;

Amido: mais glicose para ser fermentado;

NEM SEMPRE NOS ESTUDOS EM QUE SE VARIA A V:C SE DETECTA EFEITO NA PRODUÇÃO DE CH_4;



Journal of Cleaner Production 312 (2021) 127693

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Enteric methane mitigation strategies for ruminant livestock systems in the Latin America and Caribbean region: A meta-analysis

Guilhermo Francklin de Souza Congio[a,b,*], André Bannink[c], Olga Lucía Mayorga Mogollón[a], Latin America Methane Project Collaborators[1], Alexander Nikolov Hristov[d,**]

[a] *Colombian Corporation for Agricultural Research, AGROSAVIA, Tibaitatá, Bogotá, D.C, 250047, Colombia*
[b] *Department of Animal Science, "Luiz de Queiroz" College of Agriculture, University of São Paulo, Piracicaba, 13418-900, SP, Brazil*
[c] *Wageningen Livestock Research, Wageningen University & Research, Wageningen, 6700, AH, the NetherlandsThe Netherlands*
[d] *Department of Animal Science, The Pennsylvania State University, 335 Agricultural Sciences and Industries Building, University Park, 16802, PA, USA*

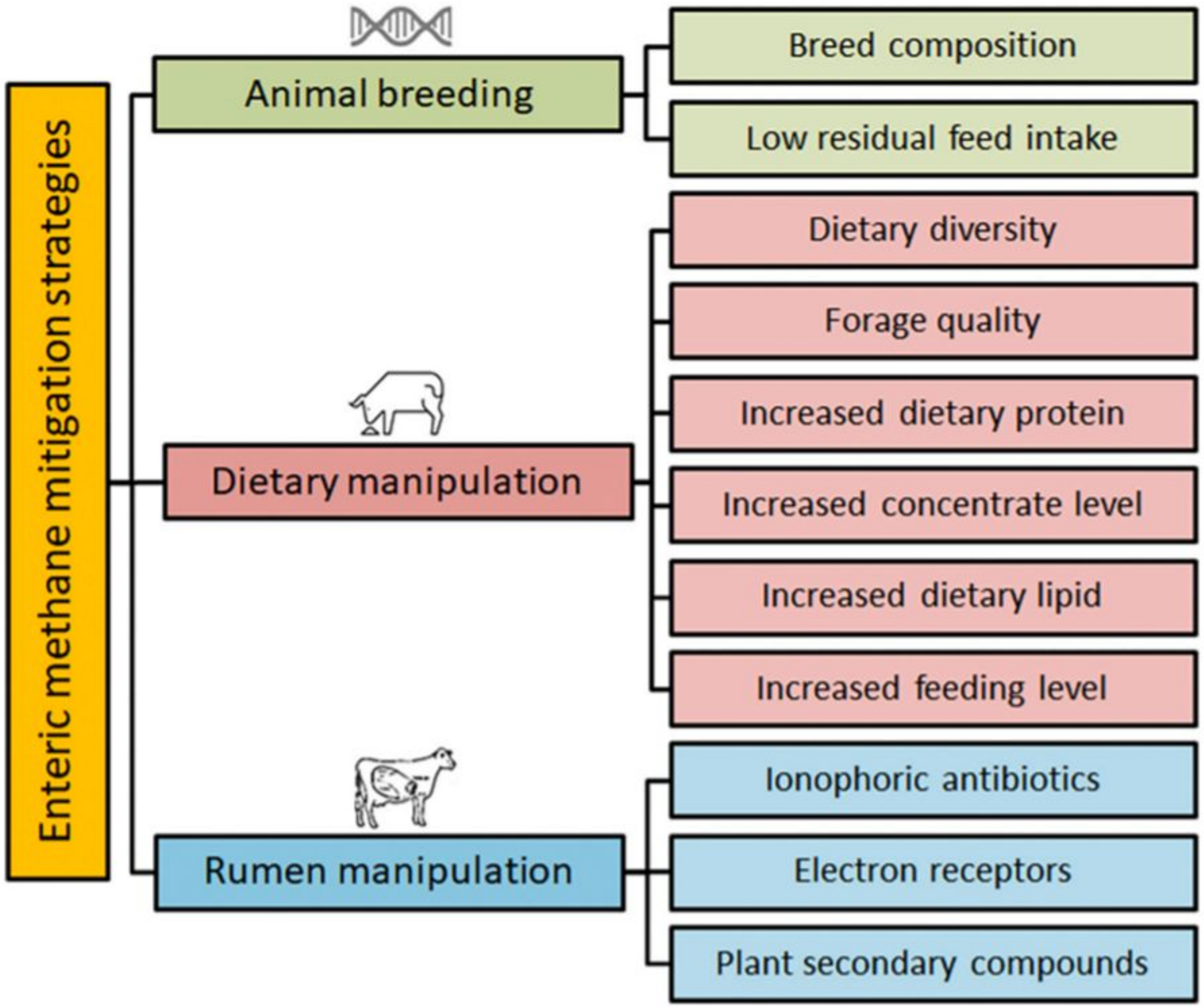
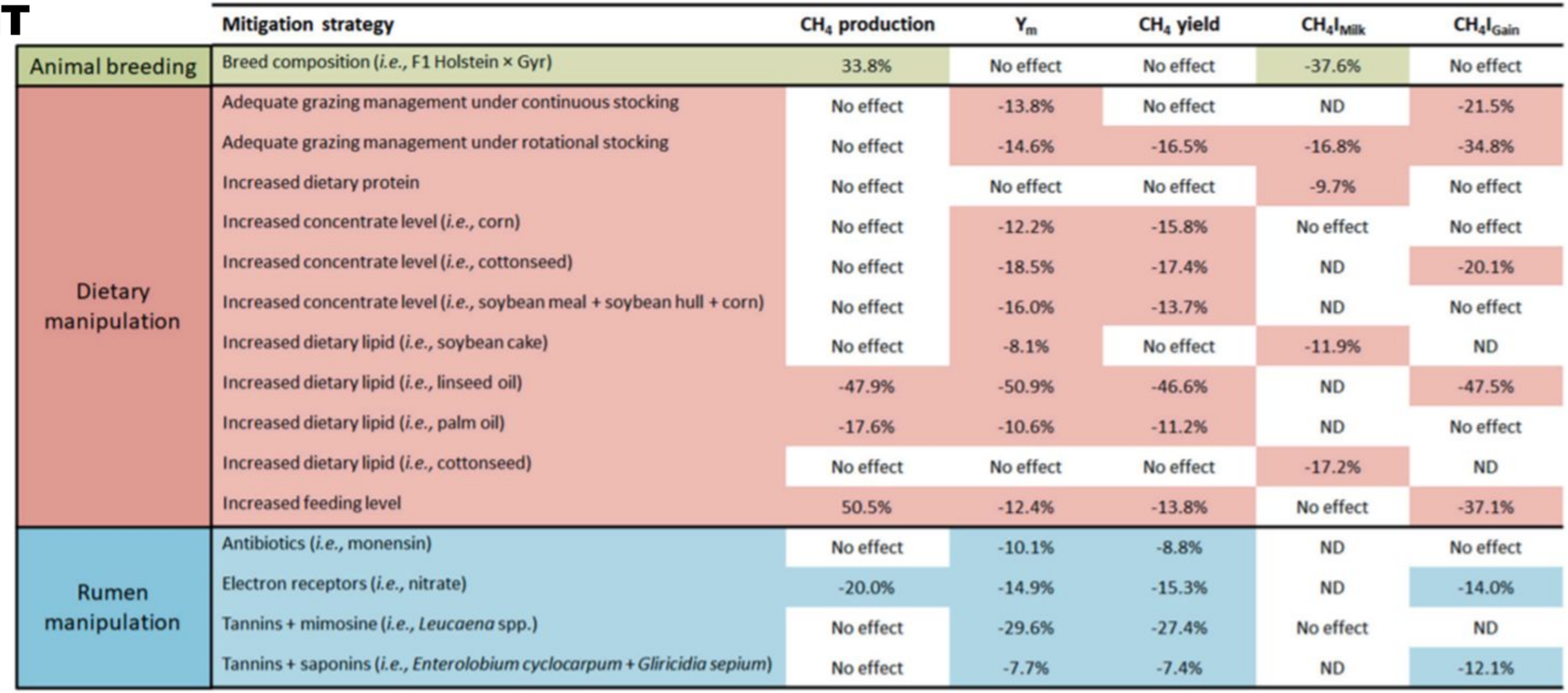


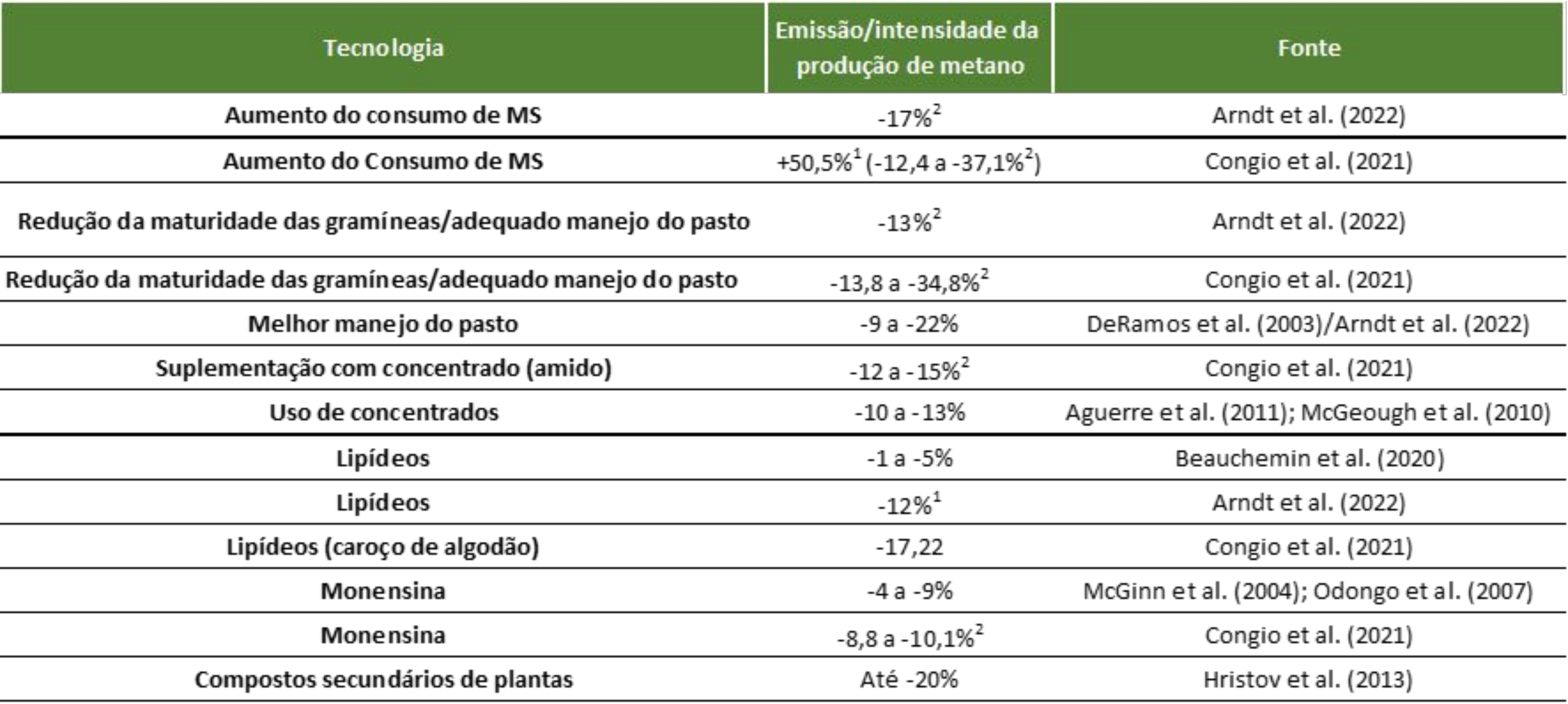
Fig. 1. Main and first-order mitigation strategies included in the current meta-analysis. For a complete list of potential mitigating strategies see Table A.1 (Appendix A).



	Mitigation strategy	CH_4 production	Y_m	CH_4 yield	CH_4I_{Milk}	CH_4I_{Gain}
Animal breeding	Breed composition (*i.e.*, F1 Holstein × Gyr)	33.8%	No effect	No effect	-37.6%	No effect
Dietary manipulation	Adequate grazing management under continuous stocking	No effect	-13.8%	No effect	ND	-21.5%
	Adequate grazing management under rotational stocking	No effect	-14.6%	-16.5%	-16.8%	-34.8%
	Increased dietary protein	No effect	No effect	No effect	-9.7%	No effect
	Increased concentrate level (*i.e.*, corn)	No effect	-12.2%	-15.8%	No effect	No effect
	Increased concentrate level (*i.e.*, cottonseed)	No effect	-18.5%	-17.4%	ND	-20.1%
	Increased concentrate level (*i.e.*, soybean meal + soybean hull + corn)	No effect	-16.0%	-13.7%	ND	No effect
	Increased dietary lipid (*i.e.*, soybean cake)	No effect	-8.1%	No effect	-11.9%	ND
	Increased dietary lipid (*i.e.*, linseed oil)	-47.9%	-50.9%	-46.6%	ND	-47.5%
	Increased dietary lipid (*i.e.*, palm oil)	-17.6%	-10.6%	-11.2%	ND	No effect
	Increased dietary lipid (*i.e.*, cottonseed)	No effect	No effect	No effect	-17.2%	ND
	Increased feeding level	50.5%	-12.4%	-13.8%	No effect	-37.1%
Rumen manipulation	Antibiotics (*i.e.*, monensin)	No effect	-10.1%	-8.8%	ND	No effect
	Electron receptors (*i.e.*, nitrate)	-20.0%	-14.9%	-15.3%	ND	-14.0%
	Tannins + mimosine (*i.e.*, *Leucaena* spp.)	No effect	-29.6%	-27.4%	No effect	ND
	Tannins + saponins (*i.e.*, *Enterolobium cyclocarpum* + *Gliricidia sepium*)	No effect	-7.7%	-7.4%	ND	-12.1%

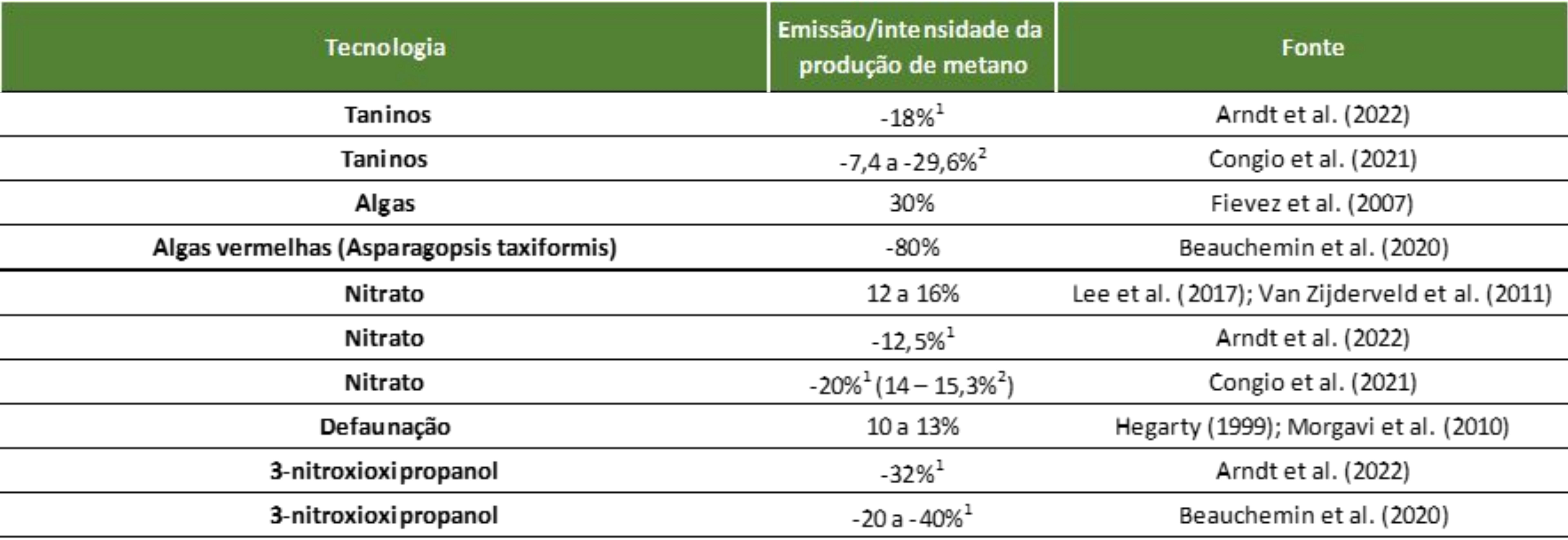
Fig. 2. Successful mitigation strategies and their mean effect size (%) on enteric methane emission metrics. Positive values indicate an increment by the potential mitigation strategy compared with a control and negative values indicate a reduction. All effects in the table are statistically significant at adjusted $P \leq 0.05$, whereas no effect indicates adjusted $P > 0.05$. All adjusted *P*-values as well as 95% confidence intervals were provided in tables in Appendix A. CH_4 production: daily CH_4 emission (g/d); Y_m: CH_4 energy as a percentage of gross energy intake; CH_4 yield: g CH_4/kg dry matter intake; CH_4I_{Milk}: CH_4 emission intensity for milk (g CH_4/kg of milk yield); CH_4I_{Gain}: CH_4 emission intensity for body weight gain (g CH_4/kg of average daily gain); ND: no data.

Tabela 1. Tecnologias utilizadas e seus impactos sobre a redução da produção do metano ruminal.



Tecnologia	Emissão/intensidade da produção de metano	Fonte
Aumento do consumo de MS	-17%[2]	Arndt et al. (2022)
Aumento do Consumo de MS	+50,5%[1] (-12,4 a -37,1%[2])	Congio et al. (2021)
Redução da maturidade das gramíneas/adequado manejo do pasto	-13%[2]	Arndt et al. (2022)
Redução da maturidade das gramíneas/adequado manejo do pasto	-13,8 a -34,8%[2]	Congio et al. (2021)
Melhor manejo do pasto	-9 a -22%	DeRamos et al. (2003)/Arndt et al. (2022)
Suplementação com concentrado (amido)	-12 a -15%[2]	Congio et al. (2021)
Uso de concentrados	-10 a -13%	Aguerre et al. (2011); McGeough et al. (2010)
Lipídeos	-1 a -5%	Beauchemin et al. (2020)
Lipídeos	-12%[1]	Arndt et al. (2022)
Lipídeos (caroço de algodão)	-17,22	Congio et al. (2021)
Monensina	-4 a -9%	McGinn et al. (2004); Odongo et al. (2007)
Monensina	-8,8 a -10,1%[2]	Congio et al. (2021)
Compostos secundários de plantas	Até -20%	Hristov et al. (2013)

Tabela 1. Tecnologias utilizadas e seus impactos sobre a redução da produção do metano ruminal.



Tecnologia	Emissão/intensidade da produção de metano	Fonte
Taninos	-18%[1]	Arndt et al. (2022)
Taninos	-7,4 a -29,6%[2]	Congio et al. (2021)
Algas	30%	Fievez et al. (2007)
Algas vermelhas (Asparagopsis taxiformis)	-80%	Beauchemin et al. (2020)
Nitrato	12 a 16%	Lee et al. (2017); Van Zijderveld et al. (2011)
Nitrato	-12,5%[1]	Arndt et al. (2022)
Nitrato	-20%[1] (14 – 15,3%[2])	Congio et al. (2021)
Defaunação	10 a 13%	Hegarty (1999); Morgavi et al. (2010)
3-nitroxioxipropanol	-32%[1]	Arndt et al. (2022)
3-nitroxioxipropanol	-20 a -40%[1]	Beauchemin et al. (2020)

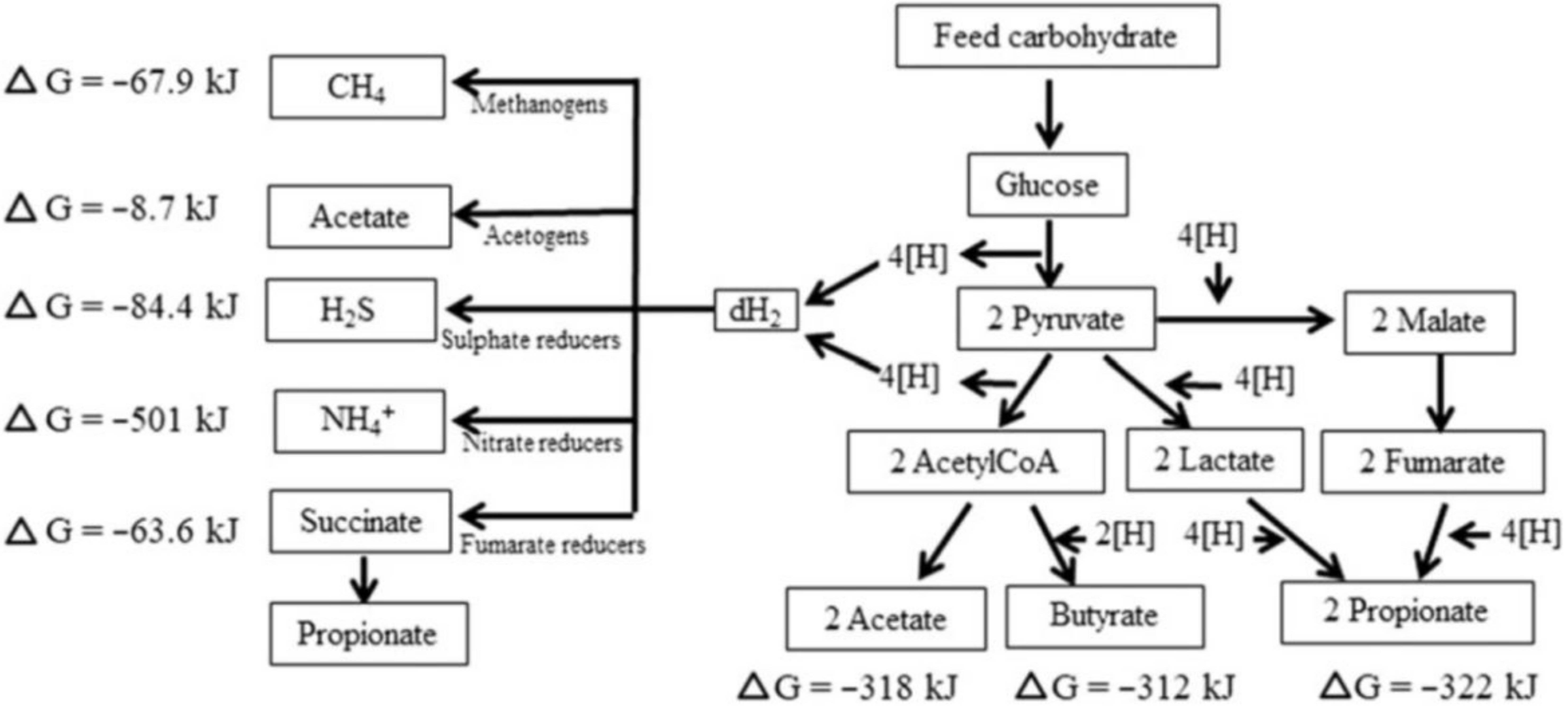


Figure 2 Scheme of the major pathways of rumen fermentation including generation and incorporation of metabolic hydrogen ([H]) and dihydrogen (H_2). Estimated Gibbs energy changes are based on Kohn and Boston (2000) and Ungerfeld and Kohn (2006) without considering ATP generation. Generation and incorporation of [H] are estimated based on 1 mol of glucose fermentation according to the following reactions: $C_6H_{12}O_6$ (glucose)→2 $C_3H_4O_3$ (pyruvate)+ 2 [2H]; 2 $C_3H_4O_3$ + 2 HSCoA (non-esterified coenzyme A) → 2 C_2H_3OSCoA (acetyl coenzyme A) + 2 CO_2 + 4 [2H]; C_2H_3OSCoA + H_2O (water) →→ $C_2H_4O_2$ (acetate) + HSCoA; 2 C_2H_3OSCoA + 2 [2H] → $C_4H_8O_2$ (butyrate) + 2 HSCoA; 2 $C_3H_4O_3$ + 2 [2H] → 2 $C_3H_6O_3$ (lactate); 2 $C_3H_6O_3$ + 2 [2H] → 2 $C_3H_6O_2$ (propionate) + 2 H_2O; 2 $C_3H_4O_3$ + 2 [2H] + 2 CO_2 (carbon dioxide) → 2 $C_4H_6O_5$ (malate); 2 $C_4H_4O_4$ (fumarate) + 2 [2H] →→ 2 $C_3H_6O_2$ + 2 CO_2.

J. Dairy Sci. 96:5161–5173
http://dx.doi.org/10.3168/jds.2012-5923

Anti-methanogenic effects of monensin in dairy and beef cattle: A meta-analysis

J. A. D. Ranga Niroshan Appuhamy,*[1] A. B. Strathe,* S. Jayasundara,† C. Wagner-Riddle,† J. Dijkstra,‡ J. France,§ and E. Kebreab*
*Department of Animal Science, University of California, Davis 95616
†School of Environmental Sciences, University of Guelph, Guelph, ON, Canada N1G 2W1
‡Animal Nutrition Group, Wageningen University, PO Box 338, 6700 AH Wageningen, the Netherlands
§Department of Animal and Poultry Science, University of Guelph, Guelph, ON, Canada N1G 2W1

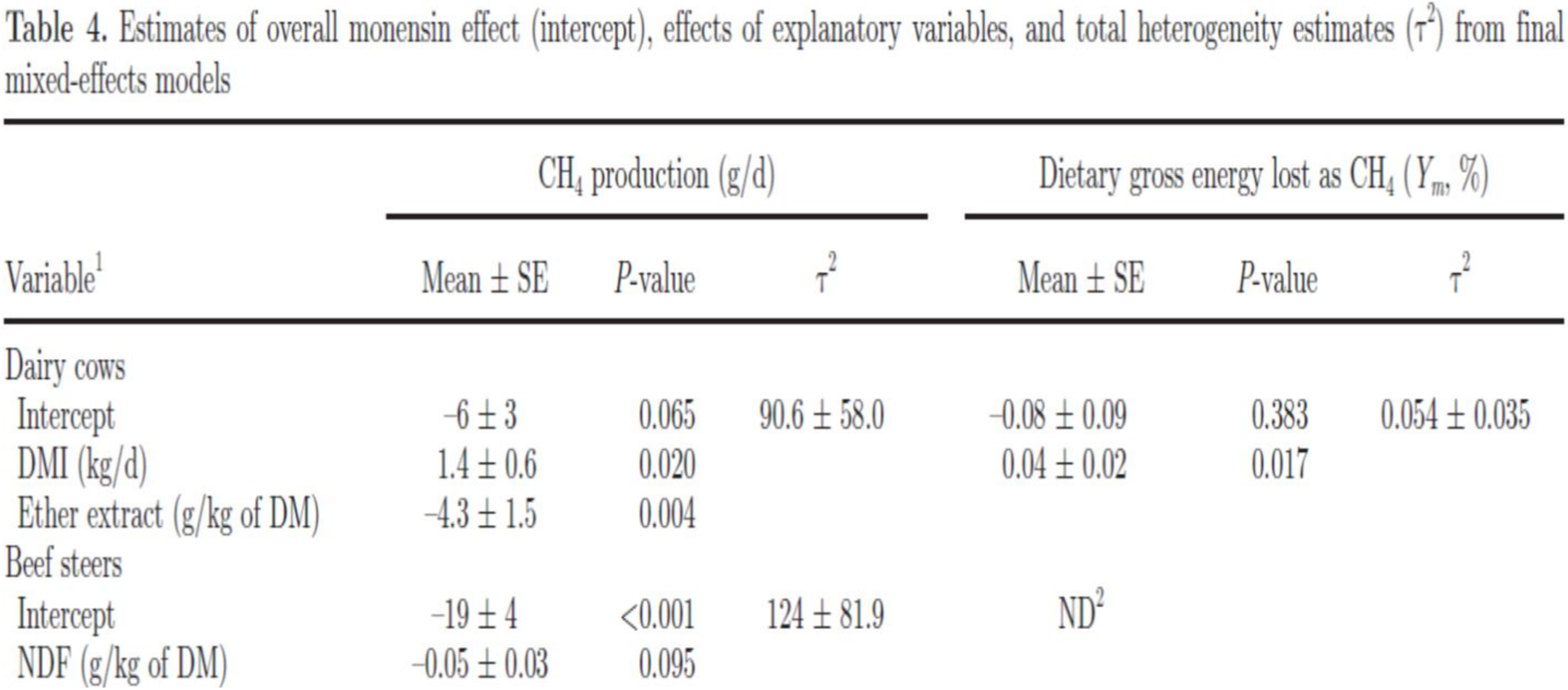


Table 4. Estimates of overall monensin effect (intercept), effects of explanatory variables, and total heterogeneity estimates (τ^2) from final mixed-effects models

	CH$_4$ production (g/d)			Dietary gross energy lost as CH$_4$ (Y_m, %)		
Variable[1]	Mean ± SE	*P*-value	τ^2	Mean ± SE	*P*-value	τ^2
Dairy cows						
Intercept	–6 ± 3	0.065	90.6 ± 58.0	–0.08 ± 0.09	0.383	0.054 ± 0.035
DMI (kg/d)	1.4 ± 0.6	0.020		0.04 ± 0.02	0.017	
Ether extract (g/kg of DM)	–4.3 ± 1.5	0.004				
Beef steers						
Intercept	–19 ± 4	<0.001	124 ± 81.9	ND[2]		
NDF (g/kg of DM)	–0.05 ± 0.03	0.095				

REDUÇÃO DA PRODUÇÃO DE CH4:

-14% EM GADO DE CORTE

- 2% EM GADO DE LEITE

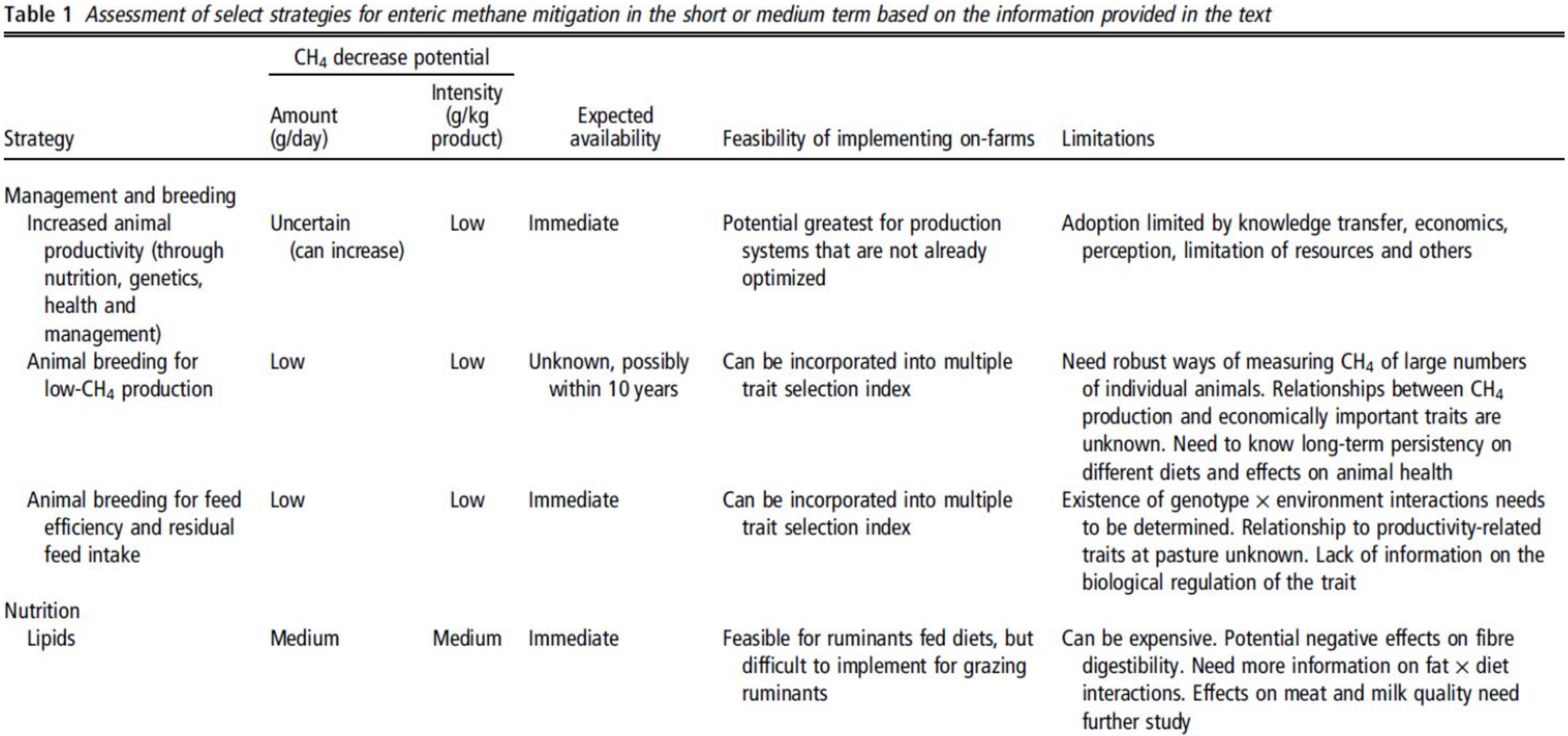


Table 1 *Assessment of select strategies for enteric methane mitigation in the short or medium term based on the information provided in the text*

Strategy	CH_4 decrease potential: Amount (g/day)	CH_4 decrease potential: Intensity (g/kg product)	Expected availability	Feasibility of implementing on-farms	Limitations
Management and breeding					
Increased animal productivity (through nutrition, genetics, health and management)	Uncertain (can increase)	Low	Immediate	Potential greatest for production systems that are not already optimized	Adoption limited by knowledge transfer, economics, perception, limitation of resources and others
Animal breeding for low-CH_4 production	Low	Low	Unknown, possibly within 10 years	Can be incorporated into multiple trait selection index	Need robust ways of measuring CH_4 of large numbers of individual animals. Relationships between CH_4 production and economically important traits are unknown. Need to know long-term persistency on different diets and effects on animal health
Animal breeding for feed efficiency and residual feed intake	Low	Low	Immediate	Can be incorporated into multiple trait selection index	Existence of genotype × environment interactions needs to be determined. Relationship to productivity-related traits at pasture unknown. Lack of information on the biological regulation of the trait
Nutrition					
Lipids	Medium	Medium	Immediate	Feasible for ruminants fed diets, but difficult to implement for grazing ruminants	Can be expensive. Potential negative effects on fibre digestibility. Need more information on fat × diet interactions. Effects on meat and milk quality need further study

Lipídeos = 1% to 5% de redução na produção de CH4 (g/dia) para cada 1% de lipídeos adicionados à dieta (Grainger and Beauchemin, 2011);

Ácidos graxos de cadeia média (C12:0, C14) e poliinsaturados são mais potentes (Patra, 2013).

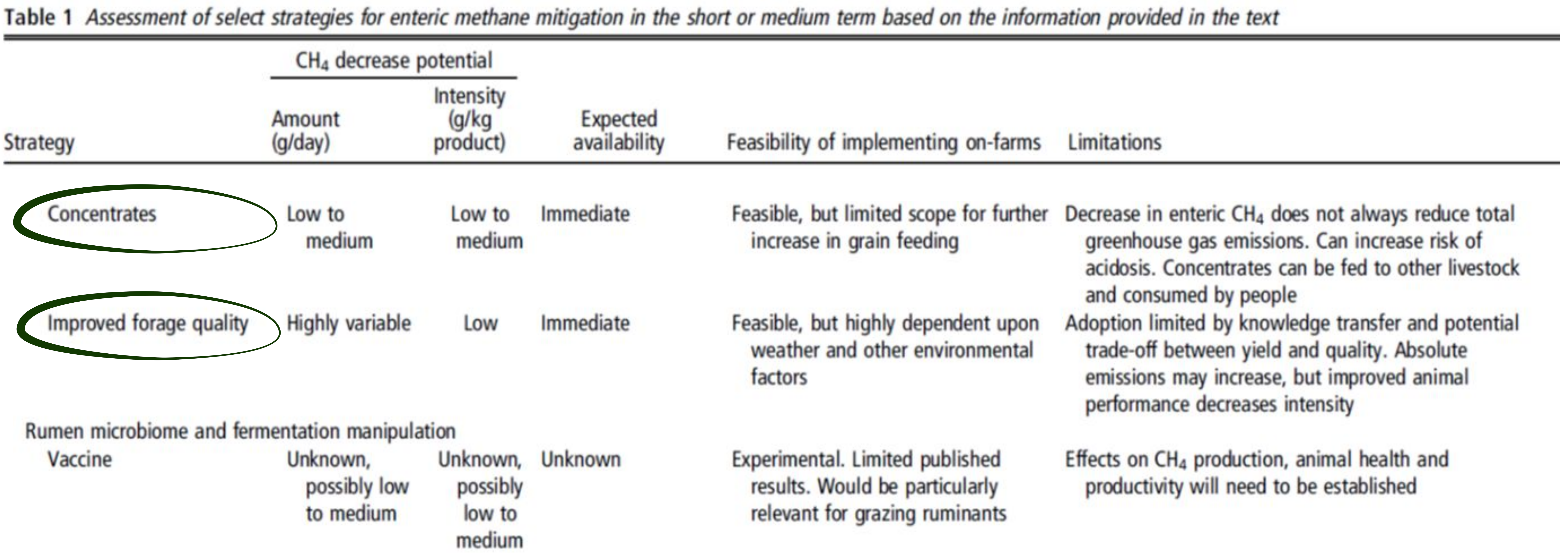


Table 1 *Assessment of select strategies for enteric methane mitigation in the short or medium term based on the information provided in the text*

Strategy	CH$_4$ decrease potential: Amount (g/day)	CH$_4$ decrease potential: Intensity (g/kg product)	Expected availability	Feasibility of implementing on-farms	Limitations
Concentrates	Low to medium	Low to medium	Immediate	Feasible, but limited scope for further increase in grain feeding	Decrease in enteric CH$_4$ does not always reduce total greenhouse gas emissions. Can increase risk of acidosis. Concentrates can be fed to other livestock and consumed by people
Improved forage quality	Highly variable	Low	Immediate	Feasible, but highly dependent upon weather and other environmental factors	Adoption limited by knowledge transfer and potential trade-off between yield and quality. Absolute emissions may increase, but improved animal performance decreases intensity
Rumen microbiome and fermentation manipulation					
Vaccine	Unknown, possibly low to medium	Unknown, possibly low to medium	Unknown	Experimental. Limited published results. Would be particularly relevant for grazing ruminants	Effects on CH$_4$ production, animal health and productivity will need to be established

CONCENTRADOS

Depende do nível de concentrado, mas as respostas são baixas em níveis moderados de suplementação; entretanto, o aumento do GMD ou PL tende a reduzir a intensidade de emissão de CH4;

QUALIDADE DA FORRAGEM

Baixa resposta, podendo chegar a 12% de redução na emissão de CH4; mas pastos bem manejados colaboram para o aumento do estoque de carbono no solo;

J. Dairy Sci. 105:4064–4082
https://doi.org/10.3168/jds.2021-20782

Methane mitigation potential of 3-nitrooxypropanol in lactating cows is influenced by basal diet composition

Sanne van Gastelen,[1*] Jan Dijkstra,[2] Jeroen M. L. Heck,[3] Maik Kindermann,[4] Arie Klop,[1] Rudi de Mol,[1] Dennis Rijnders,[4] Nicola Walker,[4] and André Bannink[1]
[1]Wageningen Livestock Research, Wageningen University & Research, PO Box 338, 6700 AH, Wageningen, the Netherlands
[2]Animal Nutrition Group, Wageningen University & Research, PO Box 338, 6700 AH, Wageningen, the Netherlands
[3]Friesland Campina, PO Box 1551, 3800 BN, Amersfoort, the Netherlands
[4]DSM Nutritional Products, Animal Nutrition & Health, PO Box 2676, 4002 Basel, Switzerland

3-Nitrooxypropanol

CH4 yield decreases of 20% to 40% have been reported depending upon animal, diet composition, dose and method of supplementing 3-NOP (Hristov et al., 2015; Dijkstra et al., 2018;

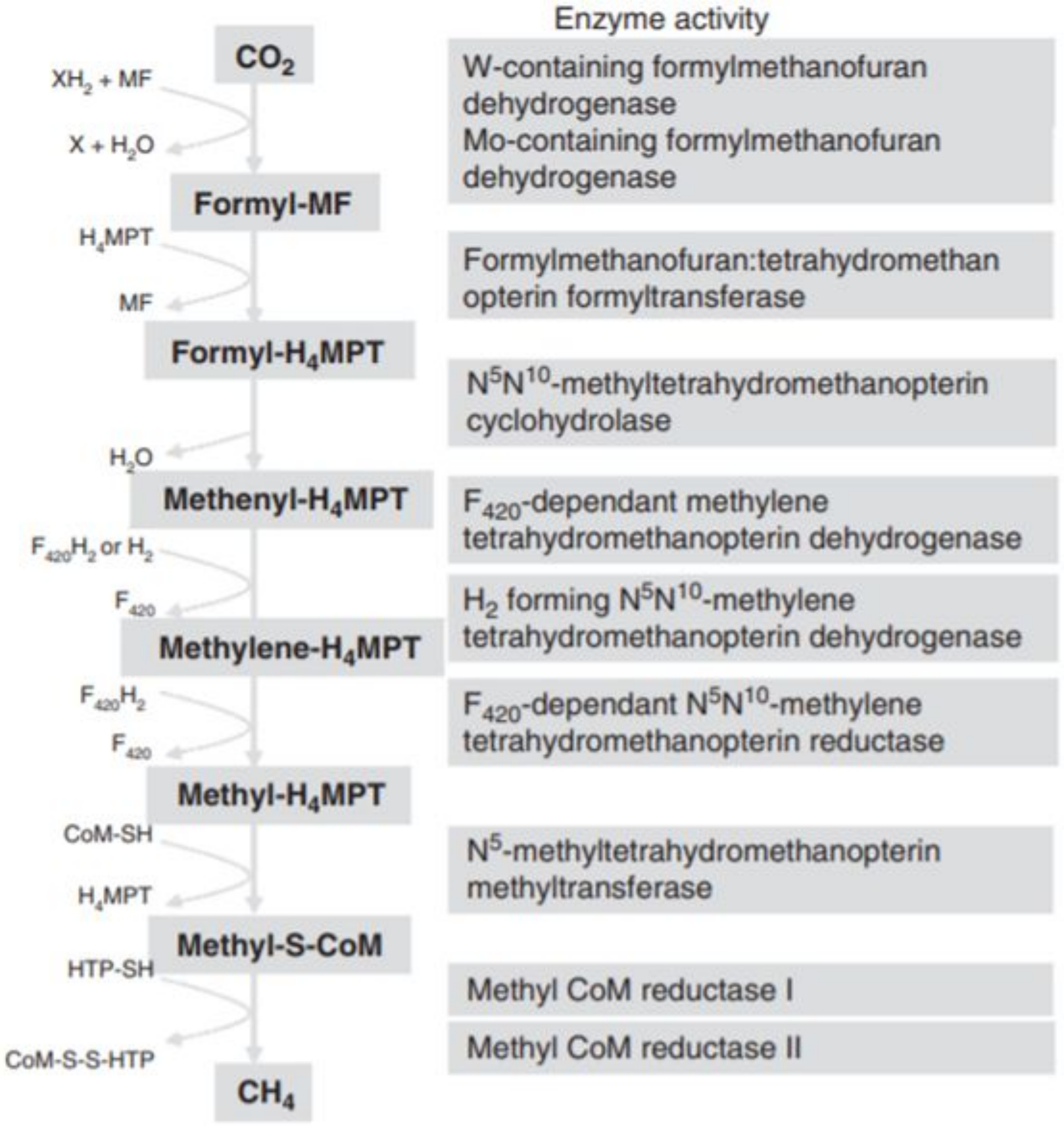
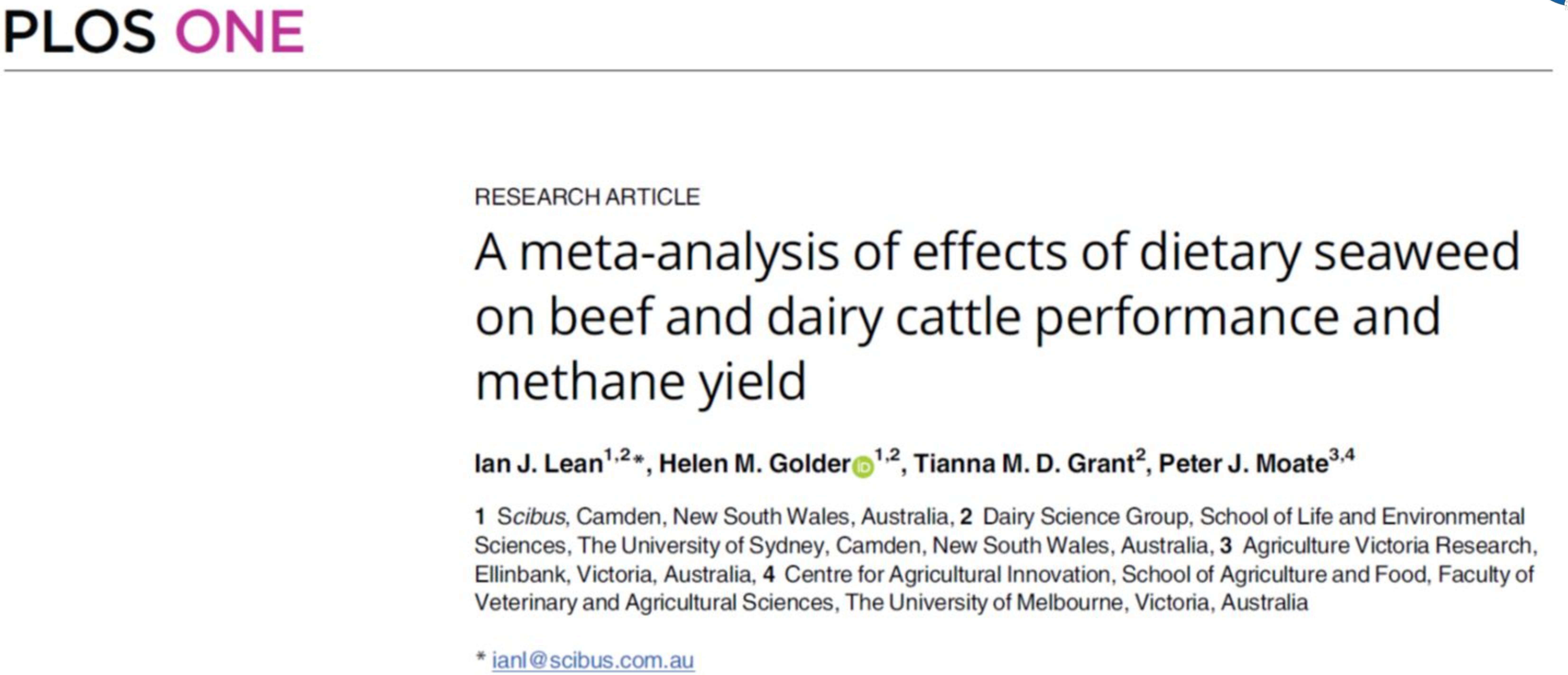


Fig. 1. Methanogenesis pathway from H$_2$ + CO$_2$. The seven-step enzymatic pathway for the formation of methane in hydrogenotrophic methanogens is shown. Formyl-MF, formylmethanofuran; Formyl-H$_4$MPT, N^5-formyltetrahydromethanopterin; Methenyl-H$_4$MPT, N^5, N^{10}-methenyltetrahydromethanopterin; Methylene-H$_4$MPT, N^5, N^{10}-methylenetetrahydromethanopterin; Methyl-H$_4$MPT, N^5-methyltetrahydromethanopterin; Methyl-S-CoM, methyl coenzyme M; F$_{420}$, coenzyme F$_{420}$; F$_{420}$H$_2$, reduced coenzyme F$_{420}$; H$_4$MPT, methanopterin; H-S-HTP, N-7-mercaptohetanoyl-O-phospho-L-threonine; X, unidentified electron donor.



PLOS ONE

RESEARCH ARTICLE

A meta-analysis of effects of dietary seaweed on beef and dairy cattle performance and methane yield

Ian J. Lean[1,2]*, Helen M. Golder[1,2], Tianna M. D. Grant[2], Peter J. Moate[3,4]

1 *Scibus*, Camden, New South Wales, Australia, **2** Dairy Science Group, School of Life and Environmental Sciences, The University of Sydney, Camden, New South Wales, Australia, **3** Agriculture Victoria Research, Ellinbank, Victoria, Australia, **4** Centre for Agricultural Innovation, School of Agriculture and Food, Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, Victoria, Australia

* ianl@scibus.com.au

Dichloromethane extract (found in A. taxiformis) was the most potent bioactive, reducing methane production by 79%, were bromoform, dibromochloromethane, bromochloroacetic acid, and dibromoacetic acid.

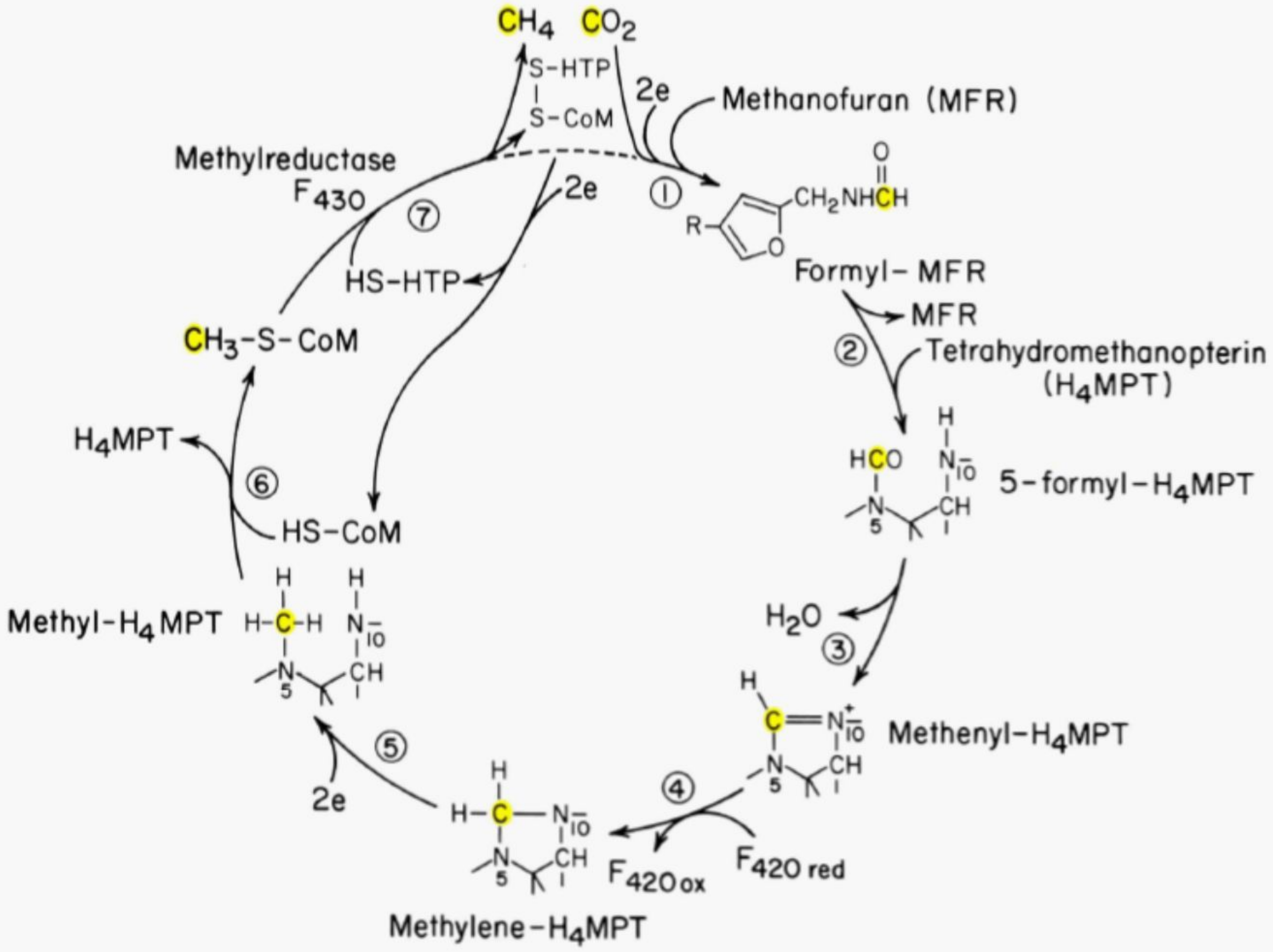
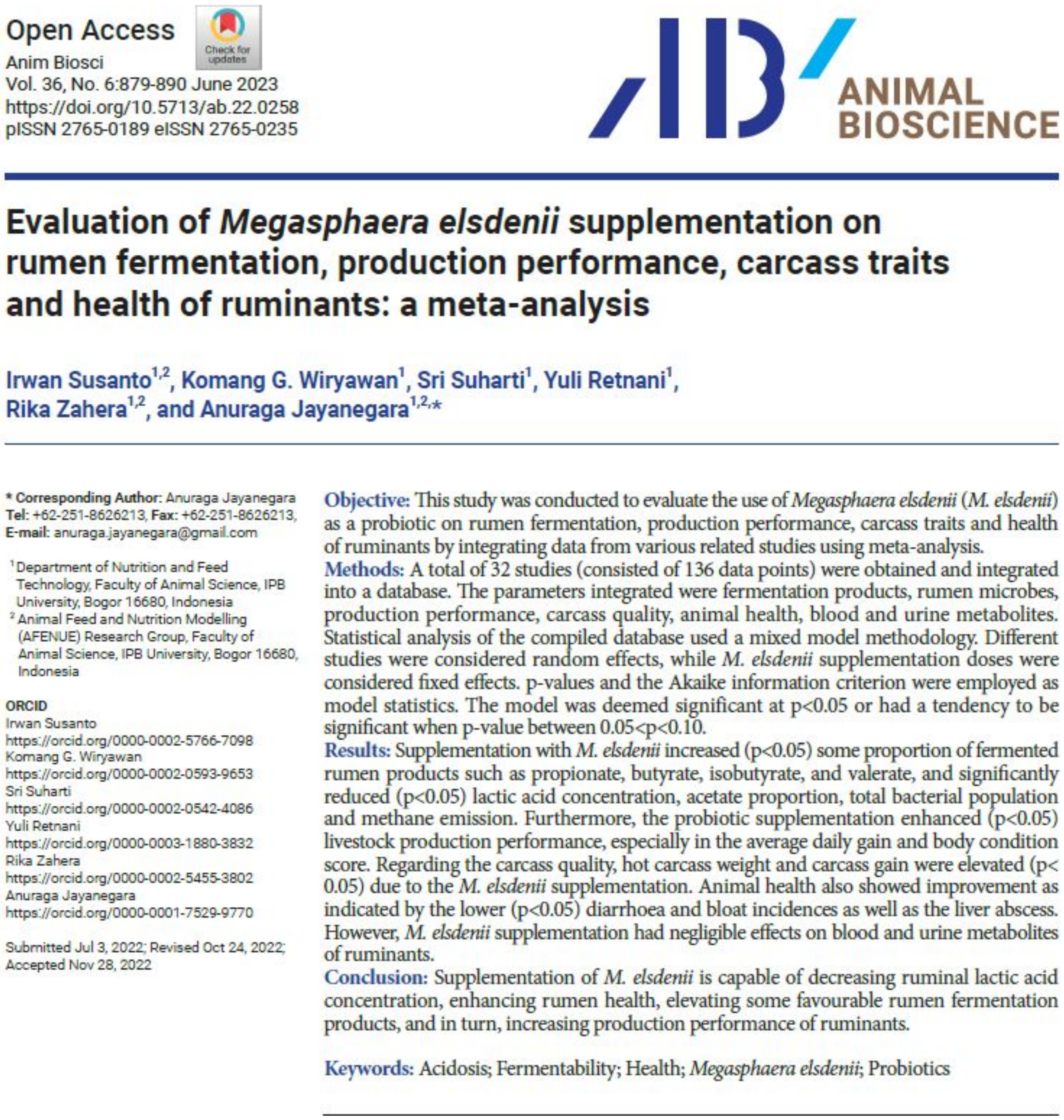


FIG. 2. **Proposed cycle for the reduction of CO_2 to CH_4.** The C_1 unit indicated by the *yellow dot* is sequentially modified, reduced, and transferred in "bucket brigade" fashion bound to coenzymes. Only that portion of the molecule involved in C_1 attachment is shown for methanofuran and tetrahydromethanopterin. The heterodisulfide couples in an unknown manner Reaction *7* to Reaction *1*.

Asparagopsis taxiformis



Open Access
Anim Biosci
Vol. 36, No. 6:879-890 June 2023
https://doi.org/10.5713/ab.22.0258
pISSN 2765-0189 eISSN 2765-0235

ANIMAL
BIOSCIENCE

Evaluation of *Megasphaera elsdenii* supplementation on rumen fermentation, production performance, carcass traits and health of ruminants: a meta-analysis

Irwan Susanto[1,2], Komang G. Wiryawan[1], Sri Suharti[1], Yuli Retnani[1],
Rika Zahera[1,2], and Anuraga Jayanegara[1,2,*]

*** Corresponding Author:** Anuraga Jayanegara
Tel: +62-251-8626213, **Fax:** +62-251-8626213,
E-mail: anuraga.jayanegara@gmail.com

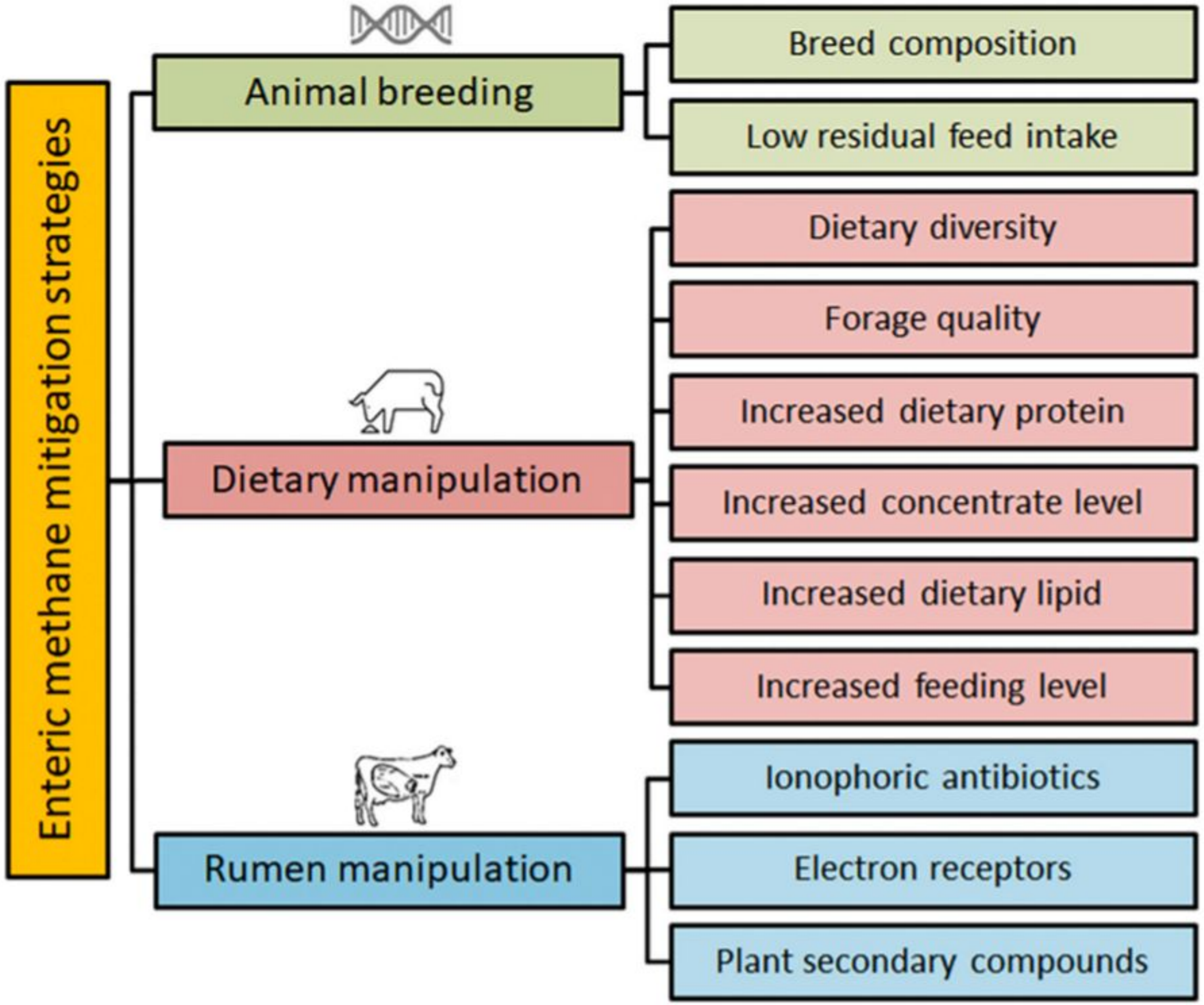
[1] Department of Nutrition and Feed Technology, Faculty of Animal Science, IPB University, Bogor 16680, Indonesia
[2] Animal Feed and Nutrition Modelling (AFENUE) Research Group, Faculty of Animal Science, IPB University, Bogor 16680, Indonesia

ORCID
Irwan Susanto
https://orcid.org/0000-0002-5766-7098
Komang G. Wiryawan
https://orcid.org/0000-0002-0593-9653
Sri Suharti
https://orcid.org/0000-0002-0542-4086
Yuli Retnani
https://orcid.org/0000-0003-1880-3832
Rika Zahera
https://orcid.org/0000-0002-5455-3802
Anuraga Jayanegara
https://orcid.org/0000-0001-7529-9770

Submitted Jul 3, 2022; Revised Oct 24, 2022; Accepted Nov 28, 2022

Objective: This study was conducted to evaluate the use of *Megasphaera elsdenii* (*M. elsdenii*) as a probiotic on rumen fermentation, production performance, carcass traits and health of ruminants by integrating data from various related studies using meta-analysis.
Methods: A total of 32 studies (consisted of 136 data points) were obtained and integrated into a database. The parameters integrated were fermentation products, rumen microbes, production performance, carcass quality, animal health, blood and urine metabolites. Statistical analysis of the compiled database used a mixed model methodology. Different studies were considered random effects, while *M. elsdenii* supplementation doses were considered fixed effects. p-values and the Akaike information criterion were employed as model statistics. The model was deemed significant at $p<0.05$ or had a tendency to be significant when p-value between $0.05<p<0.10$.
Results: Supplementation with *M. elsdenii* increased ($p<0.05$) some proportion of fermented rumen products such as propionate, butyrate, isobutyrate, and valerate, and significantly reduced ($p<0.05$) lactic acid concentration, acetate proportion, total bacterial population and methane emission. Furthermore, the probiotic supplementation enhanced ($p<0.05$) livestock production performance, especially in the average daily gain and body condition score. Regarding the carcass quality, hot carcass weight and carcass gain were elevated ($p<0.05$) due to the *M. elsdenii* supplementation. Animal health also showed improvement as indicated by the lower ($p<0.05$) diarrhoea and bloat incidences as well as the liver abscess. However, *M. elsdenii* supplementation had negligible effects on blood and urine metabolites of ruminants.
Conclusion: Supplementation of *M. elsdenii* is capable of decreasing ruminal lactic acid concentration, enhancing rumen health, elevating some favourable rumen fermentation products, and in turn, increasing production performance of ruminants.

Keywords: Acidosis; Fermentability; Health; *Megasphaera elsdenii*; Probiotics



- Enteric methane mitigation strategies
  - Animal breeding
    - Breed composition
    - Low residual feed intake
  - Dietary manipulation
    - Dietary diversity
    - Forage quality
    - Increased dietary protein
    - Increased concentrate level
    - Increased dietary lipid
    - Increased feeding level
  - Rumen manipulation
    - Ionophoric antibiotics
    - Electron receptors
    - Plant secondary compounds

Fig. 1. Main and first-order mitigation strategies included in the current meta-analysis. For a complete list of potential mitigating strategies see Table A.1 (Appendix A).

CONSIDERAÇÕES FINAIS

Metano ruminal tem contribuição na emissão de GEE;

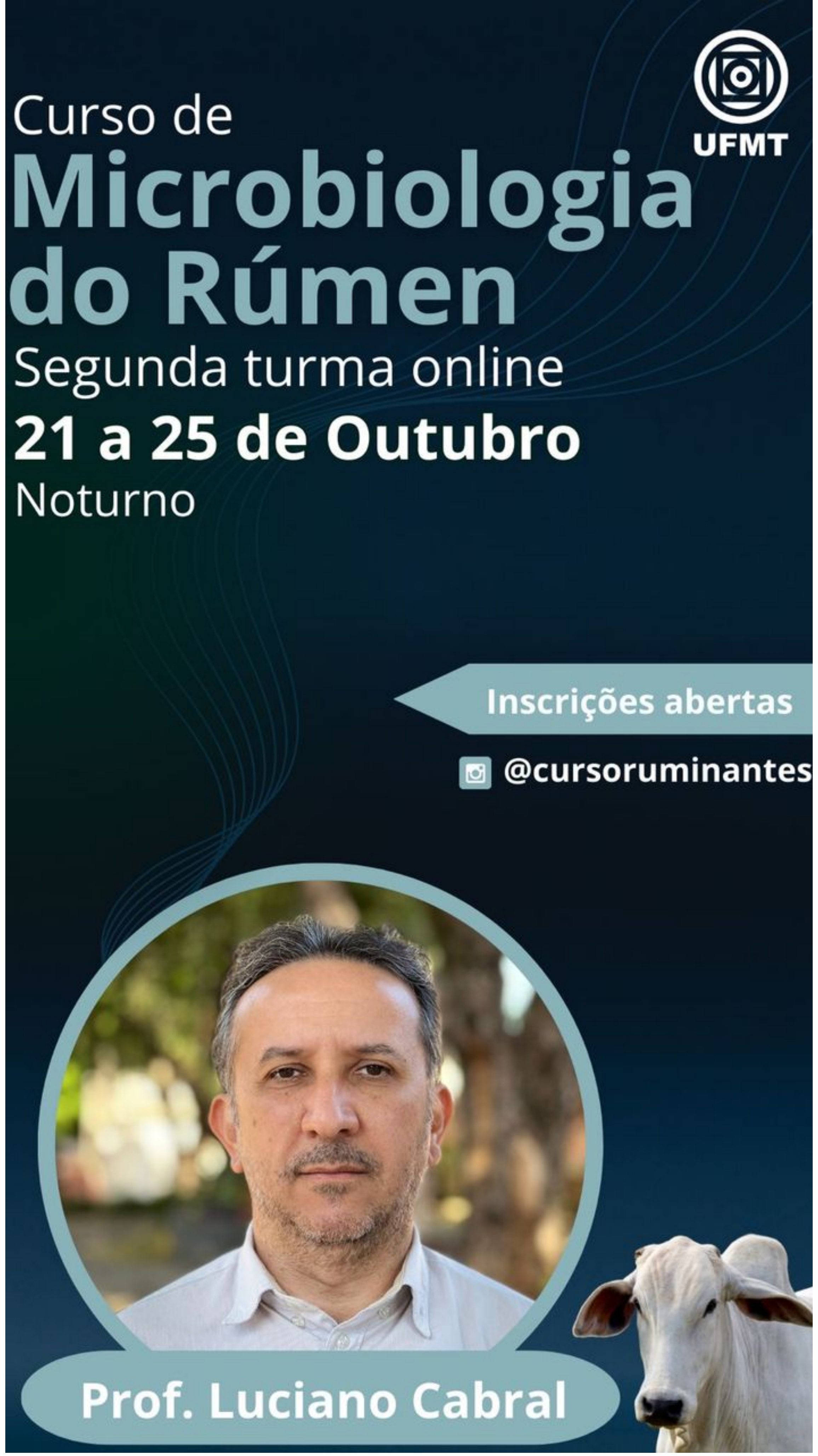
Maiores emissores são oriundas dos combustíveis fósseis e do desmatamento;

A pecuária tem um papel decisivo na redução das emissões;

Uso de tecnologias.

MUITO OBRIGADO!

lucianoufmt@gmail.com
Luciano.cabral@ufmt.br
(65) 99275-5858



UFMT

Curso de

Microbiologia do Rúmen

Segunda turma online

21 a 25 de Outubro

Noturno

Inscrições abertas

@cursoruminantes

Prof. Luciano Cabral

@CURSORUMINANTES