SEARCH

SUMMARY

A **carbon sink** is a natural or artificial reservoir that accumulates and stores some carbon-containing chemical compound for an indefinite period. The process by which carbon sinks remove carbon dioxide (CO_2) from the atmosphere is known as carbon sequestration.

The five major sinks are:

1) fossil fuels and carbonate rocks;

2) forests;

3) soils, including non-woody plants;

4) the oceans and

5) the atmosphere.

The distinction is arbitrary. Processes that release CO_2 to the atmosphere are called carbon "sources", while processes that absorb it are called carbon sinks.

Carbon (C) already in the biological cycle converted to carbon dioxide (CO_2) does not increase the size of the pool of cycled CO_2, so can have no net influence on global warming, whereas C_n does (derived from prehistoric sinks, e.g. fossil fuel and carbonate rocks).

Pastured beef can be produced with <5 % of its C derived from C_n , whereas in the manufacture, marketing and use of road, air and sea transport, it must be the case that >95 % of CO_2 produced is derived from C_n at present.

It is concluded that neither a report of the UN advice, nor the report from the University of Oxford accounted for the effects of the difference between C and C_n. This is even likely to be a factor when comparing vegetarian diets with pastured beef production, which can use less C_n than that used for producing vegetarian diets.

The report of the UN that livestock generate more greenhouse gases (GHGs) “than the entire transportation sector” would appear to be grossly incorrect, even if the C v C_n issue is ignored**.** Grasslands, fulfil several most important environmental functions.

Their mean albedo value is high and when on adequately drained soil the methanotrophic bacteria oxidise methane. But beef production on pasture is inefficient, as measured by output per ha and per unit energy intake. It is argued that these two factors are relatively unimportant in comparison to the effects of the potent GHGs, methane (CH_4) and nitrous oxide (N_2O).

Methane is eructed from the rumen and N_2O originates from faecal matter (dung) deposited on pasture. Several ways are proposed to decrease the methane production of ruminant livestock. These include: (1) plant breeding of lower protein grasses of higher digestibility, requiring a lower N input; (2) using forages of high digestibility and (3) chemical means of inhibiting rumen methanogenic bacteria. Such means could improve energy efficiency by up to 5 per cent and all three proposals may reduce ammonia and nitrous oxide emissions.

Nevertheless, ruminants will still constitute a major source of GHGs causing a disproportionately large effect on climate so that beef consumption will need to be reduced in developed countries.

Moreover, if the global number of cattle has only recently plateaued their effect on global warming will continue to increase for several decades. At this threshold global temperature rise of the earth system may be uncontrollable.

Thus, along with other means of control it will be important to cut the number of cattle now and improve their individual yield per unit of GHGs produced. But an excessive reduction in methane production could lead to a failure of cattle to achieve their goal of adequately converting fibre into human food.

Glossary

Carbon sources, C_n and C, The carbon in the biological C-cycle, derived from very long term repositories -fossil fuels and carbonate rocks for cement manufacture, is described here as new carbon, $\mathbf{C_n}$**.** The carbon in short term sinks e.g. soils, trees, animal bodies, is described as **C.** There are similar short-term repositories for nitrogen, N.

Methane sink, Any process that consumes methane from the atmosphere can be considered a "sink" of atmospheric methane.

Methanotrophic bacteria, metabolize methane as a source of energy in an aerobic environment.

Methanogenic bacteria, produce methane in an anaerobic environment.

INTRODUCTION

The global demand for animal products increases as a result of increasing prosperity and a greater efficiency of production. These facts have had the consequence that a higher proportion of the world's population now can afford to eat meat regularly.

Although beef is a more expensive meat, that derived from pastured stock is particularly prized. Anaemia is a worldwide problem in developing countries caused largely by parasite infections superimposed on poor vegetarian diets, devoid of heme iron. Nevertheless, it is considered by all scientists that as world population increases meat consumption per capita must decline in developed countries.

Pastured beef production has a relatively low productivity per ha compared with other forms of animal production. Flachowsky[1] (2002) demonstrated that the production of edible protein from beef had only a third the efficiency of milk production measured in terms of energy, and protein efficiency, or measured as emissions of N and of methane (Table 1). Moreover, compared with crop production for human consumption it has been well established that animal products compare unfavourably in efficiency per hectare or in energy use.

Pastured cattle are a major farming activity in countries of both temperate and tropical latitudes, where their contribution of ammonia (NH_3), nitrous oxide (N_2O), and methane (CH_4) emissions to the atmosphere is of considerable concern.

A 2006 UN FAO report[2] indicated that livestock generate more greenhouse gases as measured in CO_2 equivalents than the entire transportation sector. According to Henning Steinfeld of the UN, livestock account for 9 percent of anthropogenic CO_2, 65 percent of anthropogenic nitrous oxide and 37 percent of anthropogenic methane: "Livestock are one of the most significant contributors to today's most serious environmental problems."[2]

The estimate in this paper for road transport only, including **cars and commercial vehicles their annual fuel consumption produces the equivalent of 17.6 x** $\mathbf{10^9}$ **tonnes of** $\mathbf{C_nO_2}$.

This figure excludes the energy costs of manufacture and marketing of vehicles and that of air and sea transport. This figure also excludes nitrous oxide which would be minimal. **(see Appendix).**

"The study of British people's diets " conducted by University of Oxford scientists[3] found that meat-rich diets - defined as more than 100g per day – resulted in 7.2kg of carbon dioxide emissions. In contrast, both vegetarian and fish-eating diets caused about 3.8kg of CO_2 per day, while vegan diets produced only 2.9kg (The Guardian quote, Oct. 2015 omitted that the values were given as CO_2*equivalents*).

Microbial metabolism: Carbon and nitrogen in the biosphere are both parts of cycles. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other greenhouse gases (GHGs) are products of microbial activity in the soil and in the GI tracts of animals and Man and during metabolism of higher plants.

Sources of C: Fossil fuels and carbonate rocks are used in the manufacture and use of transport vehicles, agricultural implements and in fertilizer production. These sources play a much smaller role for grass-fed beef than for other crops. Thus, C in the form of CO_2 may be largely discounted as it is part of an existing bio-cycle. Our concern here is the extent to which C and N in this bio-cycle are converted to the gases CH_4 and N_2O rather than to CO_2 and to N_2**.**

PASTURE

Grasslands constitute a major global use of land and are a potential short-term sink of atmospheric carbon dioxide (CO_2). They have 5% greater mean albedo values than average agricultural crops grown in the same areas. They are a third better than deciduous trees-and have twice the value of coniferous evergreen forests, as measured by albedo.[4]

They are also an important biodiverse habitat for wildlife and a global source of large quantities of plant fibre which ruminants covert to meat and milk. Grass leys act as a rejuvenating break to continuous crop production, as a sink they absorb excess water during storms, and as a break they prevent soil erosion following heavy rainfall and following a drought with high winds.

Cattle, particularly those on grassland, pass gases such as nitrous oxide (N_2O) and methane (CH_4) in amounts that have significantly changed our atmosphere. Cattle, measured with their pasture, can also act as a sink for C and N when the stocking rate is low at less than one animal per hectare.

When stocking density is too high cattle will trample plants and soil and impede carbon storage. Under very wet conditions, the soil becomes anaerobic, carbon sequestration and the soil N-cycle are arrested, when N_2O is inadequately oxidised.

However, the capacity of pasture soil to act as a sink is limited. When C-enriched pasture organic matter is at its maximum it no longer acts as a net accumulator of C and N- it is then in equilibrium with the atmosphere.

Beef (and sheep) production on pasture should viewed differently to many other forms of agricultural production. Grasslands are the natural cover of many of the world's lands. These are frequently areas unsuitable for cultivation.

If left ungrazed by wild or domestic animals many would become forested. This could help act as carbon sinks, so long as the trees are deciduous broad-leaved, but not coniferous evergreen[4].

On these lands and on cultivated pastures the carbon (C) as methane and N, as nitrous oxide lost during bovine digestion and metabolism should be taken as the net difference between those values and their losses from decaying grasslands in the absence of cattle.

This would allow for the fact that all global surfaces produce GHGs and have a radiative forcing influence. Very little of the C evolved by grassland beef cattle will be that of $C_{\mathbf{n}}$. The source of this is mainly "chemical" fertilizer which will be less than it is for milk production, owing to a lower rate of production and the potential risk of digestive disturbances caused by grazing lush pastures.

Thus, CO_2 production of pastured beef can be largely ignored. In fact cattle act as a temporary sink for C. On the other hand, a vast amount of C is used during the manufacture, marketing and use of motor vehicles and aircraft. This will be derived from $C_{\mathbf{n}}$. Thus, this source of CO_2 must be accounted.

Objectives of this review

1. To determine the critical factors in pastured beef production which need to be improved in order that it may be made a lesser source of Greenhouse Gases (GHGs) and
2. To demonstrate that the above two published quotations are misleading.

Pastured beef has been heavily criticised for two principal reasons:

a) the output per ha is low and

b) pastured cattle produce large quantities of methane and nitrous oxide -potent GHGs.

The Guardian quotation of the statement made by the University of Oxford scientists fails to distinguish between CO_2 and CO_2 equivalents and in both this and the FAO quotation no distinction is drawn between $C_{\mathbf{n}}$ and C. Such a distinction is particularly pertinent with reference to the "entire transportation sector". Nevertheless, by disregarding this distinction our conclusion is not altered.

Methane and nitrous oxide- greenhouse gases (GHGs)

Methane Sinks

Aerobic soils act as a major sink for atmospheric methane through soil methanotrophic bacteria. These bacteria oxidize methane as a source of energy, producing carbon dioxide and water:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

The largest known sink of methane[5] involves its reaction with the hydroxyl radical(-OH), produced photo-chemically in the troposphere and stratosphere creating the CH3.radical and water vapour (equations,1and 2 below).

This reaction is one of the most important sources of water vapour in the upper atmosphere. During normal daytime conditions in the troposphere formaldehyde formed can react again with a hydroxyl radical to form carbon dioxide and more water vapour (equation 3). But water vapour itself is a potent GHG:

1) CH4 +·OH →·CH3+ H2O

2) CH3+·3OH → HCHO + 2H2O

3) HCHO +·4OH →CO2 +3H2O

Potency of CH_4 and N_2O

The 100-year global warming potential of methane is 28. That is, over a 100-year period, it traps 28 times more heat per mass unit than CO2.

It now accounts for 20% of the total radiative forcing from all of the long-lived and globally mixed GHGs. Although nitrous oxide is much more potent per mole, as a GHG, than is methane, overall it has only a third the effect of methane.

Moreover, methane is probably a contributory factor in ozone depletion which otherwise has a net protective effect.[6]

Methane Sources (Fig. 2)

Soil The level of the water table represents the boundary between anaerobic methanogenic bacterial production and aerobic methane consumption. When the water table is low, the methane generated within the anaerobic wetland soil has to rise through a deeper layer of aerobic soil containing methanotrophic bacteria, thereby reducing emissions.

Two soil Bacterial methanogenic processes

1) Acetate is cleaved during anaerobic fermentation to yield methane and carbon dioxide.

H3C-COOH → CH4 + CO2 (e.g. ruminant bacteria)

2) Hydrogen is oxidized with carbon dioxide to yield methane and water.

4H2 + CO2 → CH4 + 2H2O

Anthropogenic Sources

Energy losses as methane Energy lost through eructation of CH_4 has been shown to be 4.5 ± 1.4% [8] and 8 %[9] of gross energy intake on pasture.

Earlier work indicated that of anthropogenic CH_4 6.5-7.0 x 10^6 tonnes are emitted by ruminant animals through enteric fermentation in the EU annually[10] (***approximately 2.8 billion tonnes CO_2 equivalent per year in the world***). Fig. 2 indicates that soil bacteria in wet lands account for 22% and fermentation in the GI tract (mainly ruminants) accounts for 16 % of the total world production of atmospheric methane. In the present review recent data have been adopted.

A widely held notion is that domestic cattle each release between 70 and 120 kg of methane per year. If we assume a typical cow releases 100 kg of methane/year and 10^9 is their global population this is equivalent to 2.8 x 10^9 tonnes CO_2 equivalent (2.8 billion tonnes total + 0.9 billion for nitrous oxide ***(total <4 billion tonnes ofCO_2 equivalent from CH_4 + N_2O).***

However, Wolf *et al.* (2017)[11] estimated **all global livestock** emissions of 119.1 ± 18.2 Tg methane in 2011 (119 1 x 10^6 tons X 28 = ***3.33 X 10^9 tonnes CO_2 equiv***.); this quantity is 11% greater than that obtained using the IPCC 2006 emissions factors, encompassing an 8.4% increase in enteric fermentation methane, and a 36.7% increase in manure management methane.

If 0.35 billion tonnes for N_2O (see DUNG below) is added to this figure the ***total is <4.0 x 10^9 tonnes of total CO_2 equivalent, GHGs by domestic livestock (mainly ruminant + pigs) production per year*** –a similar value to the first estimate above.

The FAO[12] estimated total emissions from **all global livestock** to be 7.1 Gigatonnes of CO_2, (***7.1 x 10^9 tonnes CO_2-equiv. per year***), representing 14.5 percent of all anthropogenic GHG emissions. This figure, covering all livestock, is in line FAO's previous assessment, Livestock's Long Shadow, published in 2006, but greater than Wolf's more recent figure for livestock[12] and comparable to our figure solely for cattle of <4x10^9 tonnes CO_2-equiv per year.

Land vehicle production of GHGs from fuel: the total production of CO_2 in 2015 by land vehicles = ***17.6 x 10^9 tonnes of C_nO_2***. This figure excludes the energy costs of manufacture and marketing of vehicles and it excludes air and sea transport. This figure also excludes nitrous oxide which would be minimal (Appendix).

Factors affecting the rate of methane production

1. **Pasture type and quality** influences methane production by grazing cattle. Heifers grazing alfalfa produced 40-50 % more methane than those on the grass pasture (59 v 41 kg. CH_4.head^{-1}·yr^{-1}).[13]
2. **Soil N content** Although contrary to evidence under laboratory conditions with rice plants, particularly in an anaerobic state[14] the CH_4 oxidation rate in soil is reduced as N inputs increase. Agriculture increases the amount of N in the soil, which inhibits methane oxidation, weakening the ability of methanotrophic bacteria in the soil to act as sinks.[15,16]
3. **Stocking density** influences the CH_4 production. Comparing two low densities of 0.1 and 0.2 cattle/ha[17] workers found that mean CH_4 emission was 69 kg/yr.animal, but for CO_2 equiv./ha the lower density of 0.1 v. 0.2 cattle/ha in the

grazed grassland was a minor source of greenhouse gas of 9kg v 338 kg CO_2 equiv. ha.yr. This study illustrates the need to consider the stocking density when evaluating the environmental sustainability of grazed grasslands.
4. **Digestibility** CH_4 production is influenced by the digestibility of the diet. Grazed cattle each produced 84 kg $CH_4.yr^{-1}$ whereas each of those given a high grain diet produced only 26 $kg.yr^{-1}$[10], i.e. 8 % v 2 % of gross energy intake for grazed v feedlot. This does not imply cattle should be given cereal based diets, as his would destroy their function of using plant fibre.

n.b. the range of values referred to above (41-84 kg methane. $hd^{-1}yr^{-1}$) is generally below the values assumed in the estimates for CO_2 equivalents made in this paper of 70-100 $kg.hd^{-1}$.

DUNG

Methane There is a range in emissions of from 100 g to 700 g CH_4hd^{-1} yr^{-1}[16,18,19]. The variation is attributed to changes in ambient temperature and rainfall[15] at the time of deposition of the dung. Emission rates, however, decline rapidly when dung patches dry out, as aerobic decomposition occurs after approximately 20 days. Nevertheless, these emission rates are insignificant (i.e. only 0.5 % of the total methane per animal) when compared with those from the rumen of cattle[19].

Nitrous oxide However, Flessa et al. (1995)[19] estimate the global N_2O emission from dung patches are significant~1.18 teragrams (1.18 x 10^9kg) N_2O-N per year, indicating that the excretory products of grazing cattle are one of the most important sources of atmospheric nitrous oxide. (1.18 million tonnes/yr),***Total annual global ruminant N_2O = 0.35 billion tonnes of CO_2 equivalent***. n.b the addition of sheep will have a very minor effect on this value.

RUMINAL METHANE METABOLISM

Acetate and butyrate promote methane production while propionate formation can be considered as a competitive pathway for hydrogen use in the rumen.

The most promising approach would be to shift the fermentation, altering the volatile fatty-acid profile toward propionate (C3) production, a more energy dense fatty acid than acetate. This shift requires increasing gram-negative bacteria that favour starch fermentation with a proportionate reduction in acetate (C2) and butyrate (C4) fermentation.

Such an approach, using roughage of higher digestibility should be an objective. Nevertheless, an excessive shifts will reduce the digestibility of fibre and productivity of cattle that make use of the large quantities of fibre present in the world[8]. A balance is required between these opposing aims!

Monensin Monensin is an ionophore that increases overall energy yield from feed, and improves animal performance when used at a rate of 33-48 mg/kg barley-based finishing rations. It does this by reducing gram-positive bacteria that favour fibre fermentation in the rumen, thereby increasing gram-negative bacteria favouring starch fermentation. Gram-negative bacteria produce more propionate fatty acid, and reducing the acetate-propionate ratio is a known benefit to feeding Monensin.

Fish oil The addition of 2 % fish oil, rich in omega-3, to the diet of cattle reduces methane emissions, as fish oil inhibits the methane-producing ruminal bacteria.[20]

Rapeseed Oil-spray on pasture as canola oil**. F**atty acid composition: Saturated: 7%. Monounsaturated: 63%. Polyunsaturated: 28% (with omega-6 and omega-3 in a 2:1 ratio, i.e. 9.5 % ω-3–linolenic acid) is an effective means of reducing CH_4emissions from grazed pasture.[21]

CONCLUSIONS

The reason ruminants are so important to mankind is that much of the world's edible biomass is rich in cellulosic fibre, which humans cannot digest.

Cattle can convert this fibre into high quality protein sources (i.e. meat and milk) for human consumption; but our problem is to balance this against the concomitant production of methane and other undesirable effluents. An excessive reduction in methane production could lead to a failure of cattle to achieve their goal of adequately converting fibre into human food.

A reduction in beef consumption:

Grazing production of beef is a relatively inefficient method of producing human food and it causes excessive quantities of greenhouse gases per unit of food it produces. This does not mean pastures should be ploughed-up and crops grown for intensively fed beef production to replace it.

But beef should come increasingly from cast-offs in milking herds. Meat consumption must decline per capita in developed countries. This subject has been discussed in considerable detail[22]. On the other hand it should not be forgotten anaemia is a worldwide problem in developing countries caused largely by parasite infections superimposed on poor vegetarian diets, devoid of heme iron.

To improve the environmental acceptability of grassland beef production:

The development of forage and grass species specifically for the purpose of reducing methane and nitrous oxide production may have the largest effects for reducing their emission intensity in pastured beef cattle. This should be coupled with chemical means of reducing the activity of ruminal methane-producing gram-positive bacteria and promoting gram-negative bacteria.

Highly digestible grass varieties of lower protein content are needed, responding to lower soil N inputs. Soil drainage should be adequate. Stocking-density presents a problem owing to the low output per unit area of beef production conflicting with the effects of an apparent exponential rise in CH_4 productionper unit area, associated with increasing stocking density.

If the present rising global number of cattle is halted and strictly maintained at a constant level the warming potential of their GHG emissions will continue for a number of decades until a threshold is approached. At this threshold global temperature rise of the earth system may be uncontrollable. Thus, along with other means of control it will be important to cut the number of cattle now and improve their individual yield per unit of GHGs produced.

Appendix

The US publisher Ward's, estimated that as of 2010 there were 1.015 billion motor vehicles in use in the world. In 2015, around 947 million passenger cars and 335 million commercial vehicles were in operation (total 1.282 billion) and assuming all commercial vehicles are diesel and all cars are petrol driven, passenger cars would produce approximately 4.94 billion tonnes of CO_2 per year and commercial vehicles 12.7 billion tonnes, giving a **total production of CO_2 in 2015 by land vehicles = 17.6 x 10^9 tonnes of C_nO_2**.

This figure excludes the energy costs of manufacture and marketing of vehicles and it excludes air and sea transport. This figure also excludes nitrous oxide which would be minimal**.**

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Figures

	Gross energy, GJ	Crude protein, kg	N emissions, kg	CH_4 kg
	All values per kg edible protein			
Beef	1.2	9.0	1.2	1.5
Cow's Milk	0.4	3.4	0.35	0.4
Pork	0.6	6.0	0.8	
Poultry meat	0.25	3.0	0.3	
Poultry eggs	0.35	3.5	0.4	

Table 1 Gross dietary requirements and emissions of N and methane related to 1 kg of edible protein production (Flachowsky, 2002)[1]

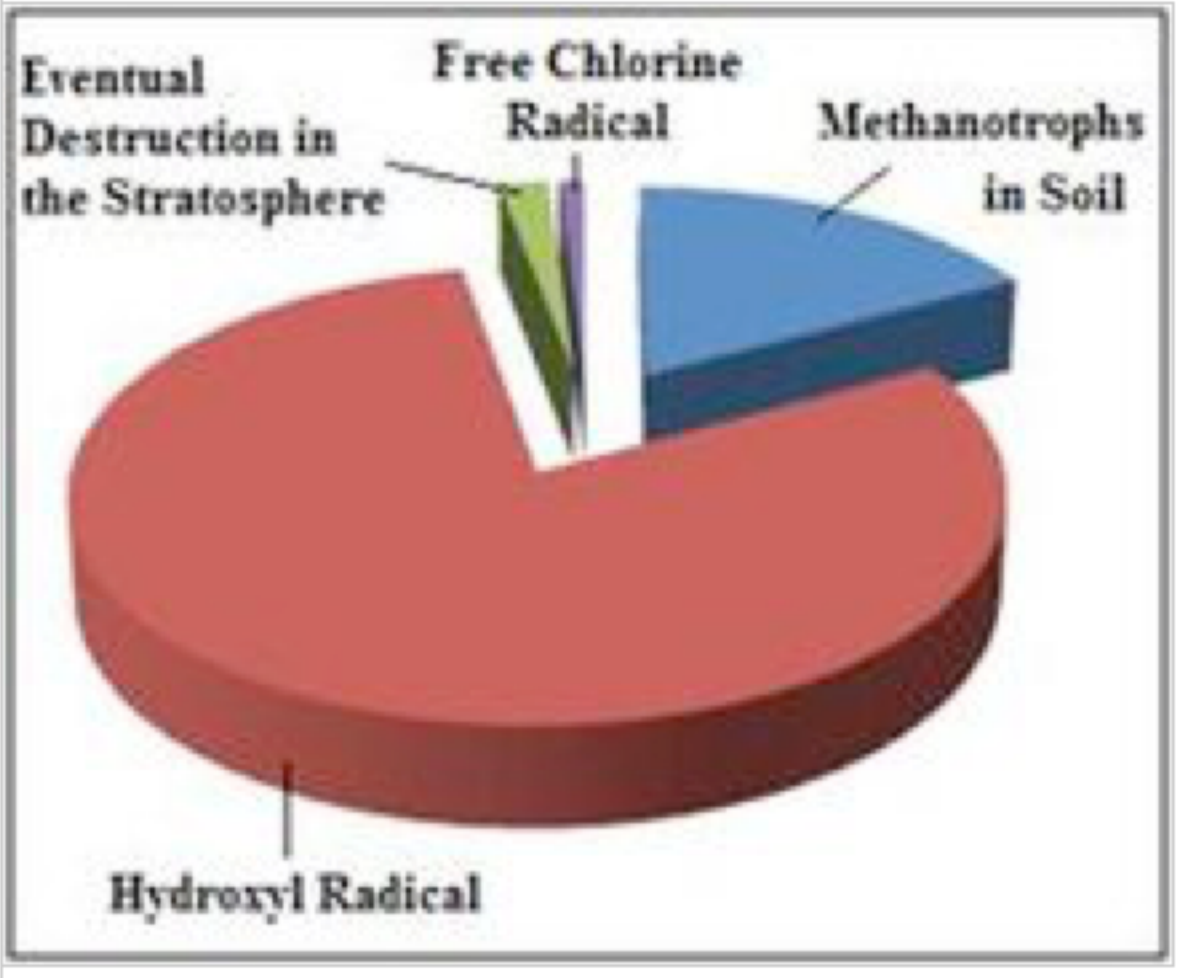

Fig. 1 Methane sinks and their proportional size.[5]

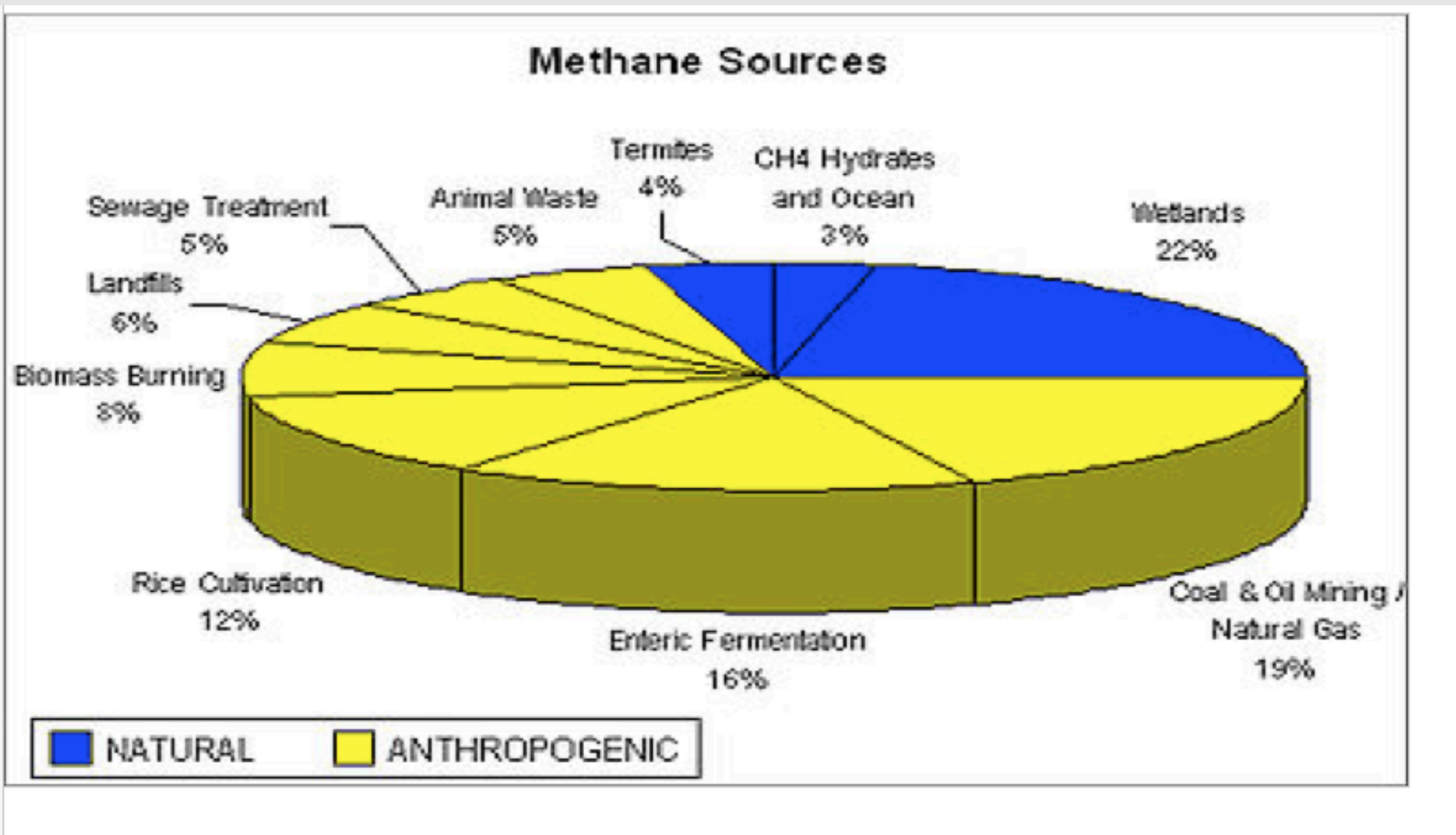

Fig. 2 Natural and anthropogenic methane sources, according to the NASA Goddard Institute for Space Studies[7]

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Dr David Frape

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