Methane production by ruminants

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Outline

› Methane emission numbers
› Methanogenesis: why? By who?
› Measurement techniques
› Mitigation strategies
CLIMATE CHANGE ??

“TWENTY-FIVE YEARS AGO PEOPLE COULD BE EXCUSED FOR NOT KNOWING MUCH, OR DOING MUCH, ABOUT CLIMATE CHANGE. TODAY, WE HAVE NO EXCUSE.”

- DESMOND TUTU

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The concept of global warming was created by and for the Chinese in order to make U.S. manufacturing noncompetitive.

- Donald Trump

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Global methane (CH₄) trends

Increase in world population!

14% of the increase was in only 23 years!!
NO GREENHOUSE GASSES !!

-18 °C
CO₂-EQ

- 1 kg Carbon dioxide (CO₂) = 1 kg CO₂-eq.
  - Fossil fuels

- 1 kg Methane (CH₄) = 25 kg CO₂-eq.
  - Digestion
  - Manure

- 1 kg Nitrous oxide (N₂O) = 298 kg CO₂-eq.
  - N metabolism in manure and soil

(100-years timespan, IPCC)
THE COST OF PRODUCING MILK

Mølkeproduktion: 18 Mio. Ton CO2e
  - CO2
  - Metan
  - Lattergas

Andre råvarer
Forpakning
Møjeri og adm
Transport
Detail & forbruger

Blijaard (2017)
COWS AND METHANE IS HOT

Danske kører skal prutte og bøvse mindre

Tang-spisende kvæg bøvser op til 99 procent mindre metan

Ny forskning viser, at uledningen af drivhusgasser fra produktion af kvæg kan reduceres dramatisk blot ved at tilføje lidt tang til dyreaes menu.

Superfoder skal bekæmpe prutter fra kører

Kør og svin forurener mere end biler

Koldboen producerer 18 procent flere skadelige drivhusgasser end transportsektoren, viser ny rapport fra FN. Rapporten konkluderer, at der er et akut behov for mere effektive produktionsteknikker.

Kritik af forslag om bøvse- og prutteafgift på kører

Skattelomstillingens forslag om en klimaafgift på mellemværd fra haver og grise giver

Fotografiske Fortellinger

Information
SPIN!!

Danger CO₂W

Climate change is a real problem and airlines are partly responsible.

Air transport produces 2% of global CO₂ emissions. But it might surprise you to know that this is actually less than the CO₂ produced worldwide by cattle.

Nevertheless, we’re working hard to limit the environmental impact of flying by investing in new, more fuel-efficient aircraft and pushing for shorter routes and improved air traffic control.

Flying’s a wonderful thing

This advertisement is supported by Airbus, The Boeing Company, Pratt & Whitney and Rolls-Royce.
BEWARE OF CO² FIGHT THE FARTS

"Livestock are responsible for 18 per cent of the greenhouse gases that cause global warming, more than cars, planes and all other forms of transport put together."


BJÖRN BORG

One Secret Society is an independent organization devoted to exploring the undiscovered secrets of life. Find out more at www.onesecretsociety.com.
Global greenhouse gas sources

- Sinks:
  - Atmosphere: $\text{CH}_4 + \text{OH} \rightarrow \text{CH}_3 + \text{H}_2\text{O} \rightarrow \ldots$ (83%)
  - Microbial uptake in soil (~5%)
  - Excess: 12%

- Natural wetlands: 37%
- Rice growing: 16%
- Oil industry: 14%
- Livestock, enteric: 11%
- Livestock, manure: 4%
- Garbage: 6%
- Combustion: 6%
- Coal mines: 5%
- Sea and lakes: 1%

~70% anthropogenic source
~30% natural source

Moss *et al.*, 2000
Enteric methane production Denmark

Nielsen et al. 2014

- Dairy cattle; 56.9
- Non dairy cattle; 29.5
- Swine; 9.8
- Poultry; 0.04
- Sheep and goats; 1.2
- Horses; 2.4
Comparison of countries

![Graph showing GHG emissions for cow milk and beef across different countries with EU-27 average comparison.](image)
Yield level is important

1 symbol = 1 country

![Graph showing kg CO₂-eq. per kg ECM vs. Kg ECM per cow with different systems: Multipurpose, Extensive, and Intensive.]
Emission of methane

1-5% intestinal

13% intestine
89% via lungs
11% via rectum

87% rumen

95-99%
Why is it a problem?

› Global warming potential: 28 (IPCC, 2014)
› 2-12% loss of gross energy (feed)
  › CH₄ GE value: 55 MJ/kg (e.g. glucose 15.6, fat 39.3)

Gross energy

→ Faecal energy

Digestible energy

→ Urine + methane energy

Metabolizable energy
Why do cows produce CH$_4$...?
Hydrogen!

\[
\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}
\]
Why do cow’s produce CH$_4$...?

- Surplus H$_2$ needs to be removed (excreted or oxidized)
- Inhibits fermentation processes

CHO fermentation:

- $\text{C}_6\text{H}_{12}\text{O}_6 + 2\text{H}_2\text{O} \rightarrow 2\text{CH}_3\text{COOH} + 2\text{CO}_2 + 4\text{H}_2$  
  acetic acid

- $\text{C}_6\text{H}_{12}\text{O}_6 + 2\text{H}_2 \rightarrow 2\text{CH}_3\text{CH}_2\text{COOH} + 2\text{H}_2\text{O}$  
  propionic acid

- $\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{COOH} + 2\text{CO}_2 + 2\text{H}_2$  
  butyric acid
Diversity in the rumen

› Microbes ($10^{12}$ microbes mL$^{-1}$ in the rumen fluid)
  › Bacteria
  › Protozoa
  › Fungi
  › Archaea
  › Viruses
Diversity in the rumen

- **Microbes**
  - Bacteria
    - Digest feed CHO (fibre, starch and sugar) and protein
    - Produce hydrogen
  - Protozoa
    - Mainly fibre rich diets
    - Do not contribute to any fermentation
  - Fungi
    - Mainly methanogens
  - Archaea
  - Viruses

Protozoa foraging on organic material including fungi
Microbial community

Feed

Cow

Microbial diversity is more related to the cow than to the feed
Animal variation

HIGH METHANE

LOW METHANE
Where does $H_2$ go to?

- CHO $\rightarrow$ acetate
- CHO $\rightarrow$ butyrate
- N-reducing microbes
- S-reducing bacteria
- Acetogene bacteria
- CHO $\rightarrow$ propionate
- AA $\rightarrow$ VFA
- Methanogens
- Microbial matter
- Biohydrogenation of fatty acids
Energy efficiency

- The fermentation pathways differ in their energetic efficiency
- $\Delta G$ is the difference in free energy with a chemical reaction, i.e. a reaction is favourable when $\Delta G$ is low
- $\Delta G = $ Gibbs free energy change

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$\Delta G$</th>
<th>Substrate availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$</td>
<td>-67.4</td>
<td>High</td>
</tr>
<tr>
<td>$\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_3\text{COO}^- + \text{H}^+ + 2\text{H}_2\text{O}$</td>
<td>-8.8</td>
<td>High</td>
</tr>
<tr>
<td>$\text{SO}_4^{2-} + 4\text{H}_2 + \text{H}^+ \rightarrow \text{HS}^- + 4\text{H}_2\text{O}$</td>
<td>-84.4</td>
<td>Low</td>
</tr>
<tr>
<td>$\text{NO}_3^- + \text{H}_2 + 2\text{H}^+ \rightarrow \text{NO}_2^- + 2\text{H}_2\text{O}$</td>
<td>-130</td>
<td>Low</td>
</tr>
<tr>
<td>$\text{NO}_2^- + 3\text{H}_2 + 2\text{H}^+ \rightarrow \text{NH}_4^+ + 2\text{H}_2\text{O}$</td>
<td>-371</td>
<td>Low</td>
</tr>
</tbody>
</table>

(Ungerfeld & Kohn, 2006)
Nitrate (NO$_3^-$) as mitigation strategy

- 4 cows, Latin Square design
- Calcium nitrate (Bolifor CNF)
- Treatments with nitrate dose (g NO$_3^-$/kg DM):
  - Control: 0
  - Low: 5
  - Medium: 14
  - High: 21
Nitrate study: results

CH$_4$ production (L/kg DMI)

Control: 26.5a
Low: 24.9a,b
Medium: 23.0b
High: 20.3c

Treatment

-6%      -13%       -23%

SEM 1.79
P<0.001

Olijhoek et al., 2016
Nitrate study: results

Hemoglobin (Fe$^{2+}$)

$\text{NO}_2^-$ (absorbed from rumen)

Methemoglobin (Fe$^{3+}$)

Clinical signs of methemoglobinemia: methemoglobin at 30-40% of Hb

Olijhoek et al., 2016
Met-haemoglobin

![Graph showing Met-HB (% of HB)]

- Control: 1.25
- Low: 1.25
- Medium: 1.49
- High: 1.58
- Clinical: 30
- 1960exp: 70
Nitrate in milk (mg/kg)

<table>
<thead>
<tr>
<th>Level</th>
<th>Control</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate</td>
<td>0.11</td>
<td>0.38</td>
<td>1.35</td>
<td>1.53</td>
</tr>
</tbody>
</table>

P < 0.001
NITRATE IN MILK (MG/KG)
$\text{N}_2\text{O} \ (256 \times \text{CO}_2)$

Feed intake (kg DM/15 min)

- Control
- Low
- Medium
- High

$\text{N}_2\text{O}$ concentration (μL/L)

Graphs showing the concentration of $\text{N}_2\text{O}$ at different feed intake levels.
Measurement techniques
Measurement techniques

Open circuit chambers  GreenFeed  SF$_6$ tracer
Respiration chambers

- Considered as a reference method
- Animals are kept in closed chambers (slight under-pressure)
- Continuous air flow
- Gas flow rate (L/min) measured
- Gases measured: CO$_2$, O$_2$, CH$_4$, H$_2$, H$_2$S
  - Concentration in inflow and outflow air
Welfare is important

\[ y = 1.0012x - 0.3802 \]
GreenFeed
SF$_6$ (sulphur hexafluoride) technique

Storm et al. 2012
Reducing (mitigating) methane emission

Mitigation strategies:
1. Inhibit the methanogens specifically
2. Reduce the substrate (H₂) source
3. Promote other H₂ consuming processes/organisms
4. Increase productivity
5. Combination of 1-3
Reducing (mitigating) methane emission

1. Inhibit the methanogens specifically:
   › 2-bromoethanesulphonate (BES)
   › Plant secondary metabolites: condensed tannins, essential oils
   › Vaccination
   › Long chained (unsaturated) fatty acids (see further later on)

   › Inhibitor sensitivity differs among methanogens...!
Reducing methane emission

2. Reduce the $\text{H}_2$ source
   - Inhibit $\text{H}_2$ producing protozoa (defaunation)
   - Antibiotic treatment:
     - E.g. monensin (ionophore): targets $\text{H}_2$ producing Gram$^+$ bacteria and protozoa
     - Works... but controversial approach...!
Reducing methane emission (1)

3. Promote other $H_2$ consuming processes
   › More dietary starch (concentrate) and less cellulose-rich roughage
     › Less $H_2$ production
     › Risk of increased lactate production (rumen acidosis)
Reducing methane emission (2)

3. Promote other H₂ consuming processes

› Promote reductive acetogenesis: \( \text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_3\text{COO}^- + \text{H}^+ + 2\text{H}_2\text{O} \)
  › The process is thermodynamically less favorable than methanogenesis
  › Acetogens have lower H₂ affinity than methanogens
  › An enigma why the process can dominate in e.g. Kangaroos

› Dietary nitrate/sulphate (electron acceptors) addition
  › Works... but problematic...?!?
  › Production/emission of N₂O (greenhouse gas)
  › Production of hydrogensulphide (H₂S; toxic and odorous compound) and nitrite (NO₂⁻; toxic)
Reducing methane emission

4. Increase productivity of the animal
   › By higher feed quality, management, genetics
   › Less CH₄/kg product (meat or milk)
   › "Dilution of maintenance"

5. Dietary fat (combining strategies)
Methane reduction through fat

Methane reduced 5-6% per 1% fat added
Potential: 10-25% reduction

Beauchemin (2007)
Effects of dietary fat on CH$_4$ production

- Long-chained fatty acids are **not** fermented in the rumen; no substrate input for the methanogens
- Bio-hydrogenation (saturation) of unsaturated fatty acids is an alternative H$_2$ sink
- Can inhibit methanogens directly, especially medium-chained fatty acids
- Reduces the number of protozoa (H$_2$ producers)
Effects of dietary fat on CH$_4$ production

But:

› Unsaturated fatty acids are also toxic for cellulolytic bacteria – reduced fibre digestion...!?!?
› Reduction in DMI?
› What about milk composition and quality...?!?
FAT X FORAGE – COW

CH$_4$/kg DM

-3%
-5%
-5%

Early grass -fat
Early grass +fat
Late grass -fat
Late grass +fat
Maize -fat
Maize +fat

Brask (2013)
FAT X FORAGE – BIOGAS POTENTIAL

Møller (2013)
GHG from feed + CH$_4$ from cow, kg CO$_2$/kg ECM

Maize ration:
- More from feed
- Due to C in soil
- Less CH$_4$ from cow

Grass ration:
- More from feed
- Due to C in soil
- Less CH$_4$ from cow

Mogensen (2013)
FORAGE: CONCENTRATE RATIO

Methane L/d

High quality GS

50:50  80:20

Low quality GS

50:50  80:20

Hellwing (2012)
GHG from feed + CH$_4$ from cow, kg CO$_2$/kg ECM

50% roughage:
- More from feed
- Less from CH$_4$ cow

80% roughage:
- More from feed
- Less from CH$_4$ cow
WUNDERDRUGS

› Nitrate
› Oregano
› Garlic
› Essential oils
› 3 NitroOxyPropanol
› Saponins
› Tanins
› Sea weed
› ....

25-32 % reduction
ORGANIC VS CONVENTIONAL

CO₂ eq per ha

- mælk
- svin
- fjerkæ
- plante
- gennemsnit

konv  φko

Kristensen (2017)
ORGANIC VS CONVENTIONAL

The graph shows the CO₂ eq per kg for different products under organic and conventional farming. The products include milk (mælk), pork (svinekød), eggs (æg), and plants (plante). The data is compared using LCA (Light Catalytic Analyzer) and DK-diel (Danish-Danish) methods. The graph indicates that organic farming generally results in lower CO₂ eq emissions compared to conventional farming for all the products shown.

Kristensen (2017)
The future

- Feeding
- Breeding
- Management
- Manure
- Biogas

Same # of cows in DK (12500 EKM)
Same milk production in DK

Change in methane in 2030 (% of 2015)

Lund & Kristensen (2017)
Thank you for your attention!