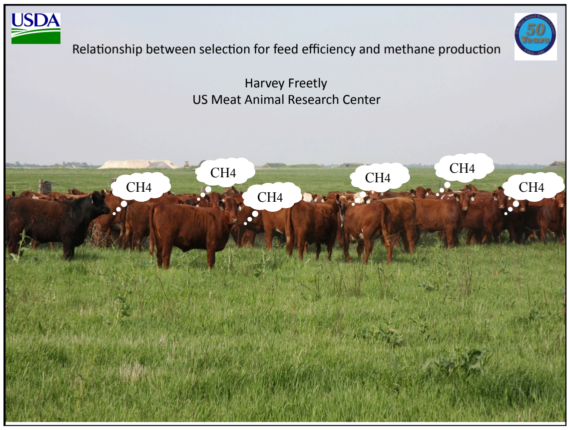
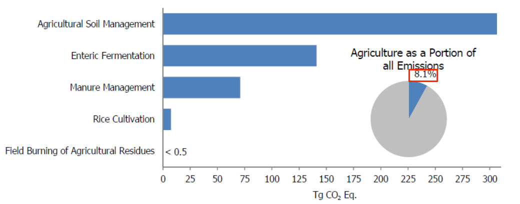


The problem

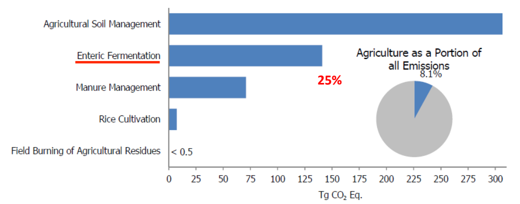
- Methane is a greenhouse gas
- Methane represents a loss of feed energy

Figure 6-1: 2012 Agriculture Chapter Greenhouse Gas Emission Sources



Source: EPA INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-2012 (April 2014), http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html, accessed 6/12/14

Figure 6-1: 2012 Agriculture Chapter Greenhouse Gas Emission Sources



Source: EPA INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-2012 (April 2014), http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html, accessed 6/12/14

Beef cattle account for 71% of the enteric methane emissions

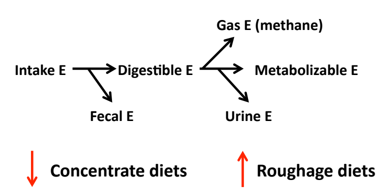
Table 6-3: CH4 Emissions from Enteric Fermentation (Tg CO2 Eq.)

Livestock Type	1990	2005	2008	2009	2010	2011	2012
Beef Cattle	100.0	105.8	107.5	106.3	105.4	103.1	100.6
Dairy Cattle	33.1	31.6	34.1	34.4	34.1	34.5	35.0
Swine	1.7	1.9	2.1	2.1	2.0	2.1	2.1
Horses	0.8	1.5	1.6	1.6	1.6	1.6	1.7
Sheep	1.9	1.0	1.0	1.0	0.9	0.9	0.9
Goats	0.3	0.3	0.3	0.3	0.3	0.3	0.3
American Bison	0.1	0.4	0.3	0.3	0.3	0.3	0.3
Mules and Asses	+	+	0.1	0.1	0.1	0.1	0.1
Total	**137.9**	**142.5**	**147.0**	**146.1**	**144.9**	**143.0**	**141.0**

Notes: Totals may not sum due to independent rounding.
+ Does not exceed 0.05 Tg CO2 Eq.

Source: EPA INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-2012 (April 2014), http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html, accessed 6/12/14

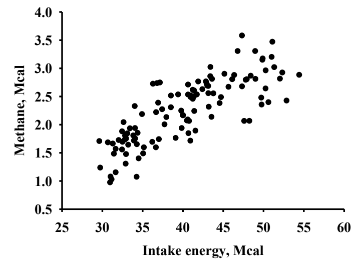
2 – 8% of the intake energy is lost as methane



Factors that contribute to enteric methane production

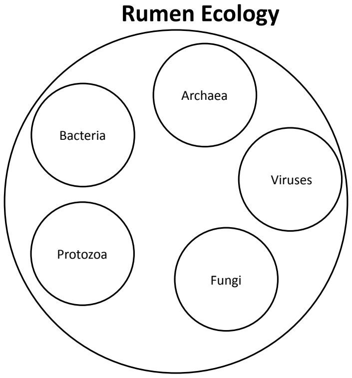
- **Level of feed intake**
- **Diet composition**

Enteric methane emissions increase with increased feed intake

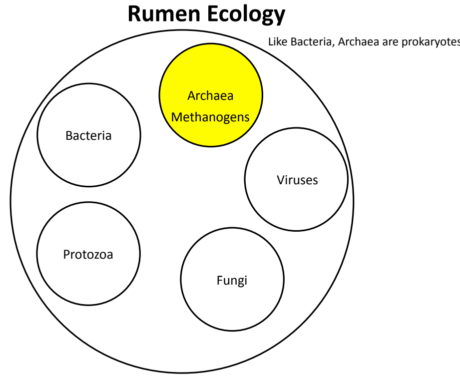


Daily enteric methane emissions from lactating beef cows.
Data from Freetly et al., 2006, J. Anim. Sci. 84:2157-2162

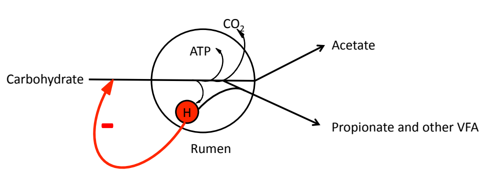
Rumen Ecology



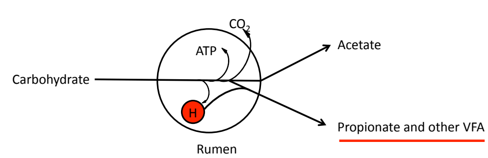
Rumen Ecology



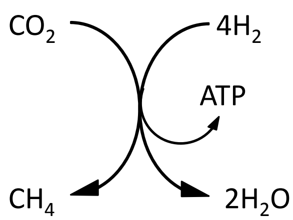
During rumen fermentation, hydrogen is produced



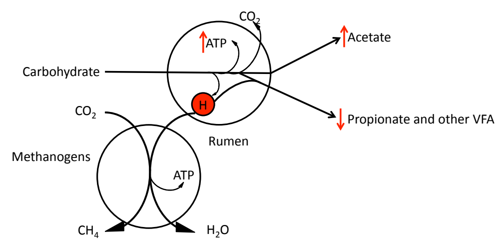
Hydrogen is kept balanced by the production of longer chain VFAs that contain more hydrogen than acetate



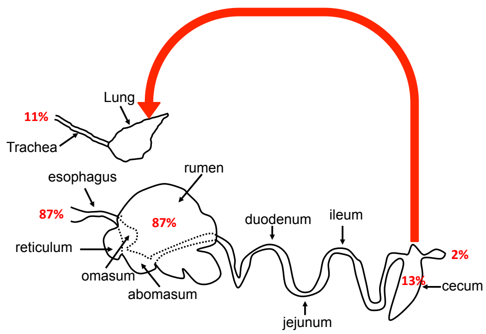
Methanogens can use the hydrogen in the rumen to generate ATP



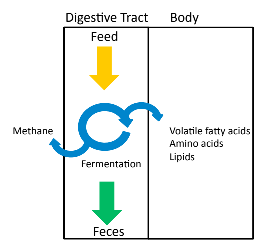
Methanogens shift fermentation patterns



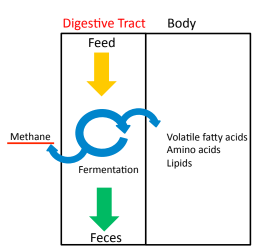
It is not about cow farts



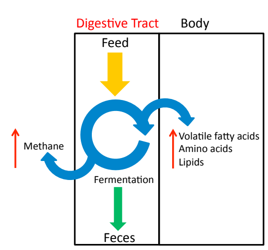
Feed efficiency can be improved by more complete digestion or improved utilization of absorbed nutrient



Improving feed efficiency through increased digestion

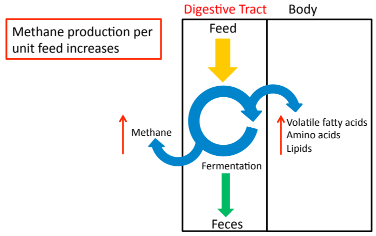


Improving feed efficiency through increased digestion

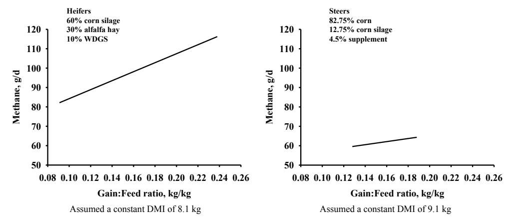


Methane production per unit feed increases

Improving feed efficiency through increased digestion



Methane production increased with increased gain:feed ratio on forage diets, but it did not increase on high concentrate diets



From Freetly and Brown-Brandl, 2013 J. Anim. Sci. 91:4826-4831

Factors that might contribute to variation in feed efficiency and methane production

- Different passage rate
- Different rumen volume

Rumen volume increased in sheep with high methane yields

Table 3. Physical characteristics of ewes selected on the basis of displaying high or low methane yield (MY; g CH_4/d per kg DM intake)

(Mean values with their pooled standard errors)

Groups…	High MY	Low MY	Pooled SEM	*P*
Rumen content weight (kg)*	5·42	4·43	0·257	0·074
Rumen volume (litres)*	7·42	5·91	0·355	0·048
Rumen gas space proportion*	0·267	0·247	0·0115	NS
Rumen estimated DM%†	12·96	12·78	0·542	NS
Rumen content complexity score‡	3·16	2·21	0·272	0·10

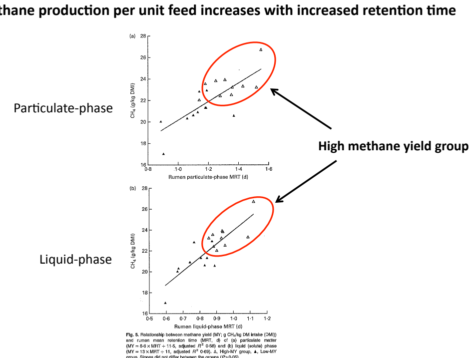
* Rumen content weight, rumen volume and rumen gas space proportion were derived from computer tomography scanning of live sheep after an overnight fast.

† Rumen estimated DM% was derived from the weight of particles (estimated using Cr-mordanted feed and Co-EDTA markers (Table 2) expressed as a percentage of the weight of the rumen contents calculated from CT scan data).

‡ Rumen content complexity score is the mean of subjective assessments of the liquid/foam/air distribution in the rumen assessed from computer-aided tomography scans viewed by an untrained panel using a scale ranging from 1 to 5.

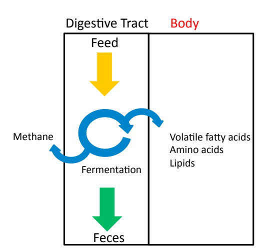
Goopy et al., 2014 Brit. J. Nutr. 111: 578-585

Methane production per unit feed increases with increased retention time



Goopy et al., 2014 Brit. J. Nutr. 111: 578-585

Improved utilization of absorbed nutrient



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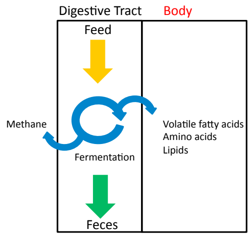
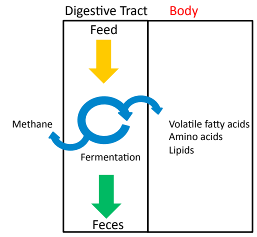


Maintenance
- **Substrate cycles**
- **Mitochondrial function**

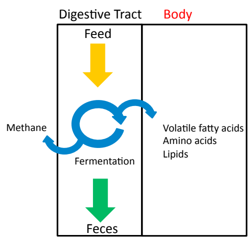
Improved utilization of absorbed nutrient



Maintenance
- **Substrate cycles**
- **Mitochondrial function**

Activity
- **Grazing behavior**
- **Temperament**

Improved utilization of absorbed nutrient



Maintenance
- **Substrate cycles**
- **Mitochondrial function**

Activity
- **Grazing behavior**
- **Temperament**

Immune function

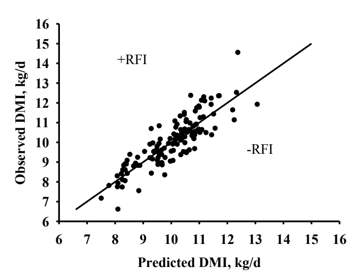
A strategy is to place downward select on feed intake while maintaining or increasing production

- Selection index
- Create a score for feed efficiency
  -Residual Feed Intake (RFI)

Residual Feed Intake has been used in conjunction with several production traits

- Growth
- Milk
- Egg

Selecting for low RFI lowers feed intake to achieve the same gain



DDMI = *f*(ADG, midMBS)

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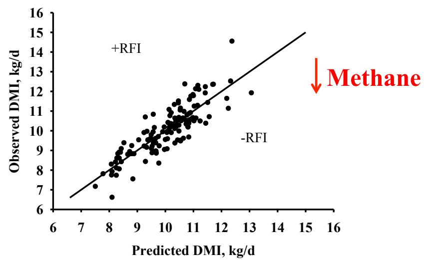

DDMI = *f*(ADG, midMBS)

Less feed consumed results in less fermented product resulting in less methane

Methane, feed intake, and growth characteristics of steers with the lowest (L; n = 10) and greatest (H; n = 10) residual feed intake measured over 15 d

Item	L-RFI	H-RFI	SED	*P*-value
DMI, kg/d	8.38	14.13	0.83	<0.001
ADG, kg	1.126	1.229	0.080	0.21
G:F	0.142	0.088	0.006	<0.001
Methane, g/d	142.3	190.2	16.5	0.01
Methane, g/kg ADG	131.8	173.0	22.8	0.09
Methane, g/kg DMI	16.3	14.7	1.8	0.37

Hegarty et al., 2007, J Anim Sci 86:1479-1486

Increasing feed intake reduces the methane production per unit feed

Methane, feed intake, and growth characteristics of steers with the lowest (L; n = 10) and greatest (H; n = 10) residual feed intake measured over 15 d

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Hegarty et al., 2007, J Anim Sci 86:1479-1486

Methane production increased with increased feed intake, but did not differ per unit of feed in animals stratified into RFI groups

Ruminal methane production of heifers with high, medium, and low residual feed intake (RFI)

	RFI group[1]				Period			*P*-value[2]	
Variable	High	Medium	Low	SEM	P1	P2	SEM	RFI	P
CH4, g/d	297[a]	275[ab]	260[b]	10.3	334	220	10.6	0.04	<0.001
CH4, g/kg DMI	36	36	38	1.4	42	31	1.6	0.52	<0.001
CH4, g/kg $BW^{0.75}$	2.9[a]	2.7[ab]	2.5[b]	0.08	3.3	2.1	0.10	0.01	<0.001

[a–b]Least squares means within a row with different superscripts differ (*P* < 0.05).
[1]High RFI = inefficient, medium RFI = intermediate, low RFI = efficient.
[2]No RFI × period interaction (*P* > 0.1).
N = 22

Table from Fitzsimons et al., 2013, J. Anim. Sci. 91:5789-5800

Methane production per unit feed decreases with increased feed intake

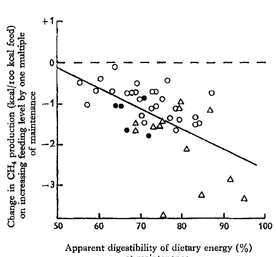

Fig. 2. Relation in sheep and cattle between the change in CH_4 production on increasing the level of feeding by one multiple of maintenance and the apparent digestibility of dietary energy in: o, roughages; ●, pelleted or milled feeds; ▵, mixed diets.

Blaxter and Clapperton, 1965, Br. J. Nutr. 19: 511-522

Steers sorted to a high RFI group have greater methane production than low RFI steers on equal feed intakes

Relationship of feedlot residual feed intake (RFI, kg od DM/d) with post-feedlot daily energy flows in beef cattle fed 2.5 times their estimated (NRC, 1996) maintenance requirements (least squares mean ± SE)

	RFI Group[1]			
Trait	High	Medium	Low	*P*-value
No. of steers	11	8	8	
Intake energy, kcal/kg of $BW^{0.75}$	384.77 ± 7.90	382.24 ± 6.26	387.98 ± 6.03	0.39
Methane energy, kcal/kg of $BW^{0.75}$	16.08 ± 1.01[c]	15.90 ± 1.30[cd]	12.09 ± 1.28[d]	0.04
Heat production, kcal/kg of $BW^{0.75}$	163.97 ± 4.17[c]	143.00 ± 5.54[d]	129.32 ± 5.16[e]	<0.001
Retained energy, kcal/kg of $BW^{0.75}$	75.34 ± 7.22[e]	104.30 ± 9.51[d]	135.23 ± 9.82[c]	<0.001

[1]Groups defined as high = RFI > 0.5 SD above the mean, medium =RFI ± o.5 SD above and below the mean, and low RFI <-0.5 SD below the mean.

Table adapted from Nkrumah et al., 2006, J. Anim. Sci. 84:145-153.

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Summary of relationships between feed efficiency and methane production in the growing animal

- Increasing rumen digestibility can increase feed efficiency and increase methane production

Summary of relationships between feed efficiency and methane production in the growing animal

- Increasing rumen digestibility can increase feed efficiency and increase methane production
- Reducing feed intake and holding weight gain constant will improve feed efficiency and decrease methane production

Reducing methane footprint of growing cattle

- Decrease the days from birth to harvest
- Reduce feed required to achieve target rates of gain

Methane production and feed efficiency in the cow

Factors that contribute to cow efficiency also contribute to methane efficiency

- Wean a calf every year
- Increase the weight of calf weaned relative to cow size
- Reduce feed inputs while holding production traits constant

There is a positive phenotypic correlation between heifer dry matter intake and lactating 3-year-old dry matter intake

0.633 (0.001) Black et al., 2013, J. Anim. Sci. 91:2254-2263

Selection for post-weaning RFI for 1.5 generations

Table 3. Least squares means (± s.e.) for maternal productivity traits of cows divergently selected for residual feed intake (RFI)

The number of cows exposed to a bull was 222 for low RFI and 247 for high RFI

Trait	Selection line		Level of significance
	Low RFI	High RFI	
Calving day[A]	215 ± 2	210 ± 1	$P = 0.07$
Milk yield (kg/day)[B]	7.5 ± 0.3	7.8 ± 0.3	n.s.
Weight of calf born per cow exposed (kg)	33.6 ± 1.1	31.8 ± 1.0	n.s.
Weight of calf weaned per cow exposed (kg)	191.3 ± 8.4	198.4 ± 7.7	n.s.

[A] 1 January is day 1 each calving year.
[B] The number measured for milk yield was 56 and 66 for low and high RFI cows, respectively.

Arthur et al., 2005, Aust. J. Exper. Agric. 45:985-993