Plants store energy in carbon compounds

Energy

$C_6H_{12}O_6$

Glucose

O_2

Oxygen

(plants' waste product)

Photosynthesis

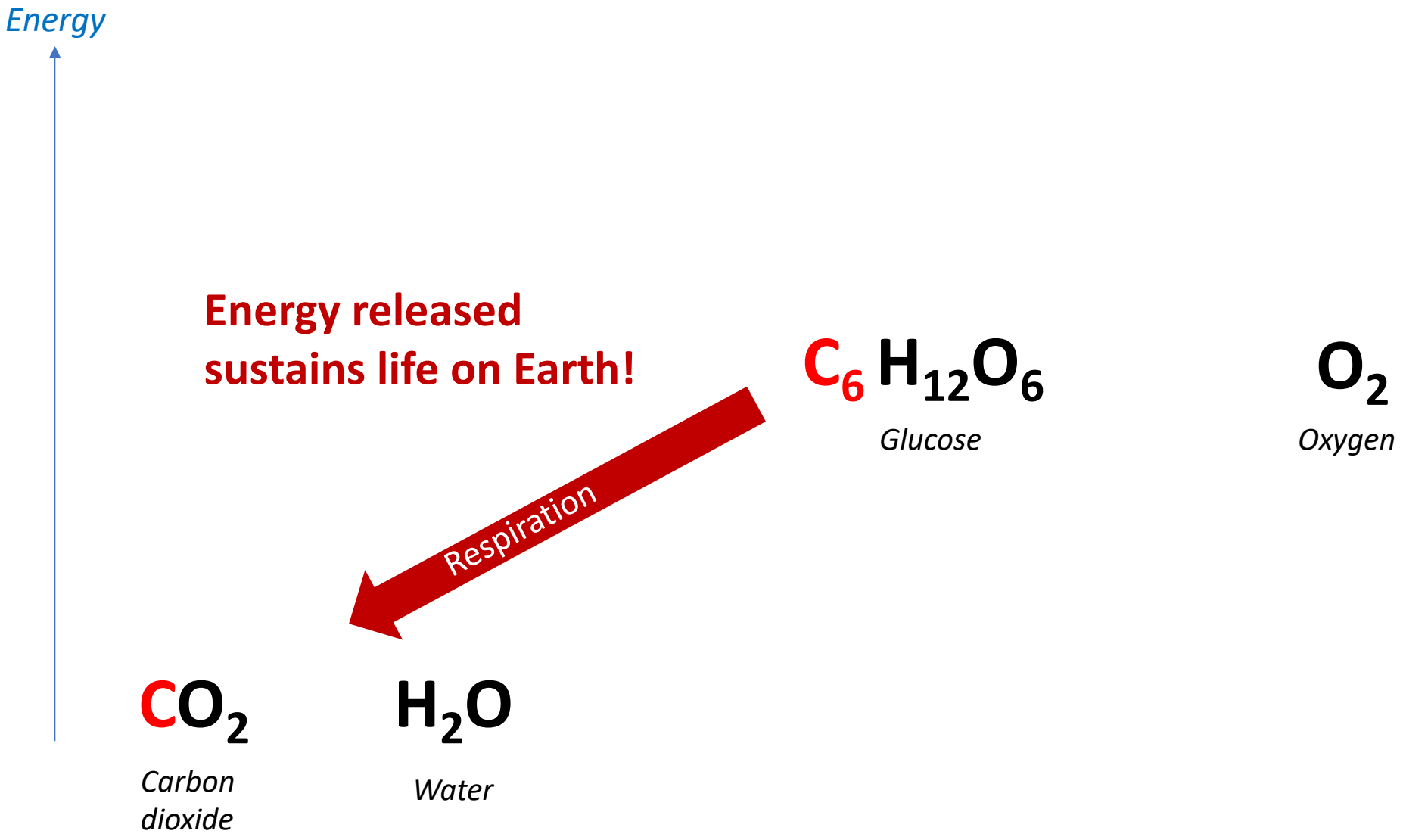
CO_2

Carbon dioxide

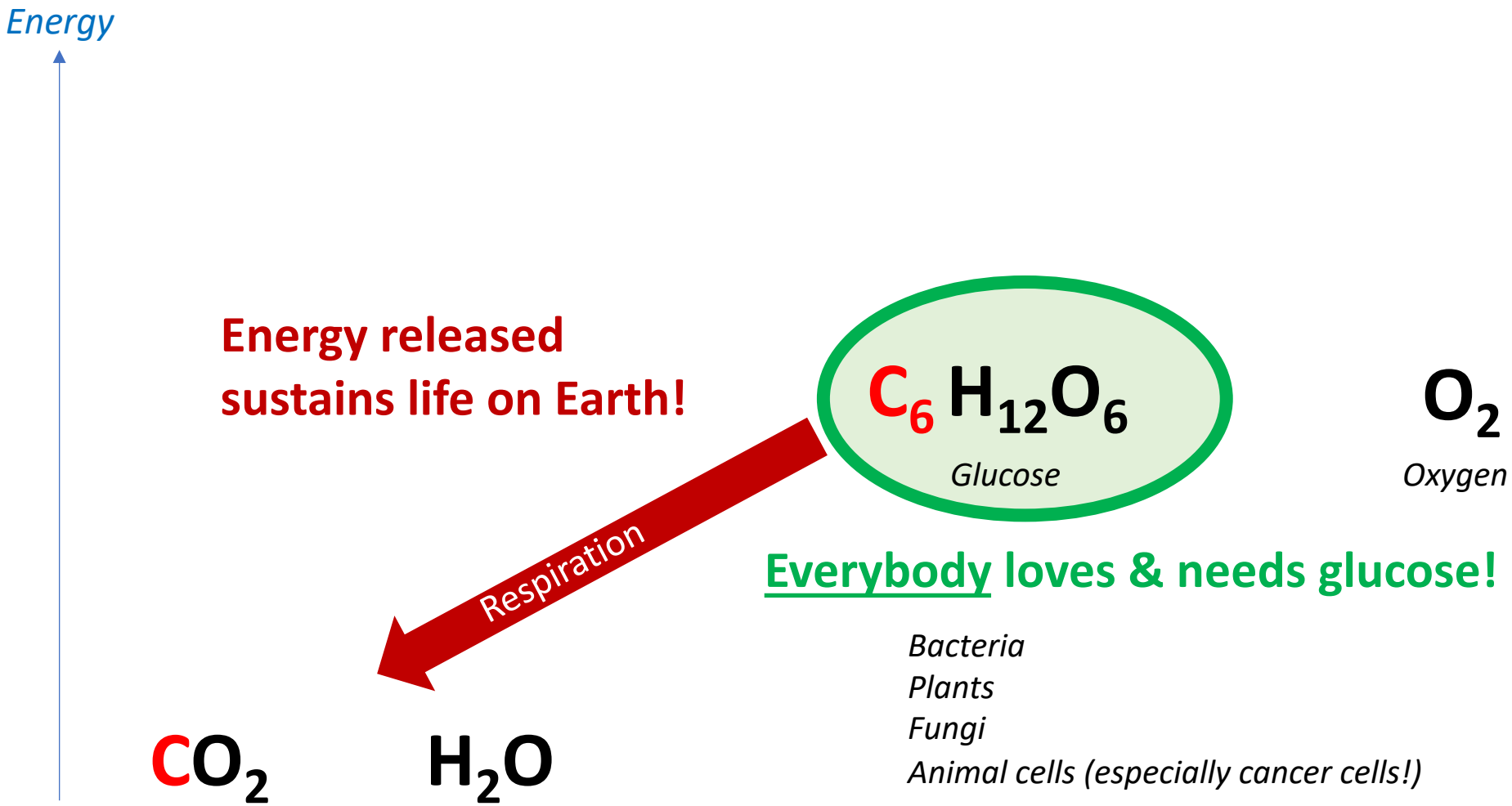
H_2O

Water

Energy is released by oxidizing glucose



Energy is released by oxidizing glucose



Glucose is not often directly available

Energy

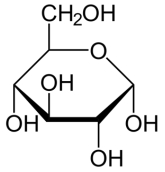
CO_2

Carbon dioxide

H_2O

Water

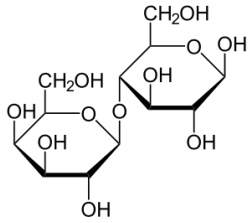
Photosynthesis



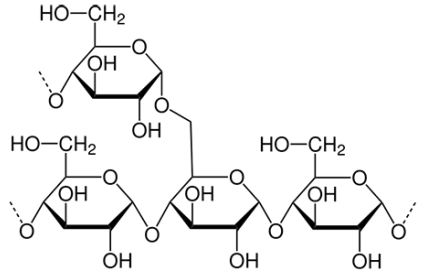
$C_6H_{12}O_6$

Glucose

Biosynthesis



lactose



starch

Glucose is not often directly available

Energy

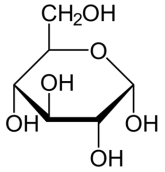
CO_2

Carbon dioxide

H_2O

Water

Photosynthesis

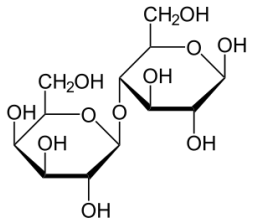


$C_6H_{12}O_6$

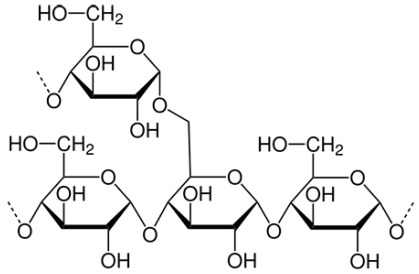
Glucose

Biosynthesis

"food"



lactose



starch

Requires DIGESTION to break these complex polymers back into glucose

Glucose is not often directly available

Energy

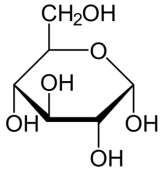
CO_2

Carbon dioxide

H_2O

Water

Photosynthesis

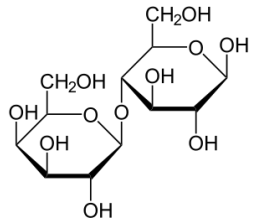


$C_6H_{12}O_6$

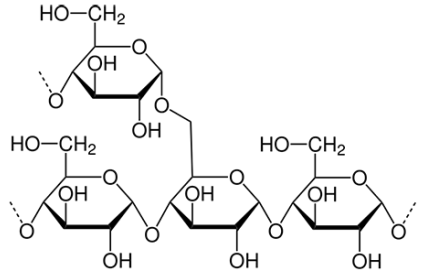
Glucose

Biosynthesis

"food"



lactose



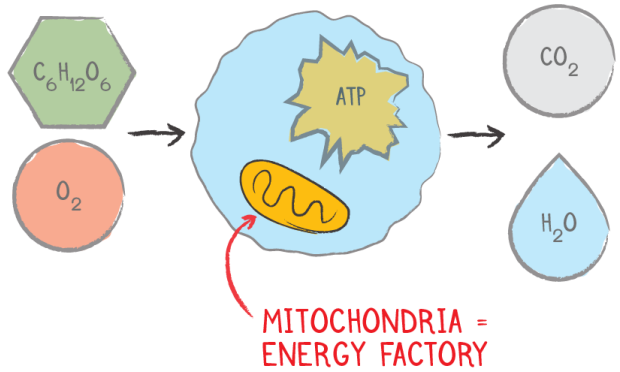
starch

Requires DIGESTION to break these complex polymers back into glucose

"HYDROLYSIS"

Aerobic glucose oxidation

Energy



Respiration

$C_6H_{12}O_6$

Glucose

O_2

Oxygen

CO_2

Carbon dioxide

H_2O

Water

Our cells get most of their energy by oxidizing glucose with OXYGEN

This creates A LOT of energy!

Anaerobic glucose oxidation

Energy

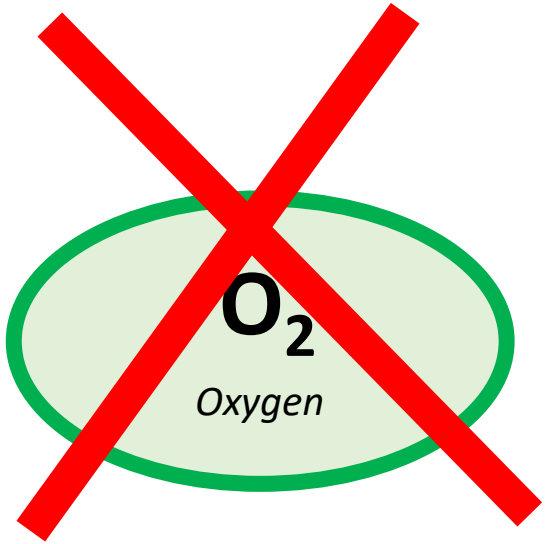
$C_6H_{12}O_6$

Glucose

Anaerobic oxidation

$C_3H_4O_3$

Pyruvic acid



ALL living cells can get SOME energy by anaerobic oxidation of glucose (WITHOUT oxygen)

Anaerobic glucose oxidation

Energy

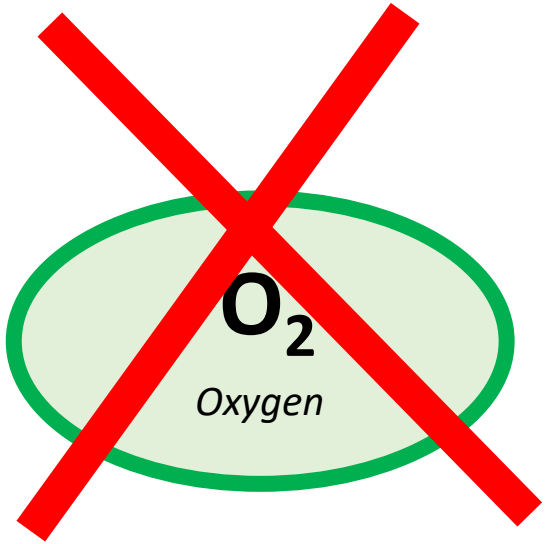
$C_6H_{12}O_6$

Glucose

Anaerobic oxidation

$C_3H_4O_3$

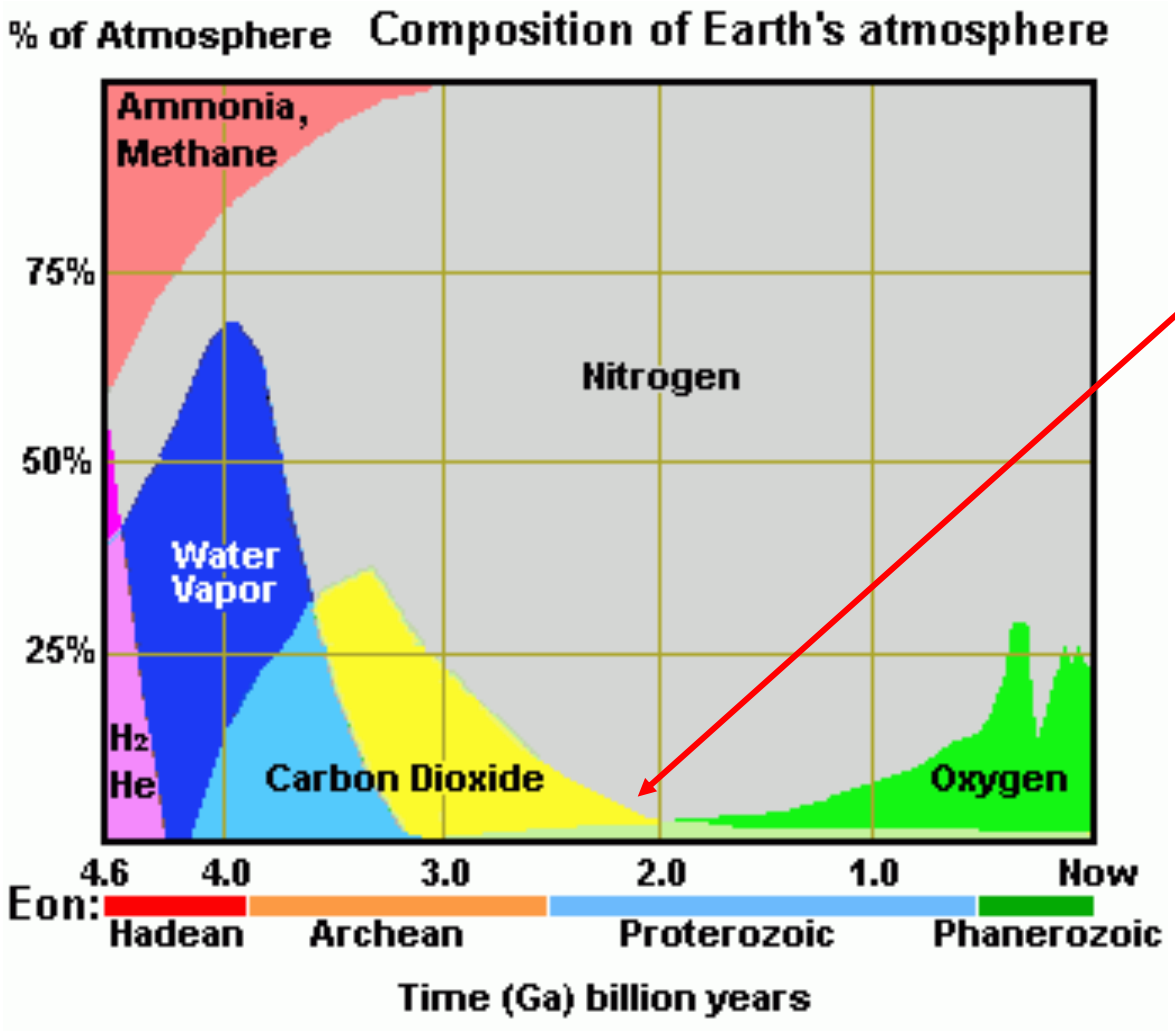
Pyruvic acid



ALL living cells can get SOME energy by anaerobic oxidation of glucose (WITHOUT oxygen)

This goes back to when the Earth had very little oxygen in its atmosphere!

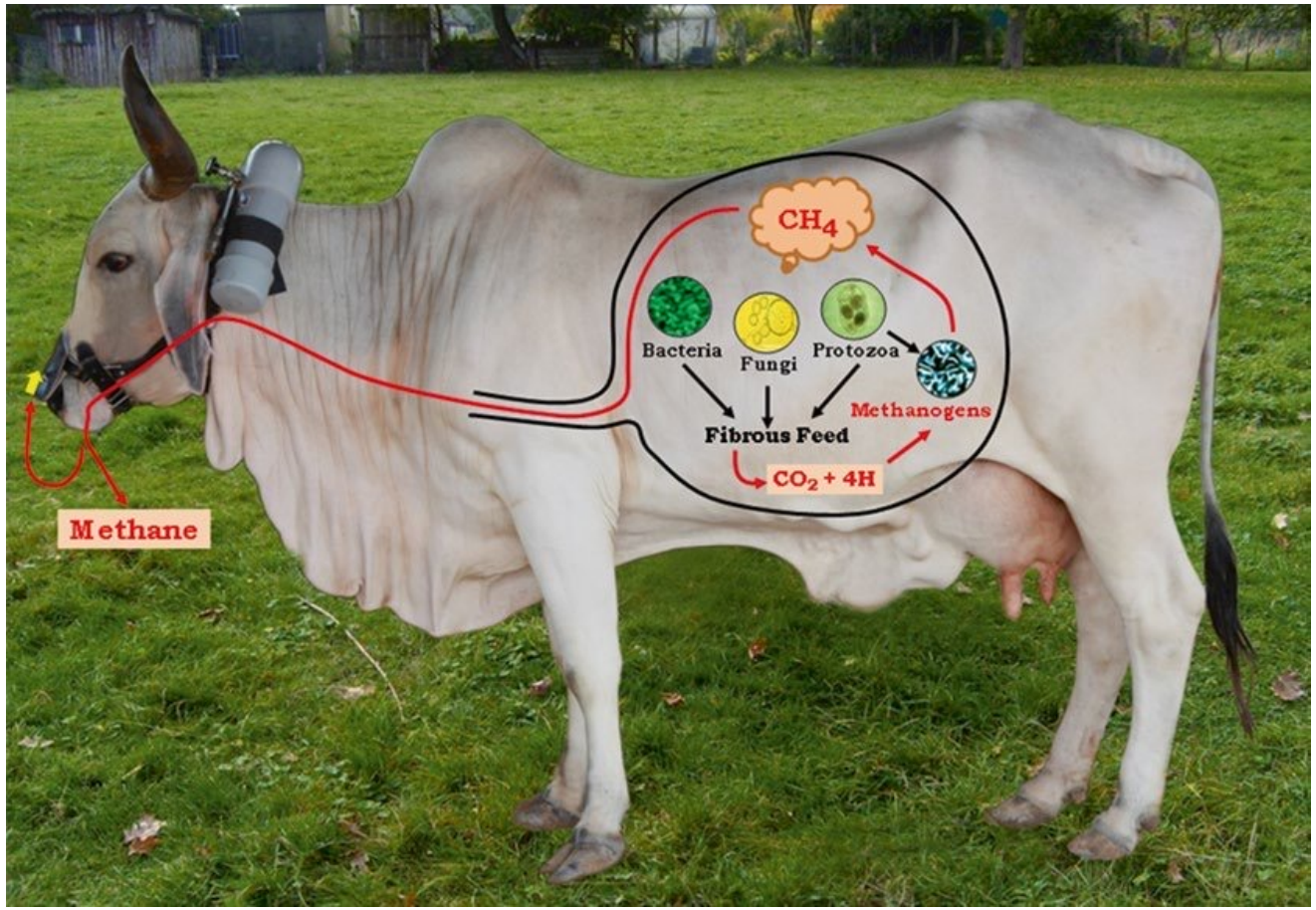
Early Earth



Almost NO OXYGEN less than 2 billion years ago!

Cells had to obtain their energy ANAEROBICALLY

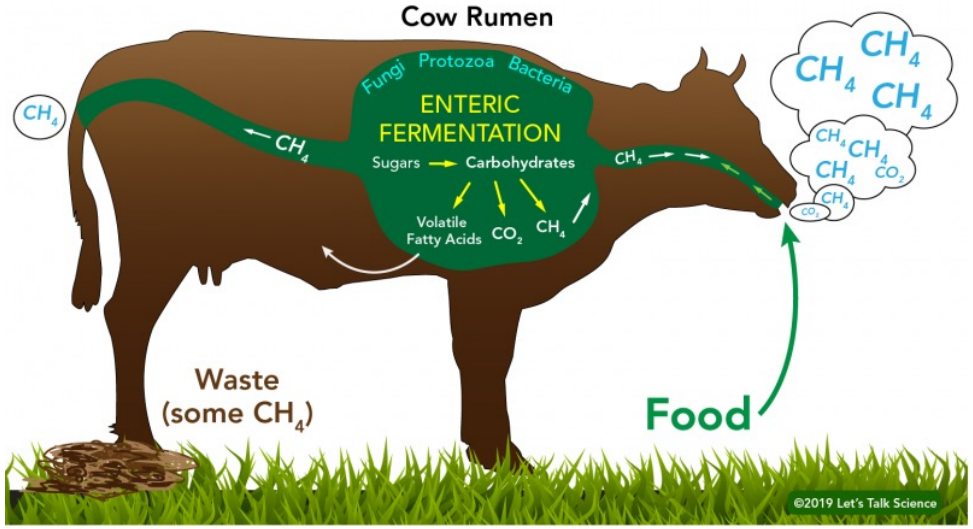
Methane produced by ruminants (biogas)



Ruminants produce biogas in their stomach via a process of **ANAEROBIC DIGESTION** known as **ENTERIC FERMENTATION**

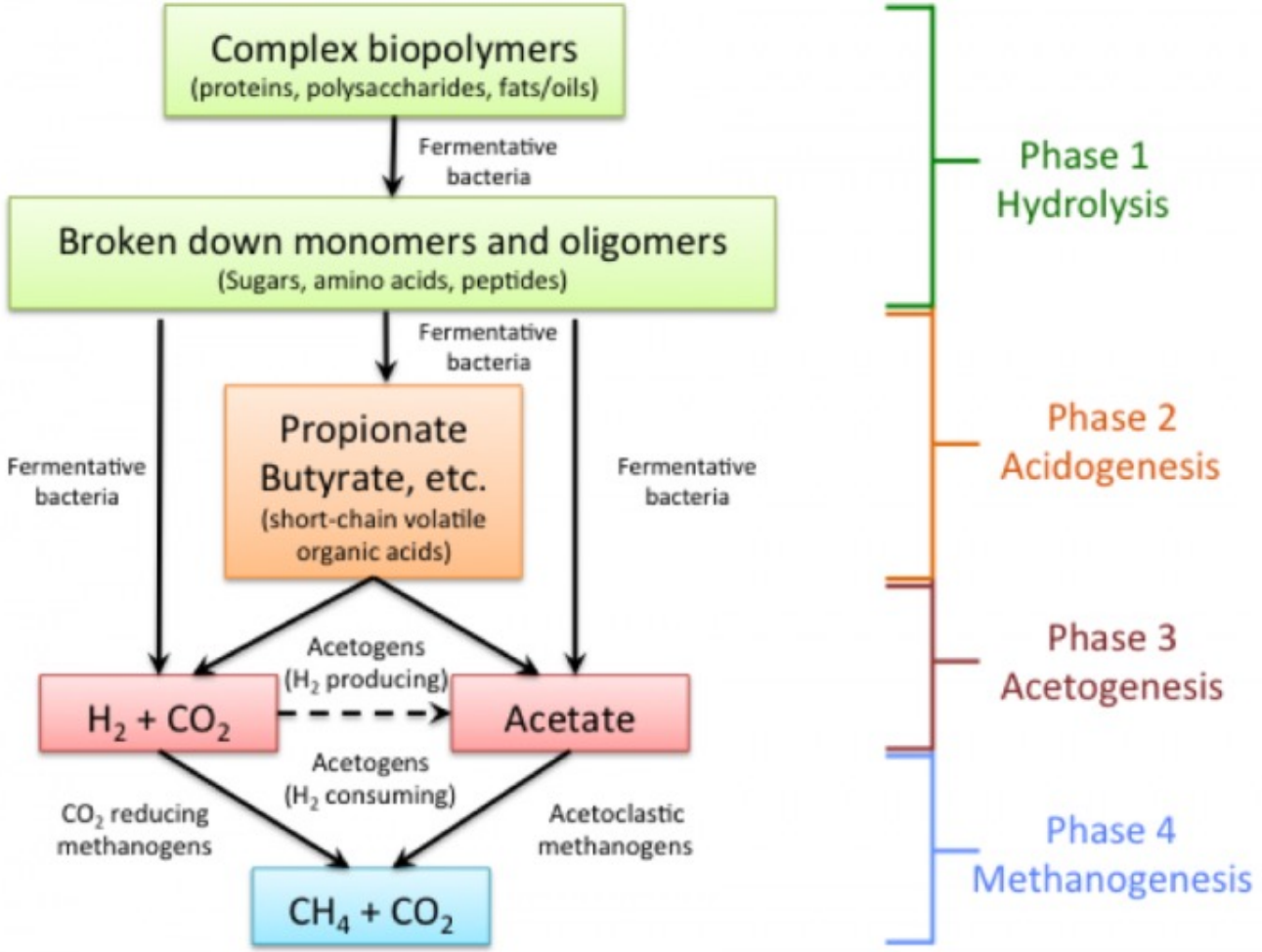
Biogas!

Methane: CH_4



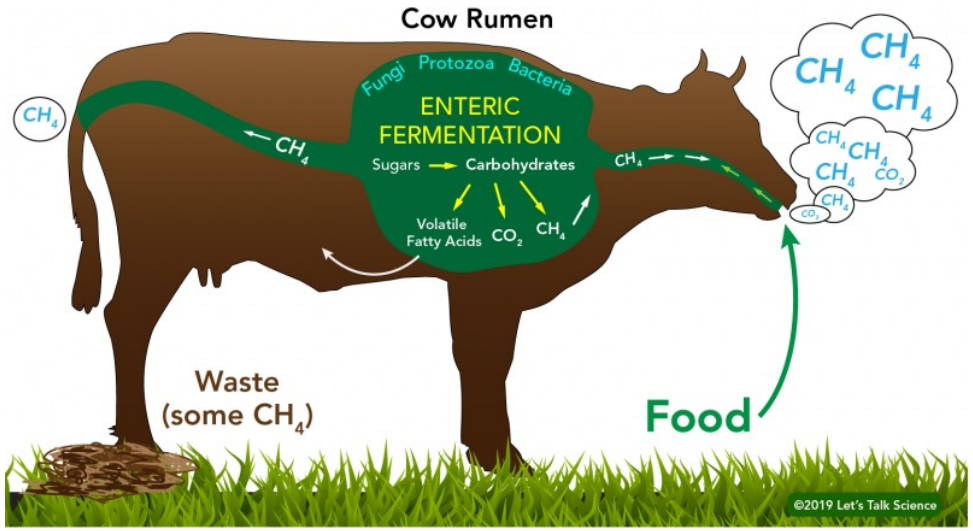
Biogas production involves complex biome

Anaerobic digestion

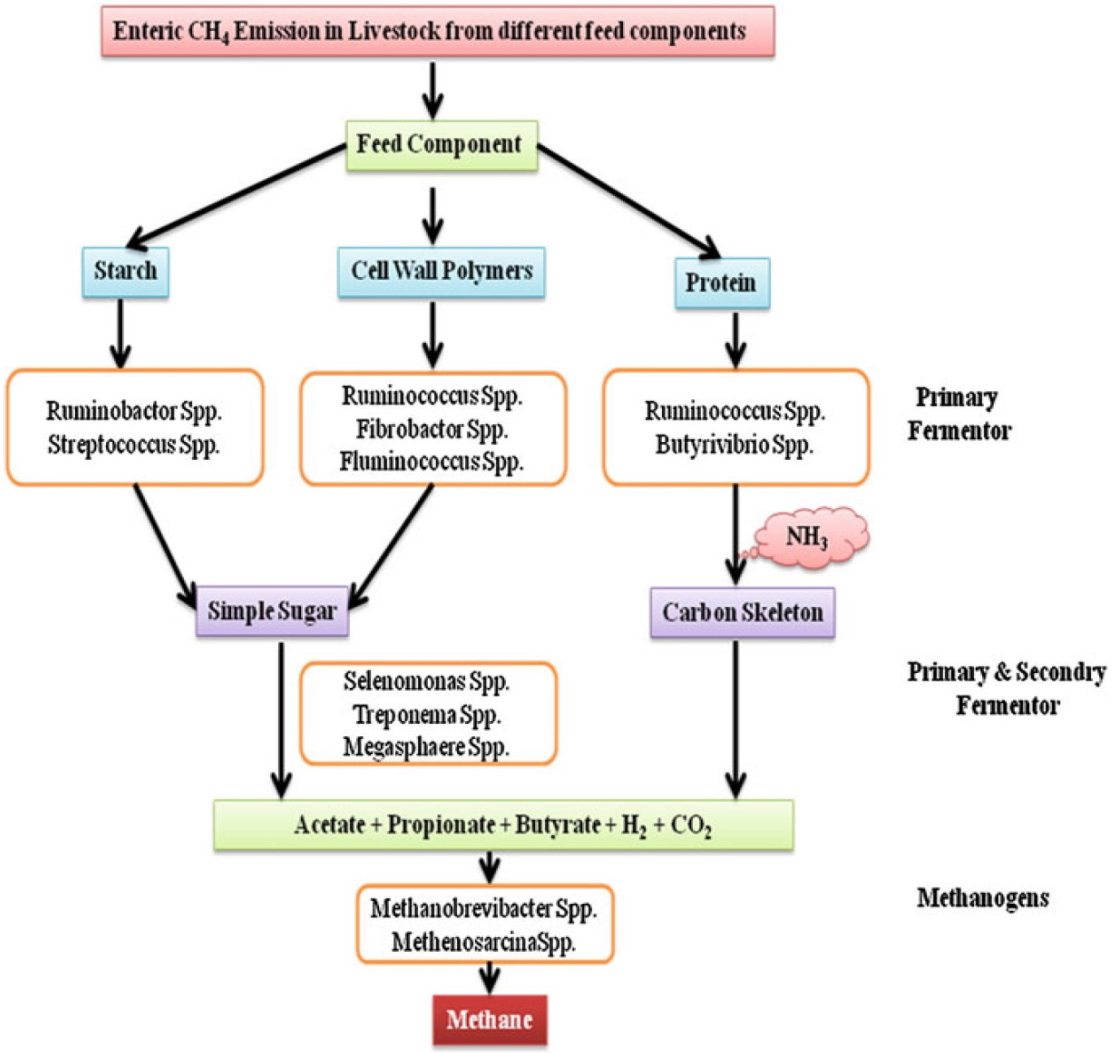


Biogas

Methane: CH_4

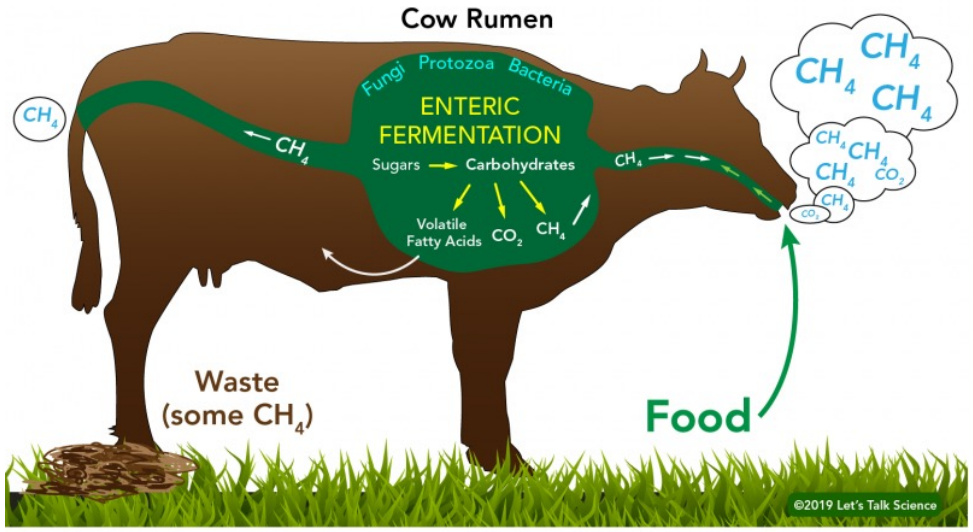


Biogas production involves complex biome



Biogas

Methane: CH_4



Evolution of life on Earth

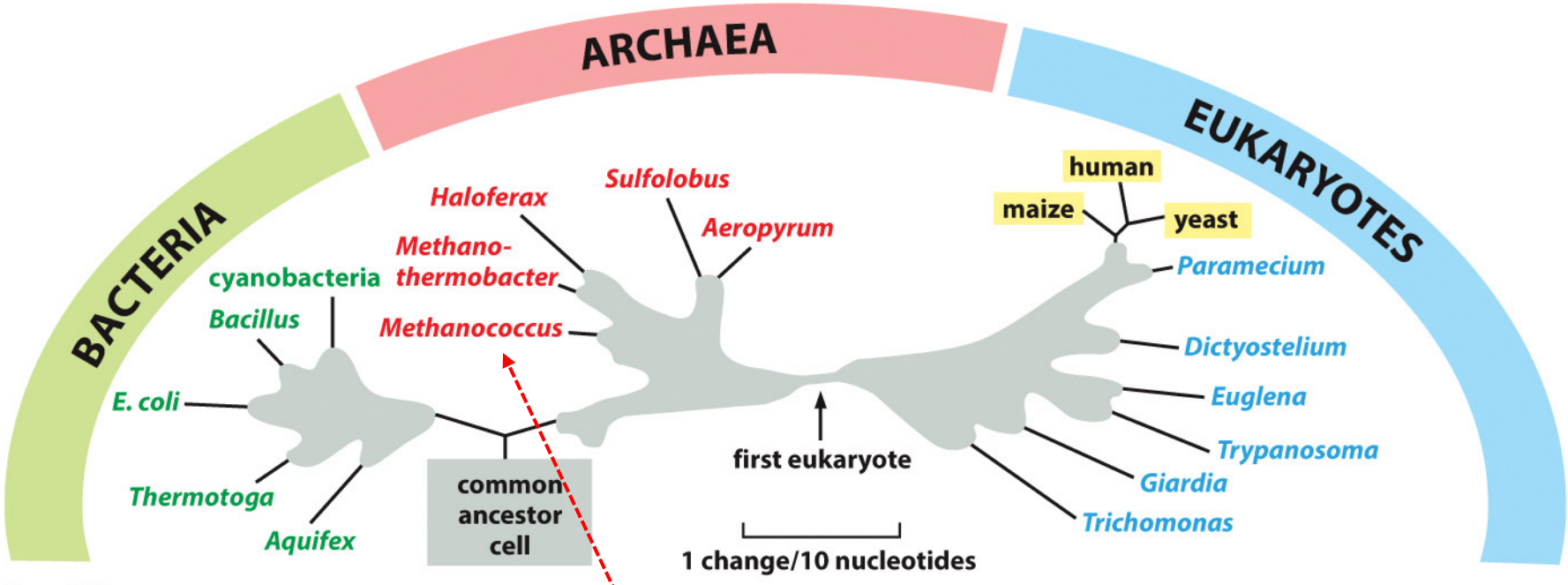
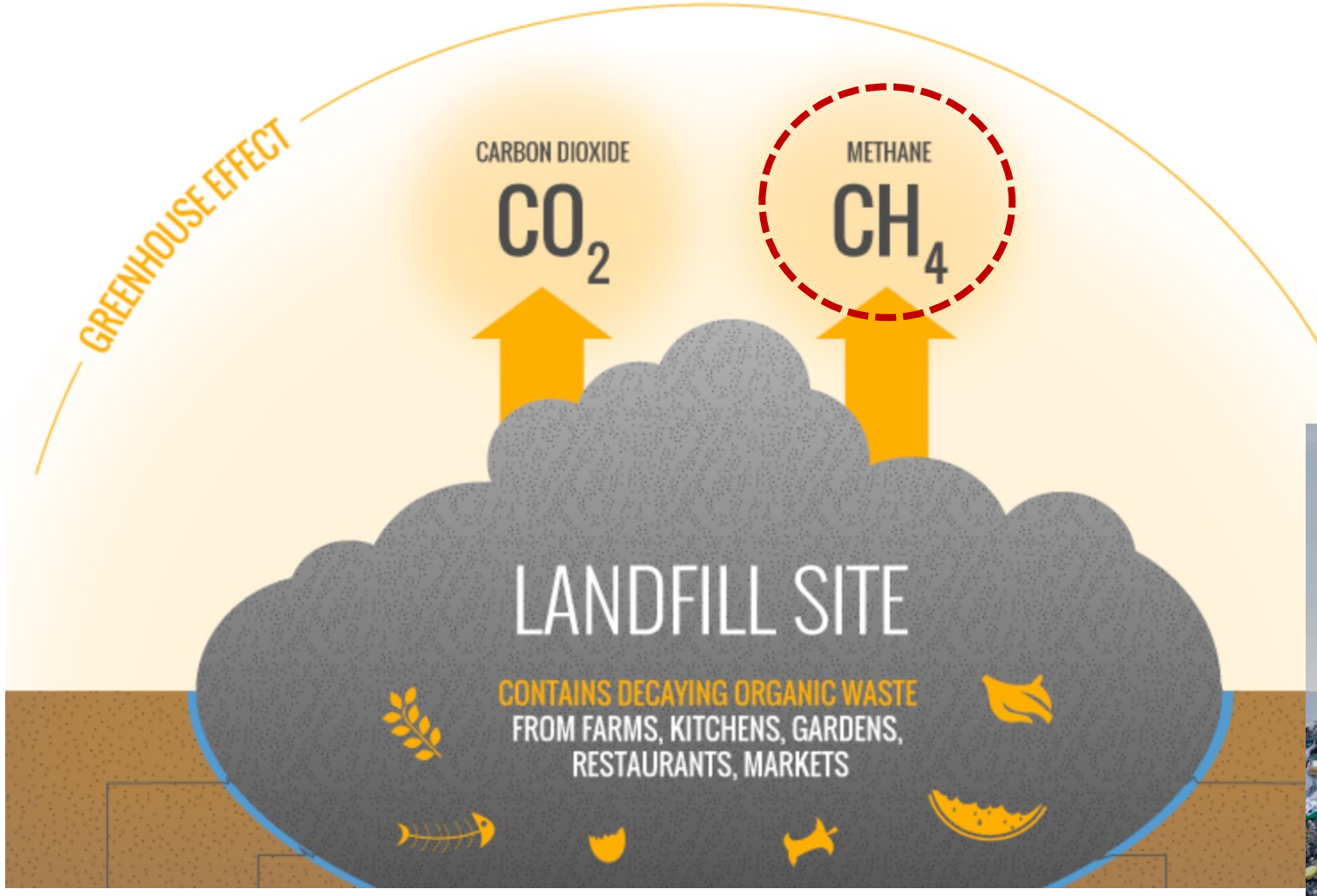


Figure 1-17

Our dear methanogens!

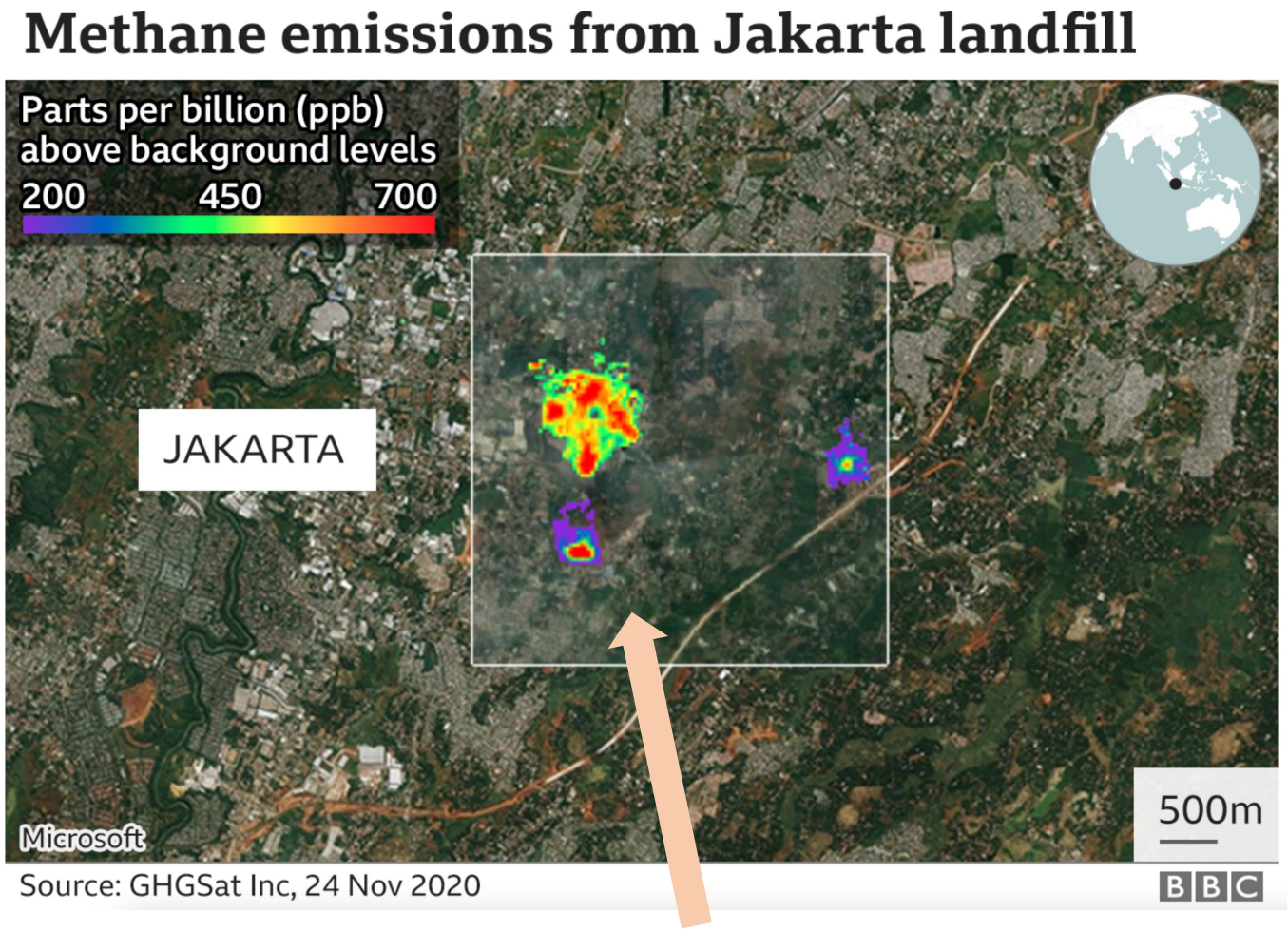
Use H_2 and CO_2 as their fuel

Biogas as a PROBLEM: LANDFILLS



Biogas production also occurs spontaneously in landfills

Methanogens are good at what they do!



Biogas production also occurs spontaneously in landfills

Global warming equivalent to the use of 750,000 cars!

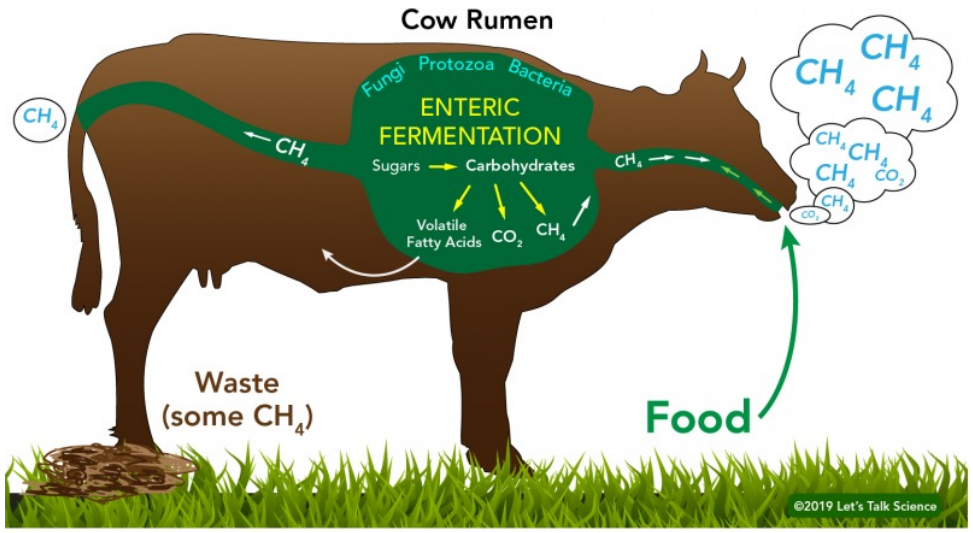
Biogas as a PROBLEM

Methane is a powerful greenhouse gas (GHG) and its emissions have contributed to **23% global warming** in the 20th century

Greenhouse gas (GHG)

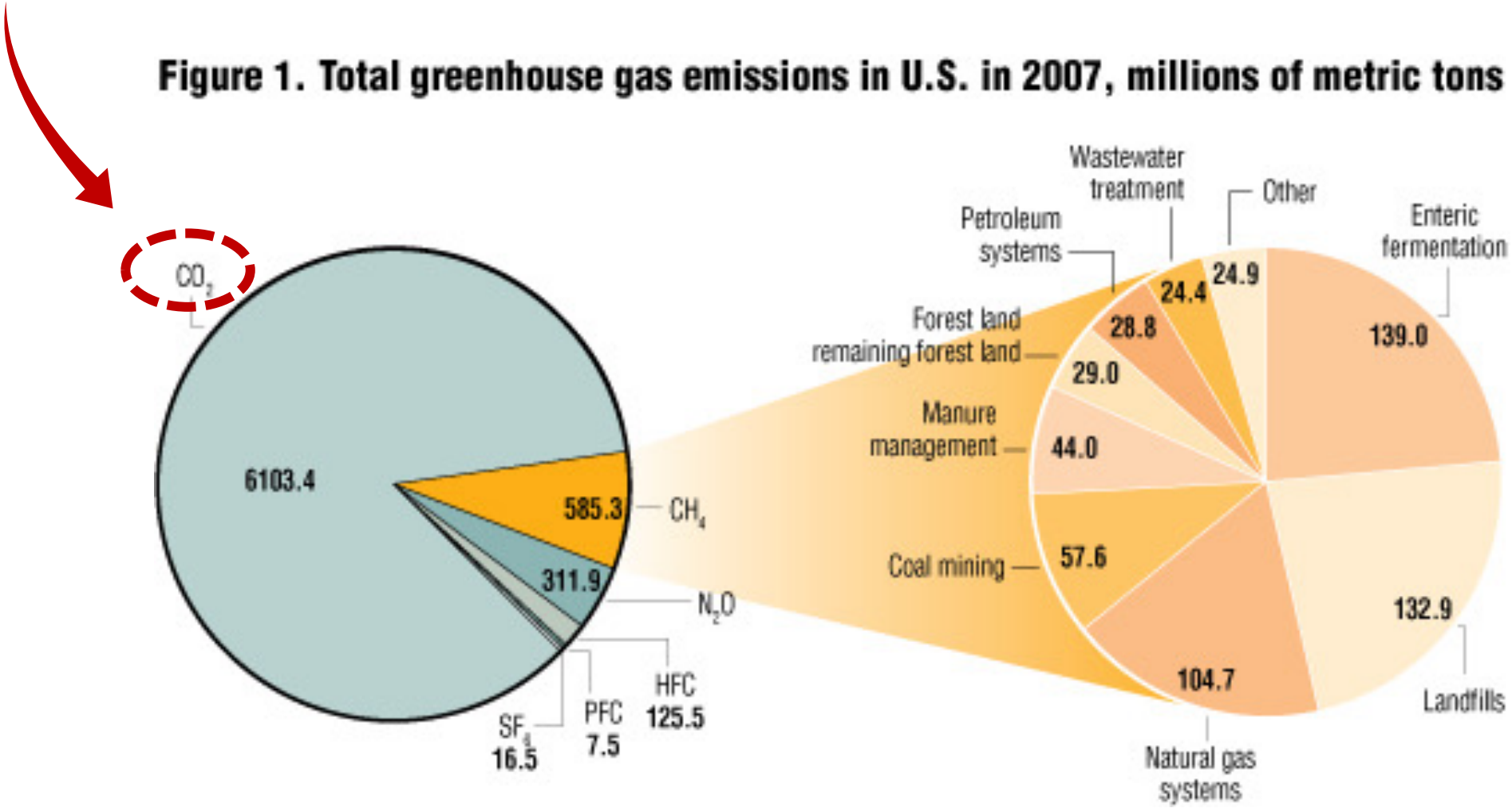
Biogas

Methane: CH_4

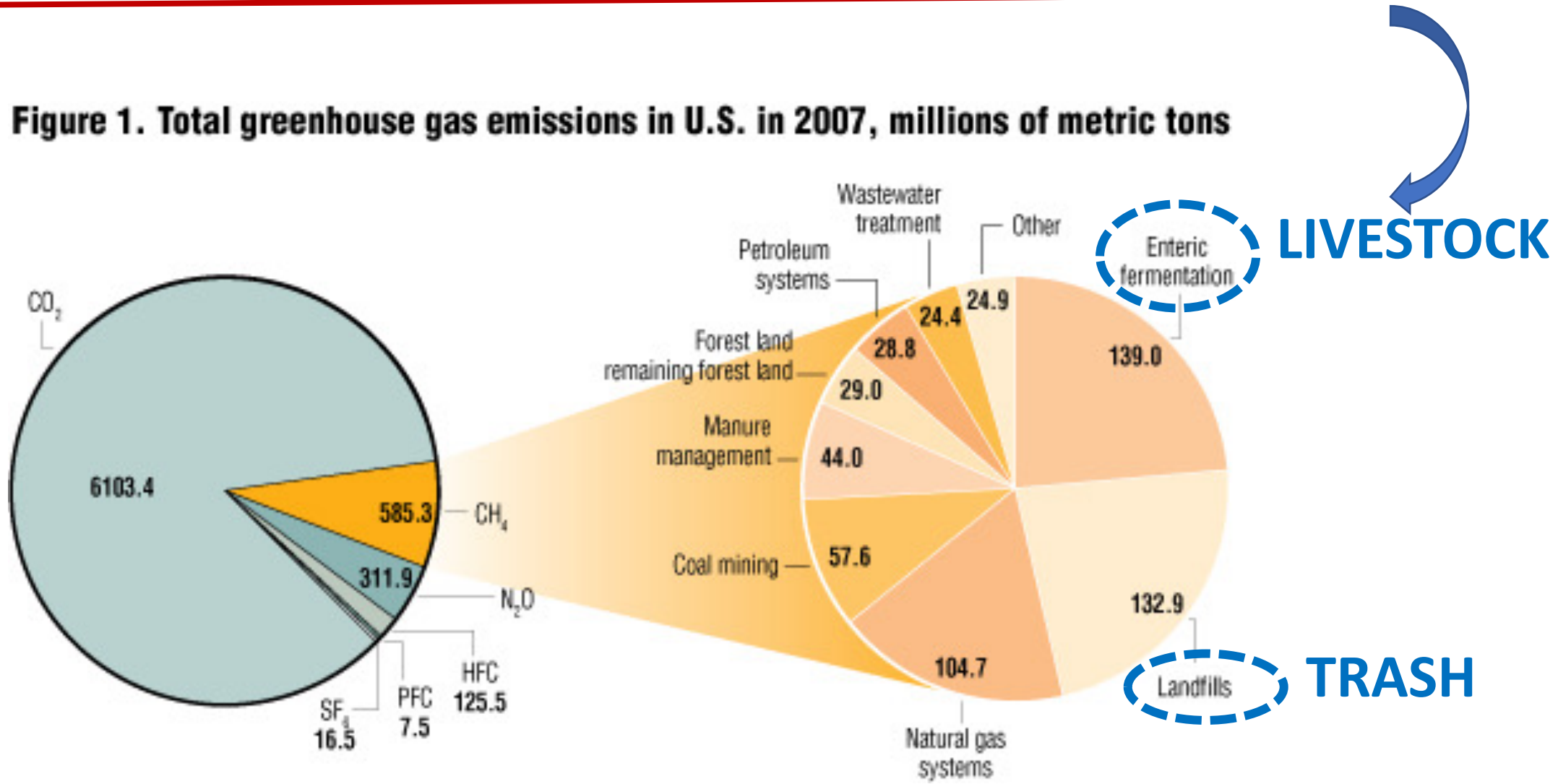


https://climate.nasa.gov/climate_resources/225/video-methane-sources/

Most global warming: CO_2 from fossil fuels

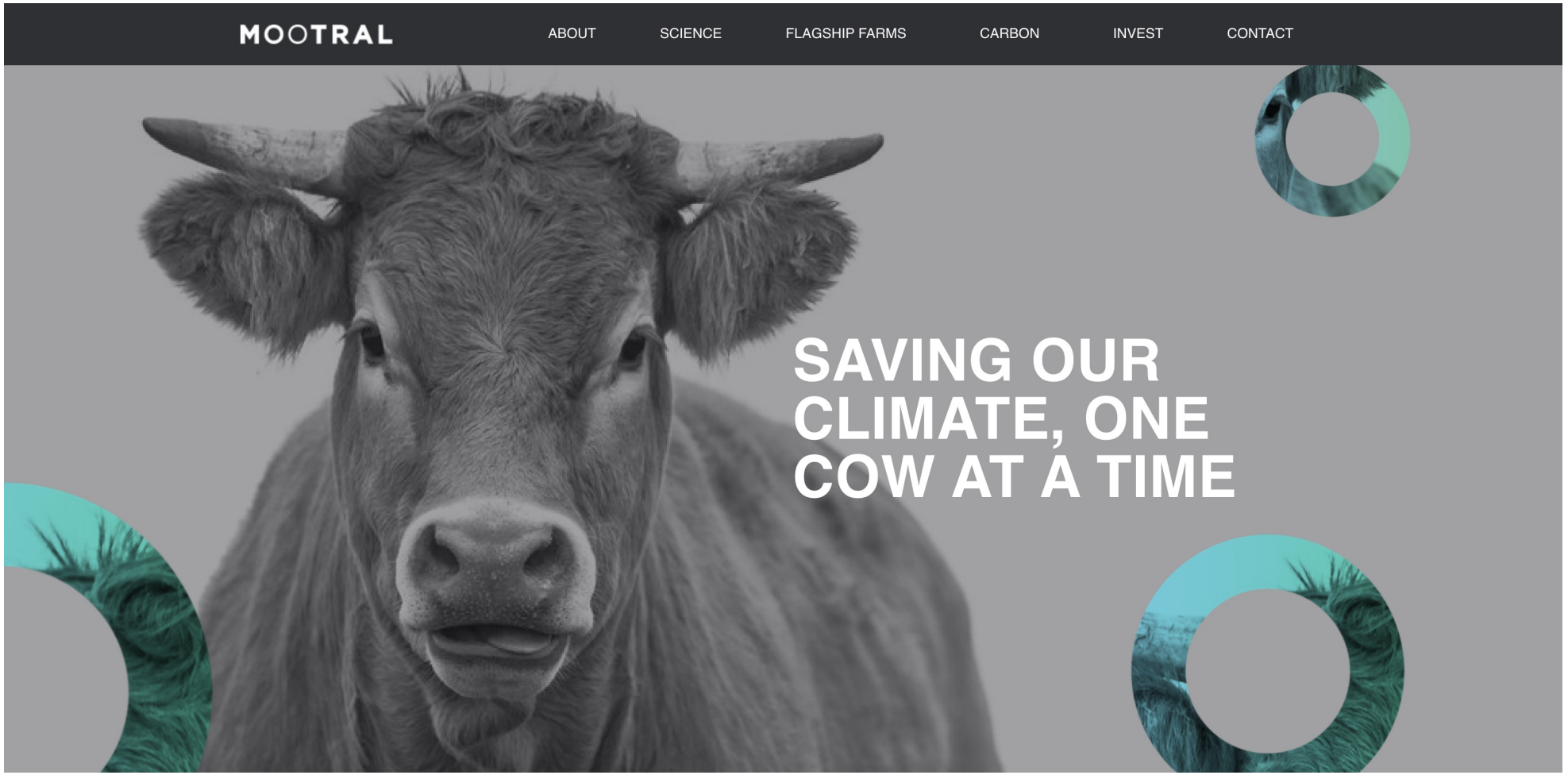


Biogas emissions from livestock and landfills



Biogas as a SOLUTION: Trap it!

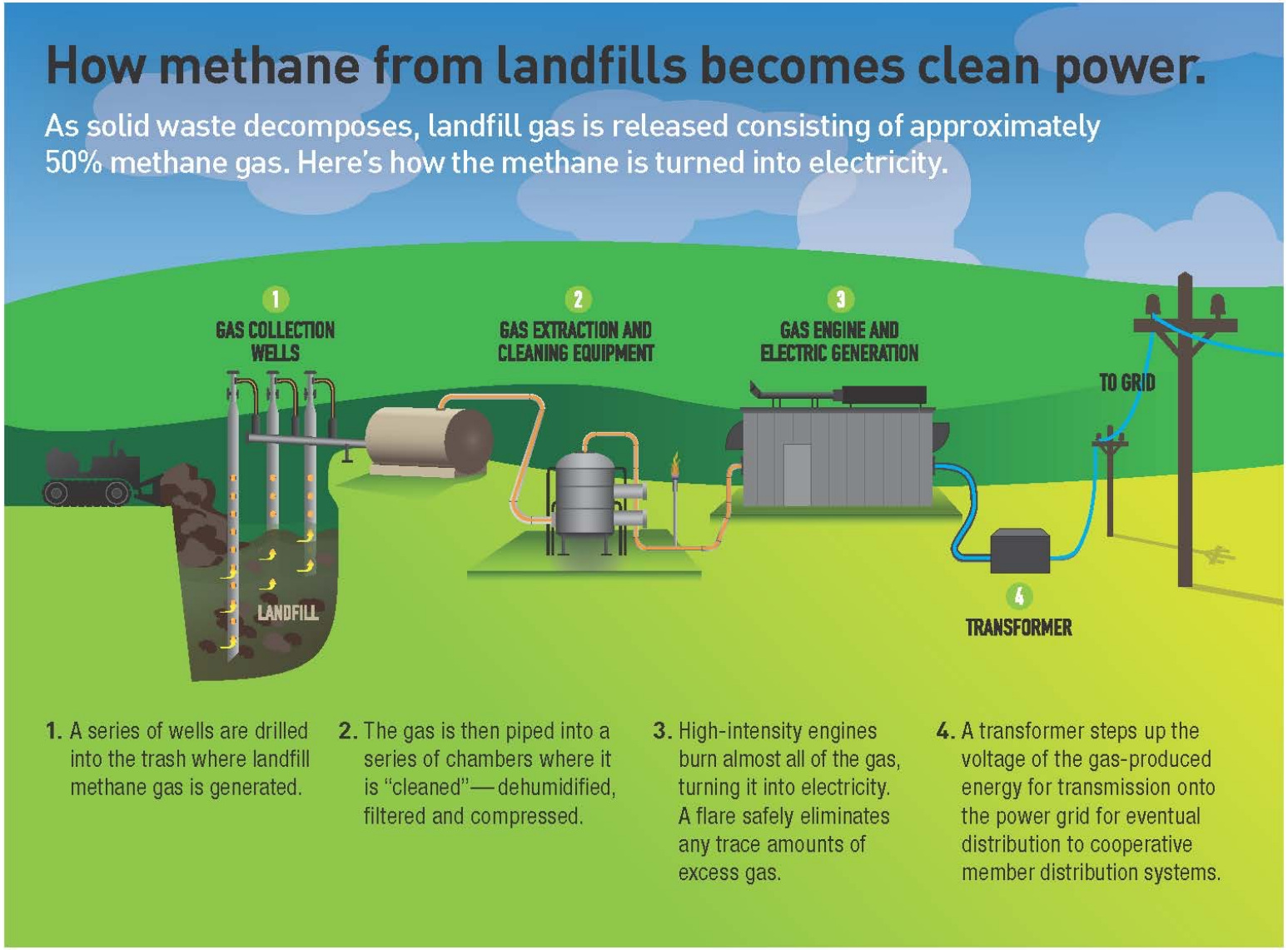
Biogas as a SOLUTION: Reduce it!



Swiss company that developed a livestock feed supplement, based on garlic and citrus extracts, that **reduces biogas emissions from cows by about 40%**

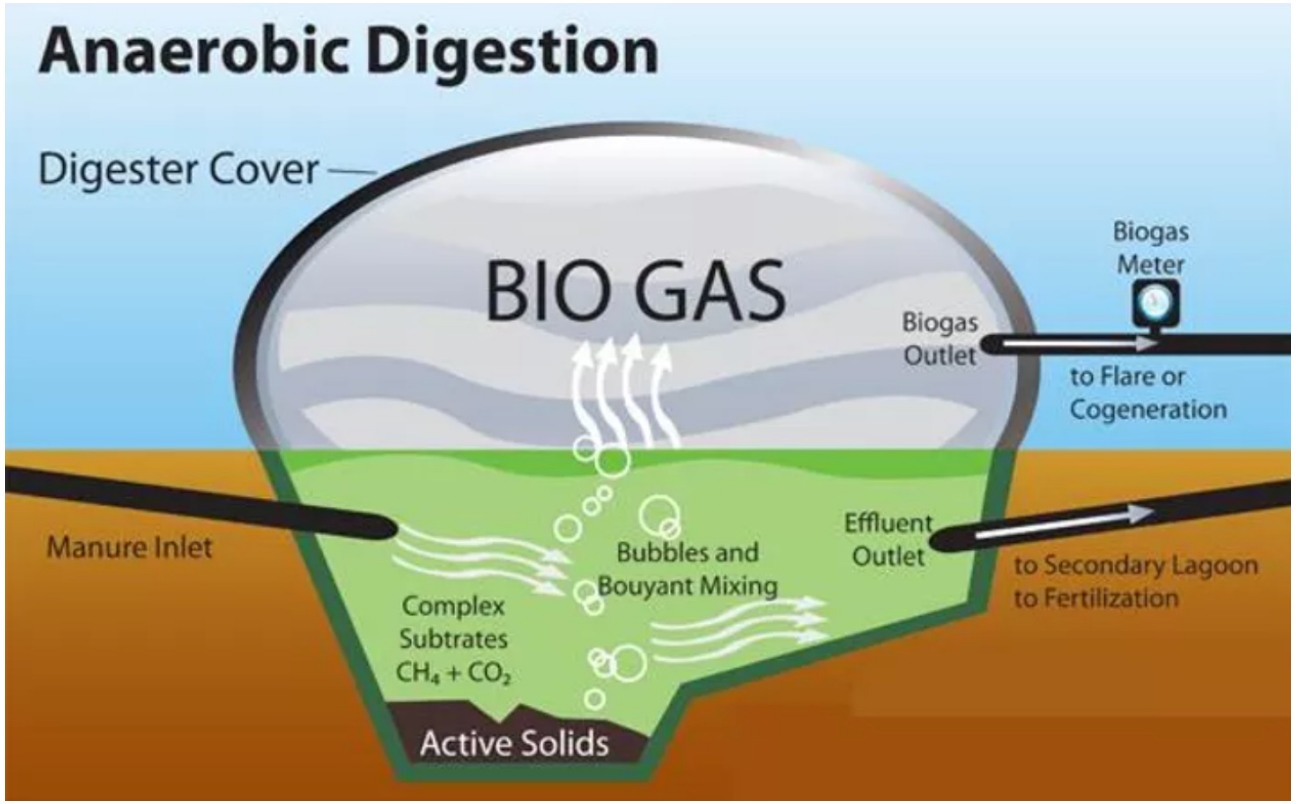
https://mootral.com/

Biogas as a SOLUTION: Trap it!



Anaerobic digesters mimic cow's stomach

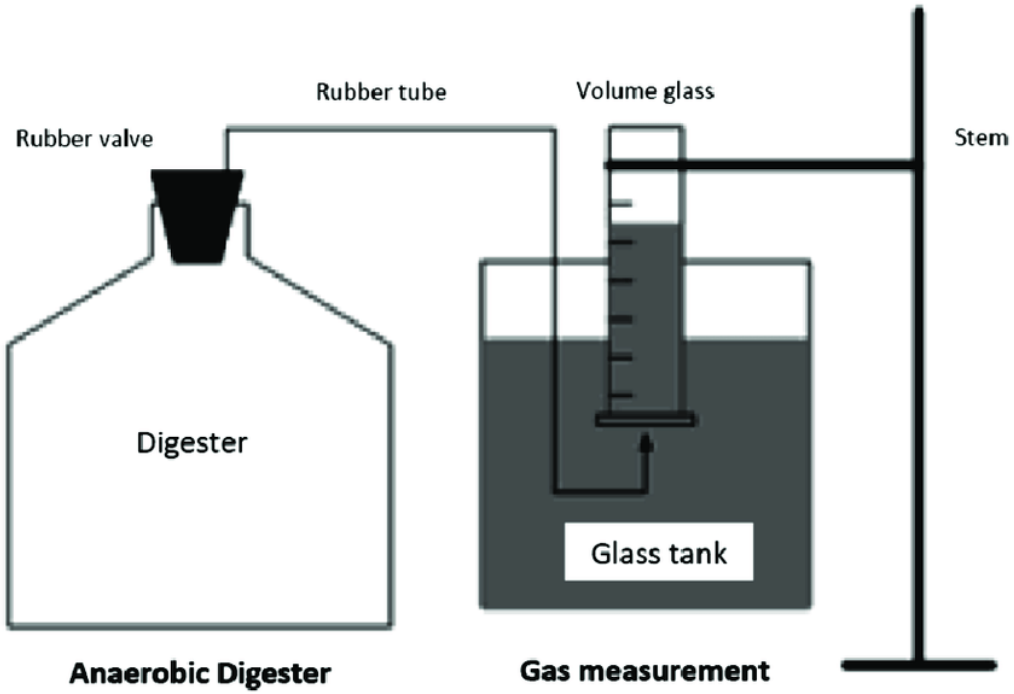
Organic waste



Biogas

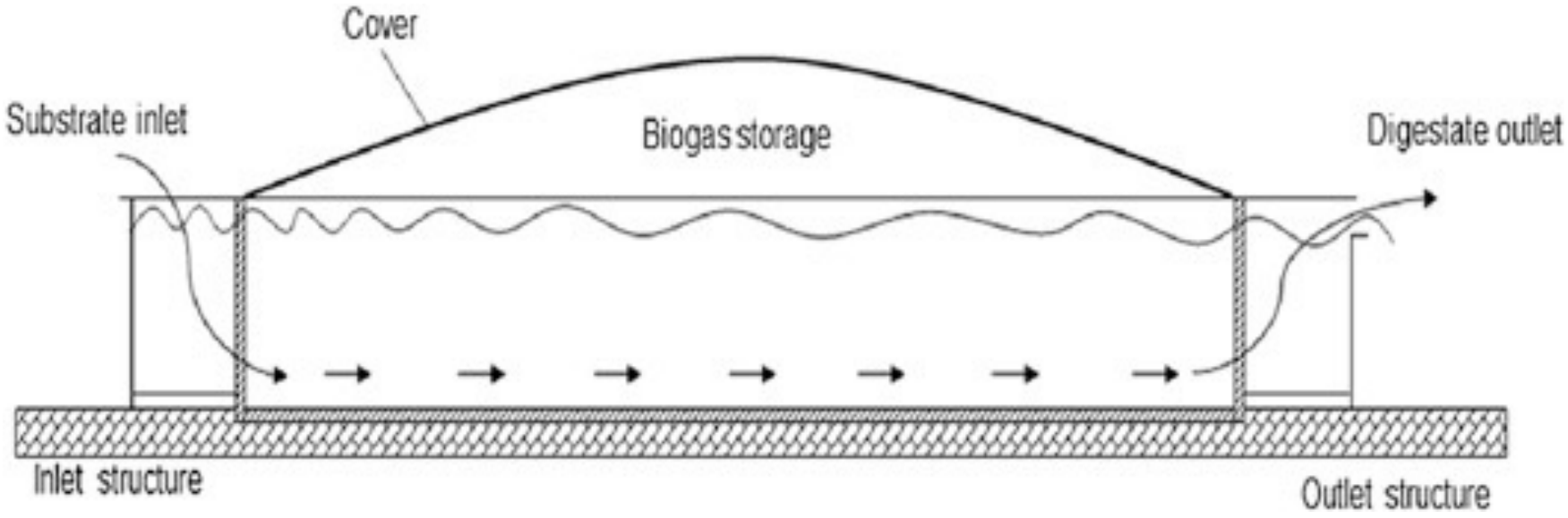
Fertilizer

Batch anaerobic digesters



- Static container, filled once and then allowed to generate biogas
- Good for benchtop research purposes

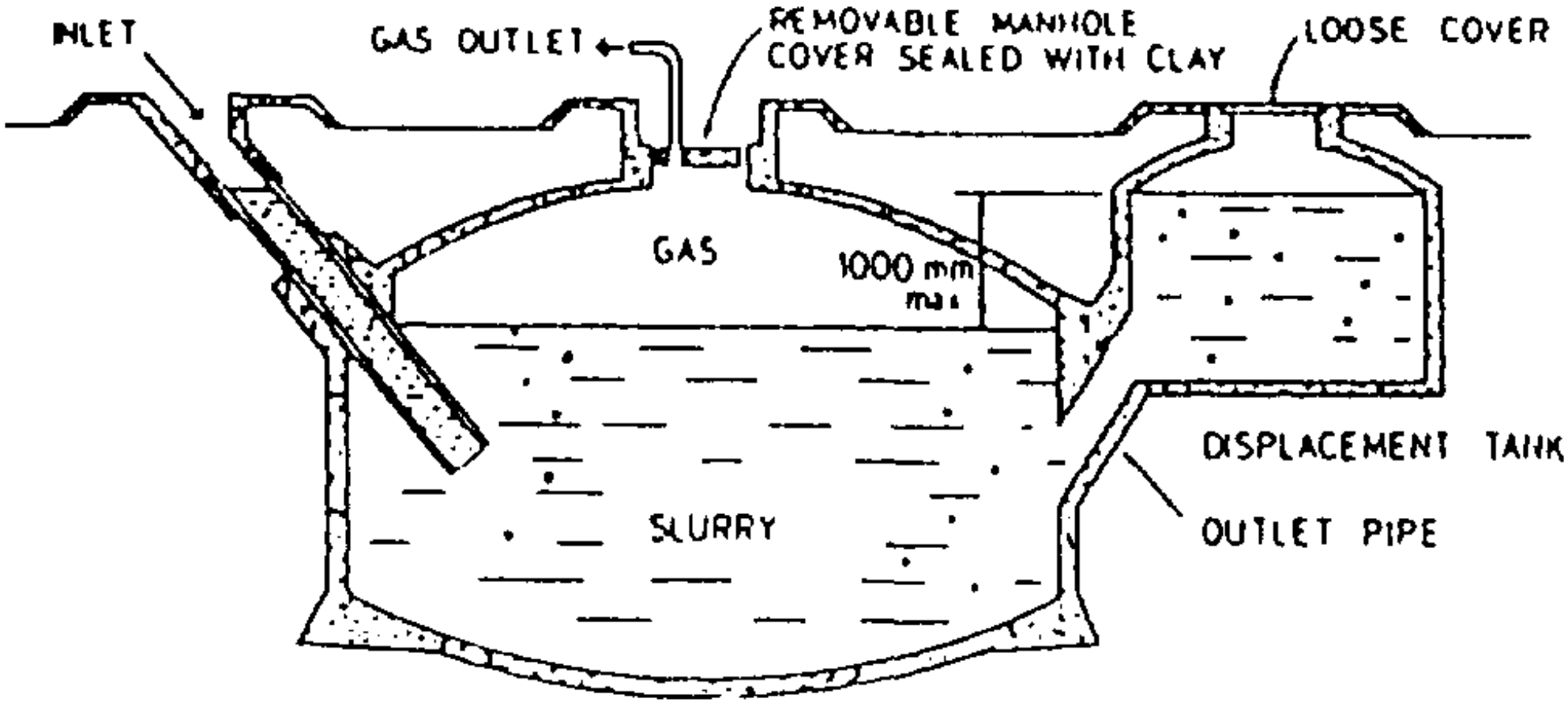
Plug-flow anaerobic digesters



- Biodigester has an INPUT ("feed") and 2 OUTPUTS (biogas & effluent/digestate)
- Feed rate depends on size of biodigester

Plug-flow anaerobic digesters

"Chinese Fixed-Dome" (1930s)



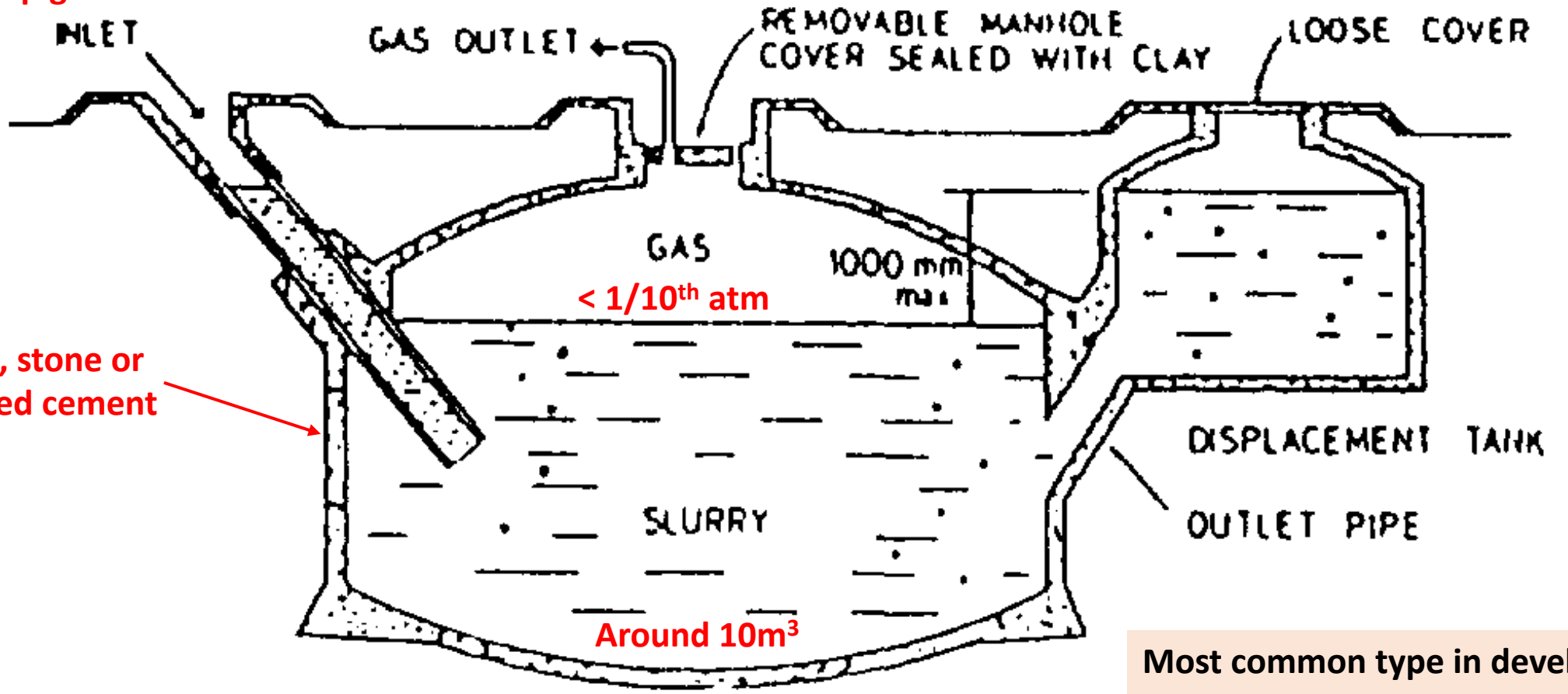
https://www.fao.org/3/t0541e/T0541E09.htm

Plug-flow anaerobic digesters

"Chinese Fixed-Dome"

Plug-flow anaerobic digesters

"Chinese Fixed-Dome" (1930s)

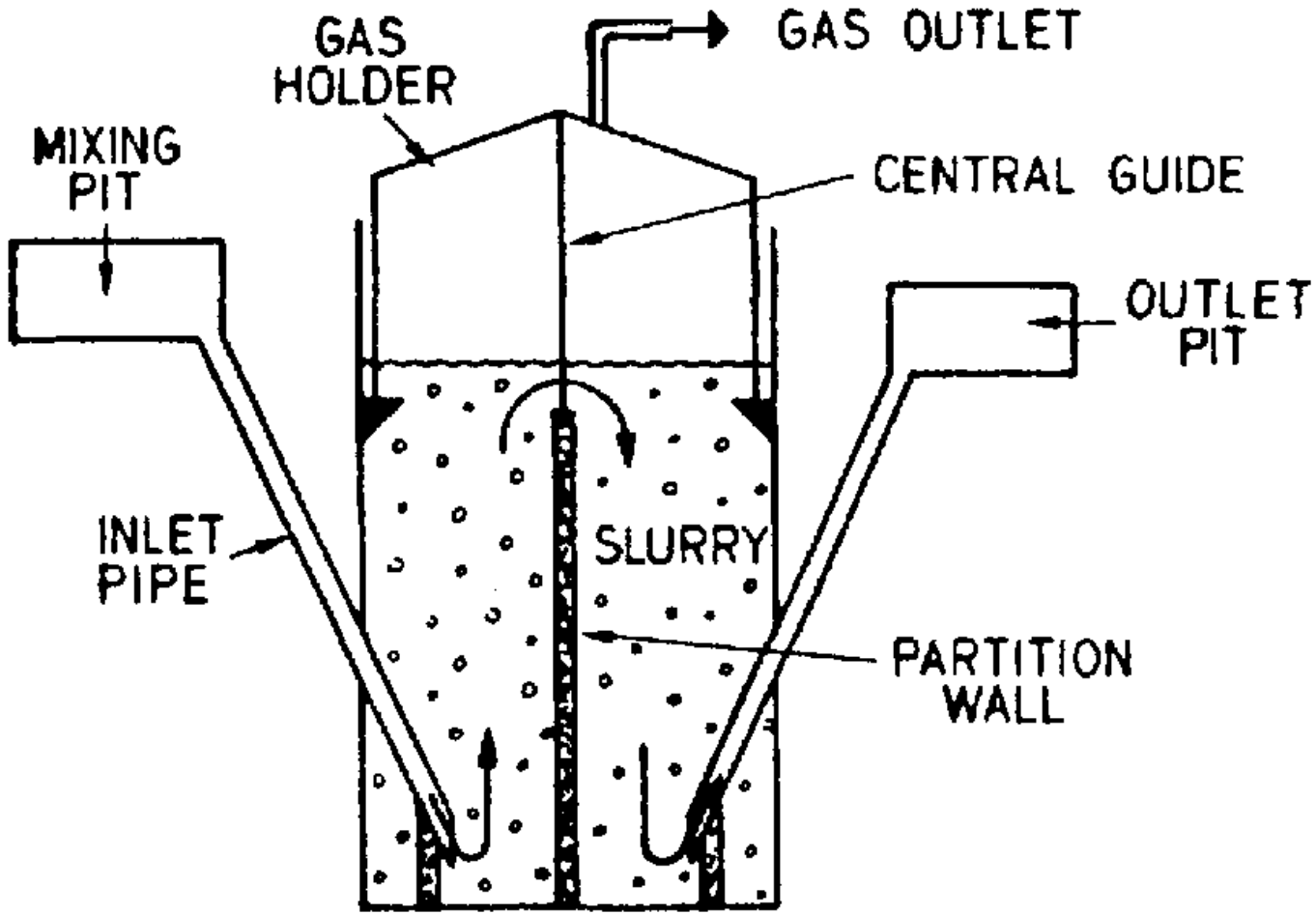


Most common type in developing world

5 million in China

Plug-flow anaerobic digesters

"Indian Floating-Dome" (1930s)



Can hold ~10m^3 of gas

Bioreactor is made of brick or reinforced concrete

Drum is made of mild steel or fiber-reinforced plastic (FRP)

Feed is mostly dung, but also humanure, agricultural waste & water plants

Biogas pressure < 1/100th atm

Plug-flow anaerobic digesters

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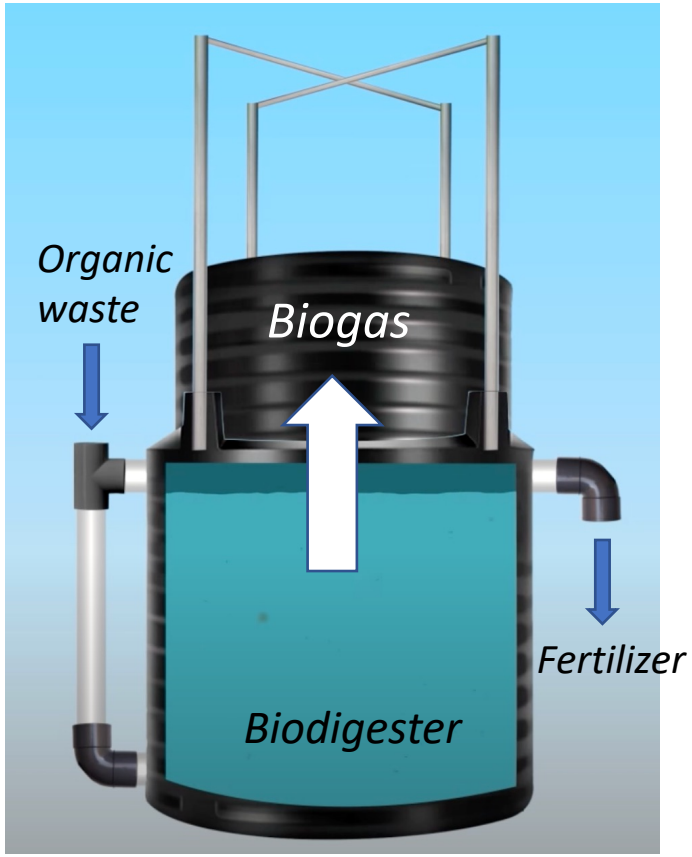
Anaerobic digesters: Small-scale

Santa Fe, Argentina

110 biodigesters installed in public schools in Santa Fe province (Argentina)

Anaerobic digesters: Small-scale

Pune, India



1m^3 biodigester can generate enough biogas to cook 3 meals/day in a hot climate*

* *needs to be fed 10 lbs kitchen waste/day*

Anaerobic digesters: Small-scale

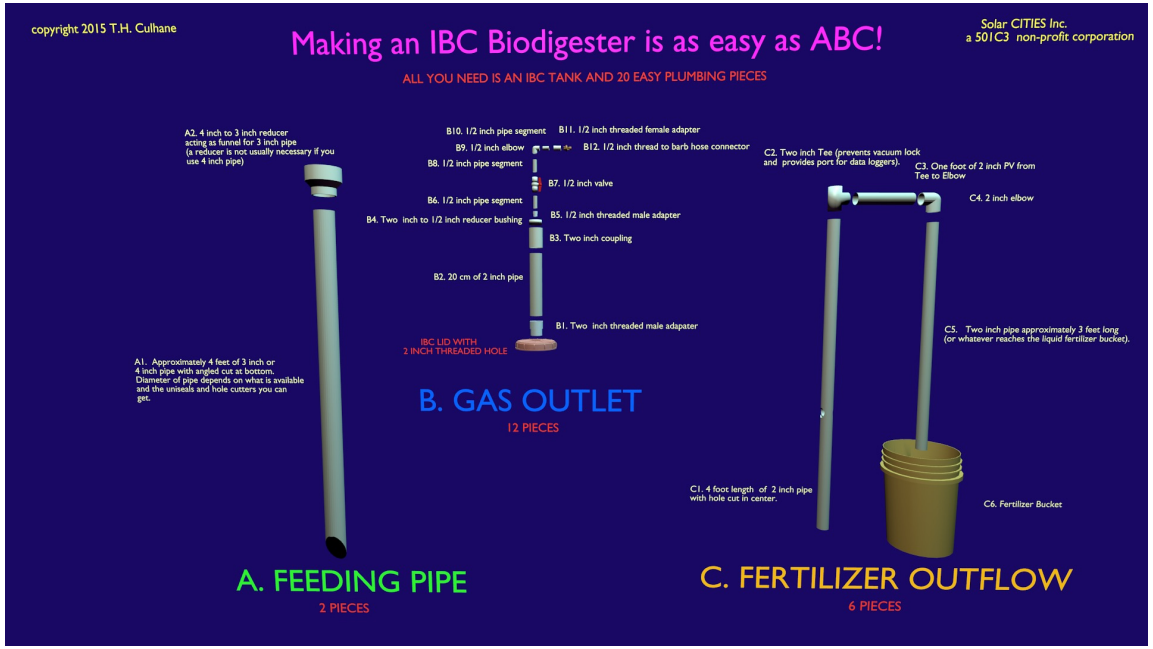
Nairobi, Kenya

http://biogas.co.ke/flexi-domestic-systems/

Anaerobic digesters: Small-scale

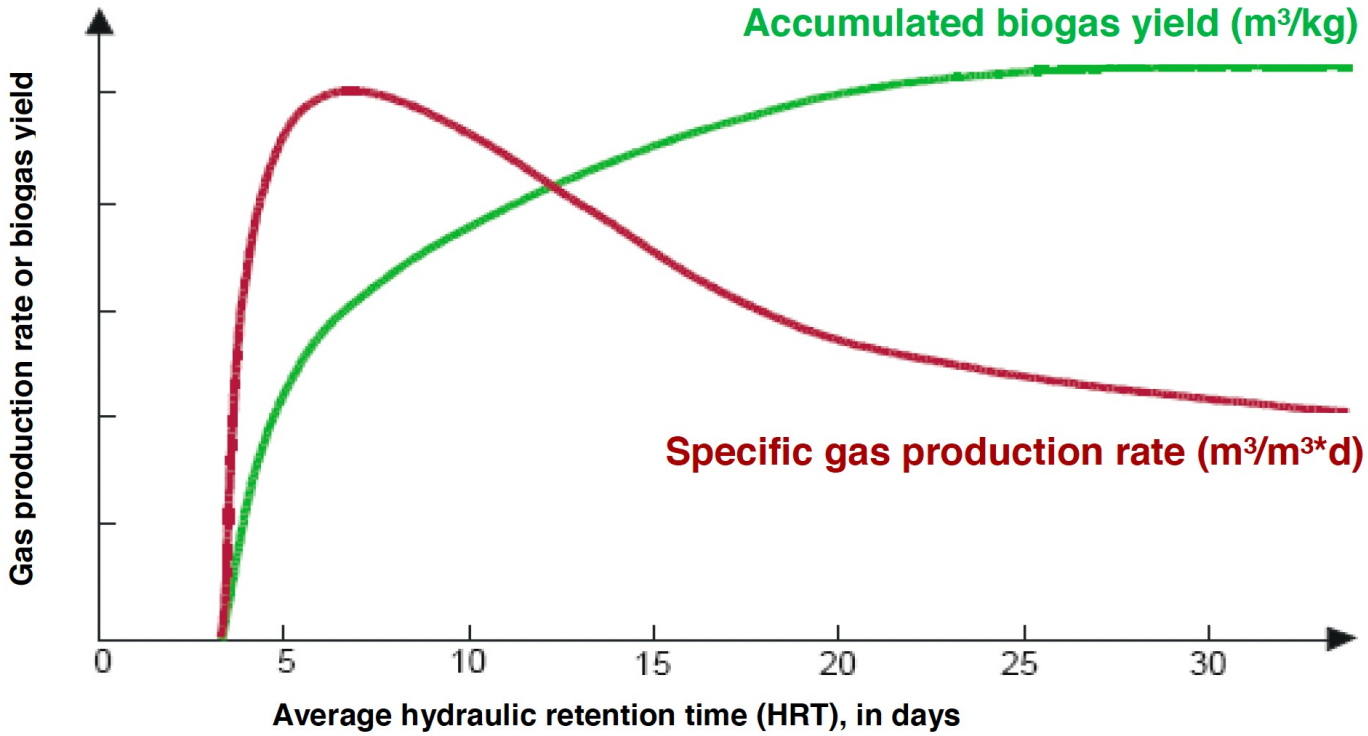
IBC container

https://www.youtube.com/watch?v=tdA4BqSEESU



https://www.solarcities.eu/education/388

Hydraulic Retention Time (HRT)



HRT = how long the "feed" stays in the biodigester before it gets flushed out

Figure 3.6 Biogas production after addition of substrate –batch test (LfU 2007)

Hydraulic Retention Time (HRT)

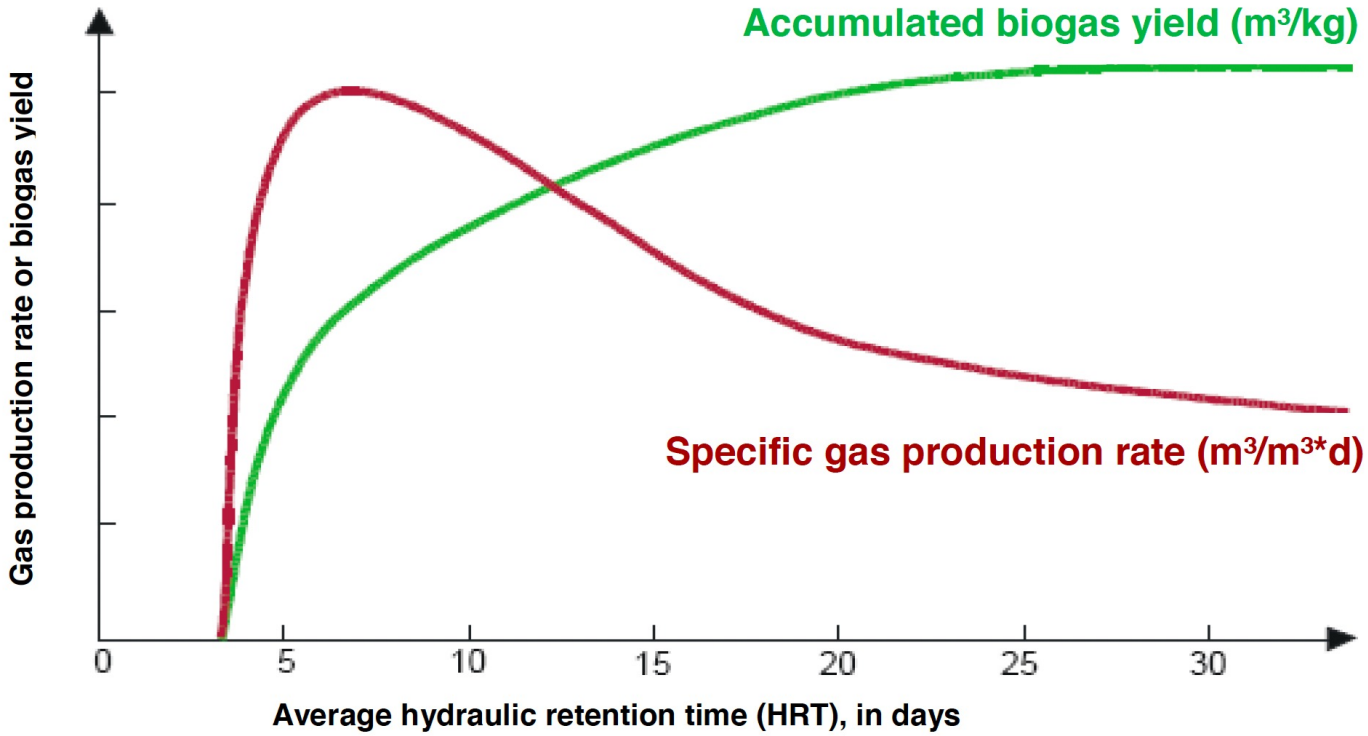


Figure 3.6 Biogas production after addition of substrate –batch test (LfU 2007)

HRT = how long the "feed" stays in the biodigester before it gets flushed out

The longer the HRT, the more biogas you produce

Hydraulic Retention Time (HRT)

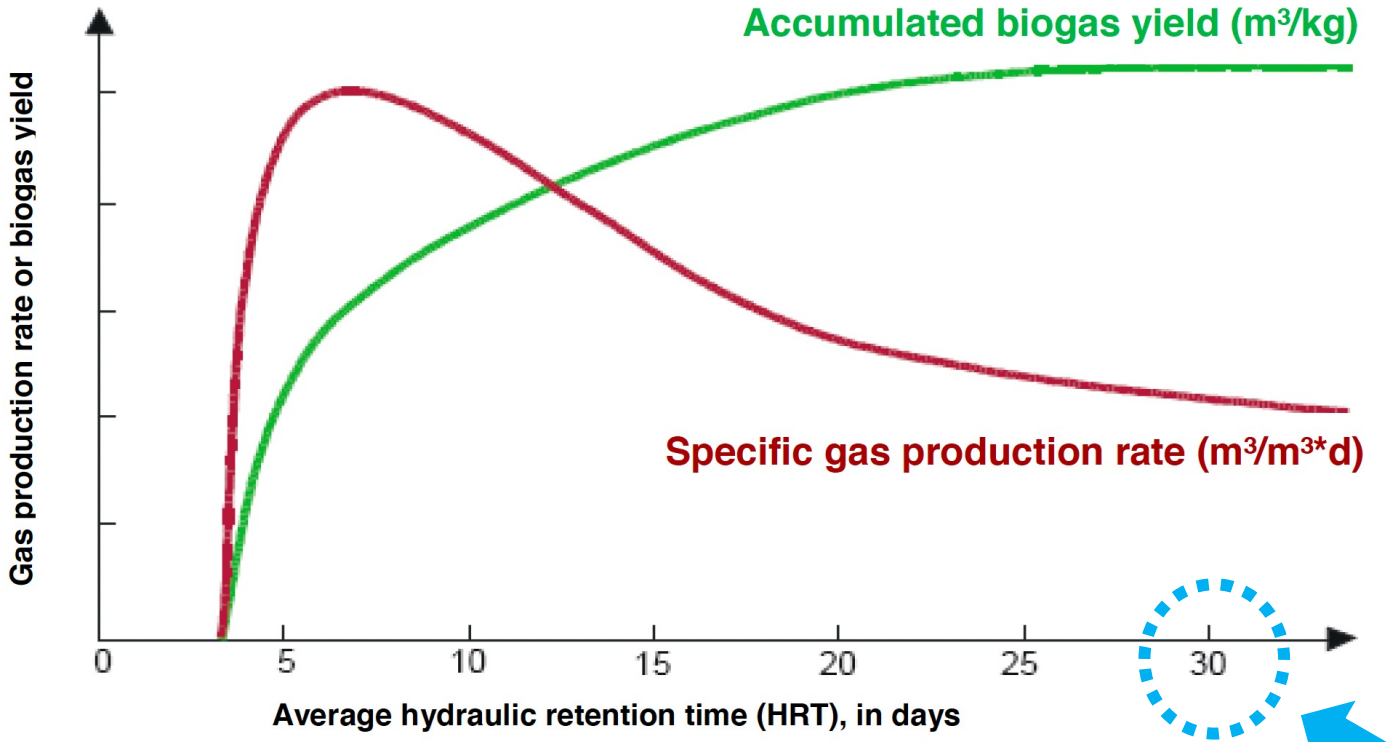


Figure 3.6 Biogas production after addition of substrate –batch test (LfU 2007)

HRT = how long the "feed" stays in the biodigester before it gets flushed out

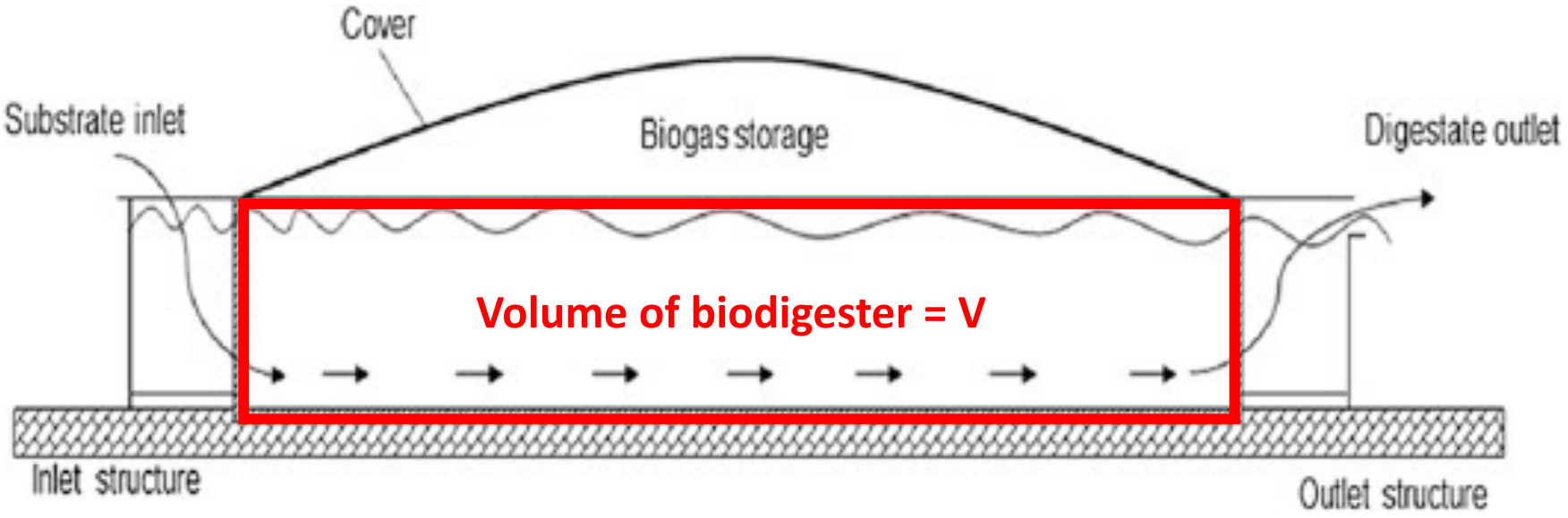
The longer the HRT, the more biogas you produce

HRT ~ 30-60 days is typical, depending on climate & feed type

HRT = 45 days for food scraps in MA

Loading Rate (LR): How much feed per day?

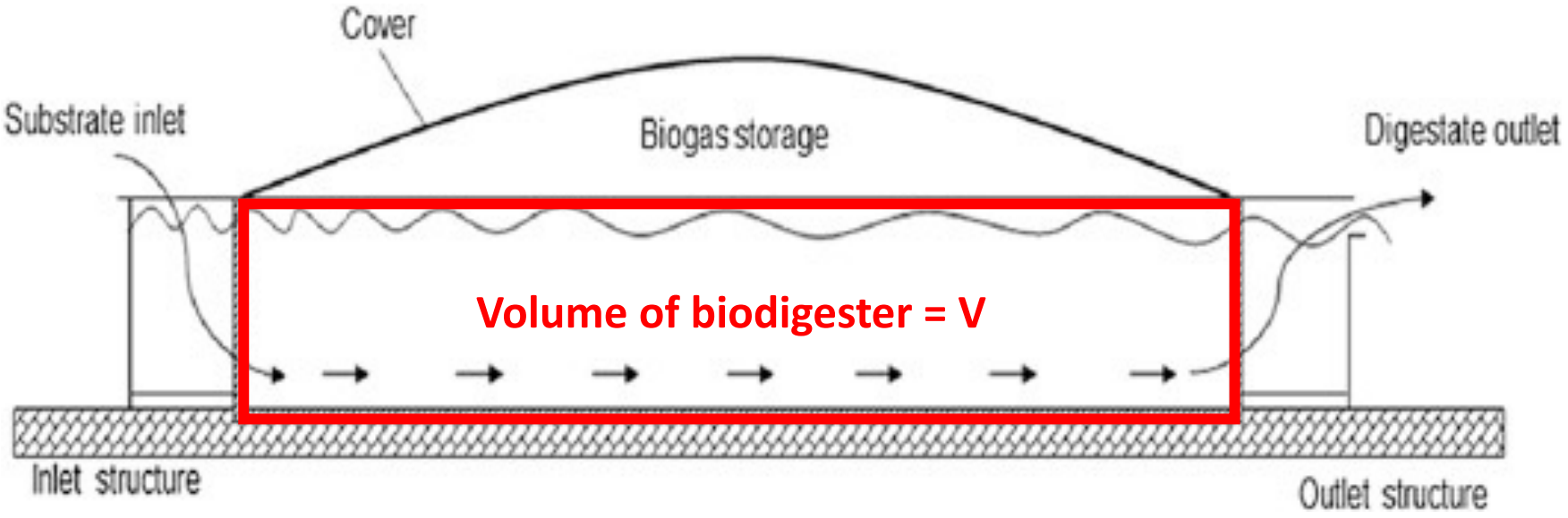
LR



$$LR = \frac{V}{HRT}$$

Loading Rate (LR): How much feed per day?

LR



$$LR = \frac{V}{HRT}$$

How much should you feed a 55 gal biodigester with a 45 day HRT?...

Loading Rate (LR): How much feed per day?

How much should you feed a 55 gal biodigester with a 45 day HRT?...

- The retention time (RT) for digesters that are fed food scraps is a 45 days.
- Substrate input is a 50:50 mixture of food to water and is measured in volume.

Sizing a biodigester

What size of a biodigester do you need if you can supply 10 gallons of food scraps per day?

Biogas production

One cubic meter of gas (1,000 liters) can

- Cook 3 meals for a family of 5-6
- Run a 1 horse power motor for 2 hours
- Illuminate a 60 to 100 watt bulb for 13 hours
- Generate 1.25 KW of electricity.

Biogas production

Traditional biodigesters used mainly animal dung…. Very inefficient!

40kg dung + 40 days -> 1kg biogas (Energy ~ 1 L gasoline)

https://www.youtube.com/watch?v=sq-qNVhxZm0]

BUT… 1 kg sugar + 1 day -> 1 kg biogas!

1 kg dung will produce 0.04 m3 of biogas.
Hence, 1/0.04 = **25 kgs is required to produce 1 m3 of Biogas.**
In terms of energy, one cubic meter of biogás is equivalent to

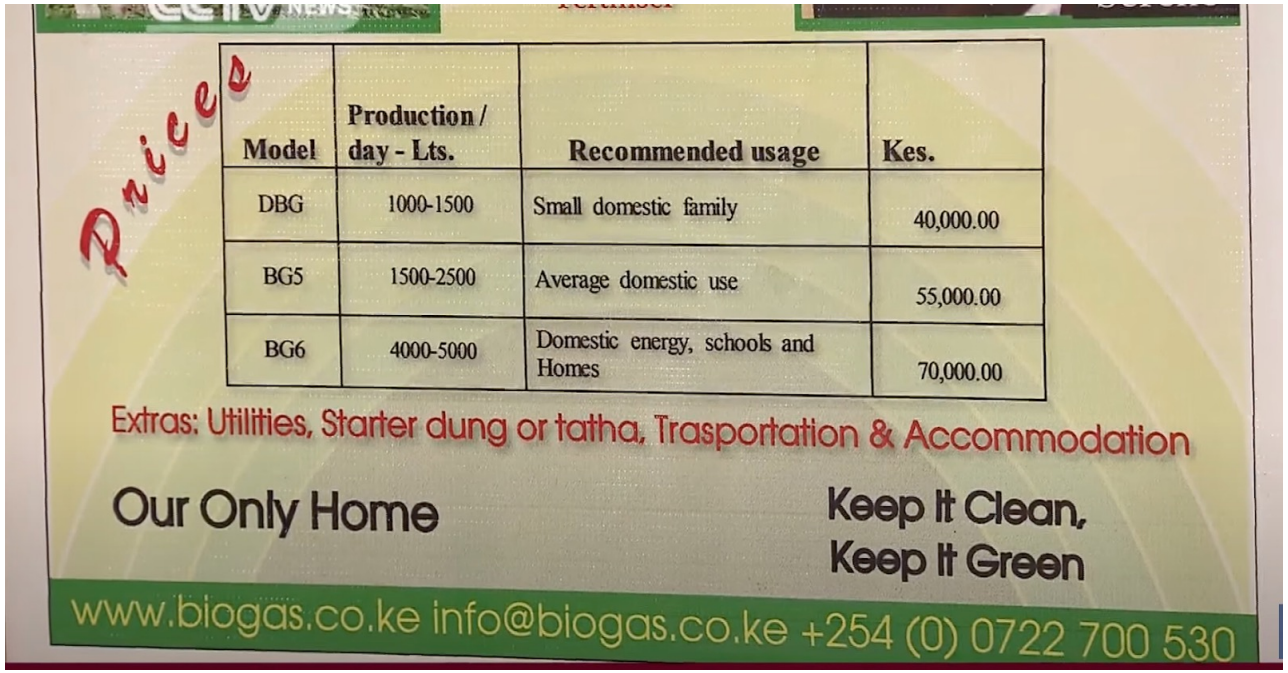
- 1,5 m³ of LPG (propane/butane);
- 0,61 to 0,70 liters (0,00061m³ to 0,00070m³) of gasoline;
- 0,55 liters (0,00055m³) of diesel oil;
- 0,80 liters (0,00080m³) of ethanol;
- 1,25 a 1,43 kWh of electric energy;

- 1,60 a 3,50 kg of firewood

Biogas production

Flexibiogas (Dominic Wanjihia; Biogas International)
1 day to install; 1 week at full production
Tube about 4m long, covered in “greenhouse” tent
1:1 20kg cow manure with water, every day
Makes 700-1,000 L biogas (0.7-1m^3); enough cooking for family of 4-6 members
Can also run generators
10 year lifetime
https://www.facebook.com/watch/?v=263139327992475
https://www.youtube.com/watch?v=hYHfmgltDb8

10,000 Kes (Kenyan shillings) = US $88
These systems cost around $350-600

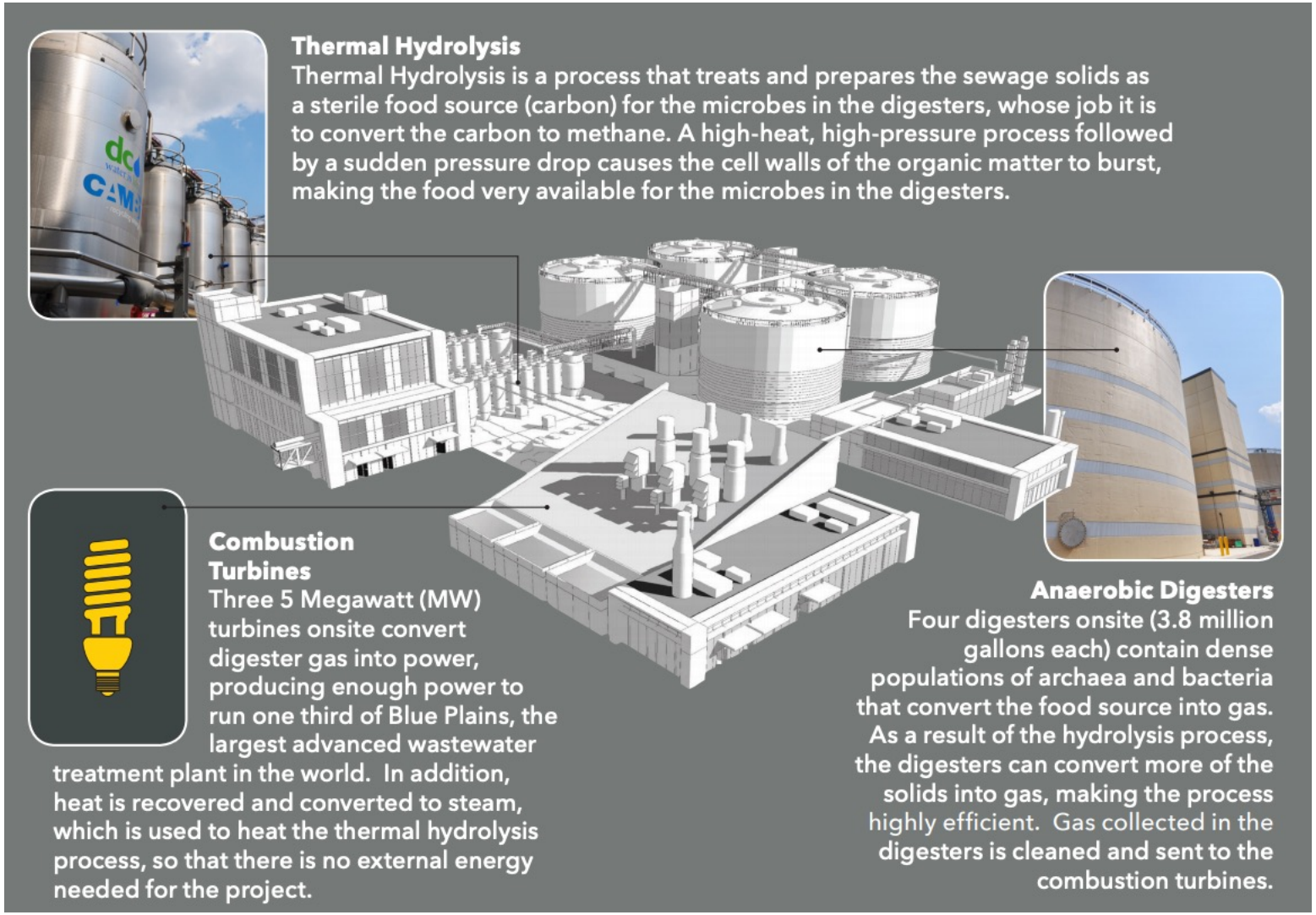


Anaerobic digesters: Medium-scale

Barstow Dairy Farm, Hadley, MA

- Use cow manure & food waste
- Run a 300kW electrical power generator

Anaerobic digesters: Large-scale



Blue Plains Advanced Wastewater Treatment Plant, Washington DC

- Processes 300 million gallons of wastewater daily
- Runs a 5MW electrical power generator
- Cost around $1 billion* to install (2011-2015)

** 0.02% of federal budget (nondefense discretionary spending)*