Envirothon 2022
Teacher Workshop
Resource Extraction from Human and Animal Waste

Sachiyo Tanaka Mukherji, Ph.D.

Department of Environmental Sciences

University of Houston Clear Lake

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Outline

Resource recovery introduction: Methane, freshwater, nutrients

Human and animal waste: How much do we generate and what's in there?

Example 1: Urine as a nutrient resource

Example 2: Sewage as a methane, freshwater, and fertilizer resource

Example 3: Manure as a methane and fertilizer resource

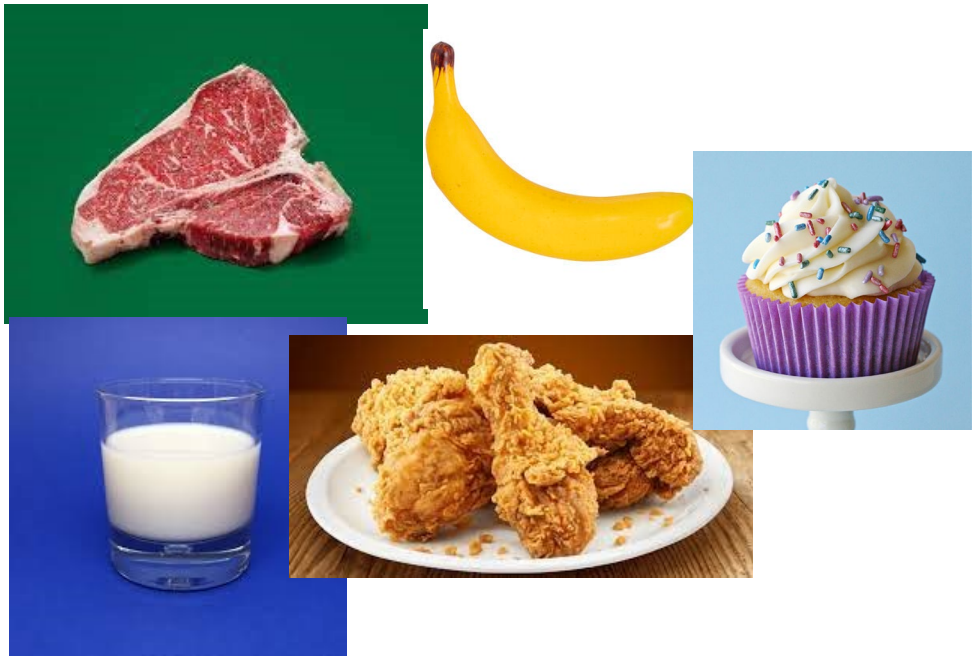
Conclusion

Questions?

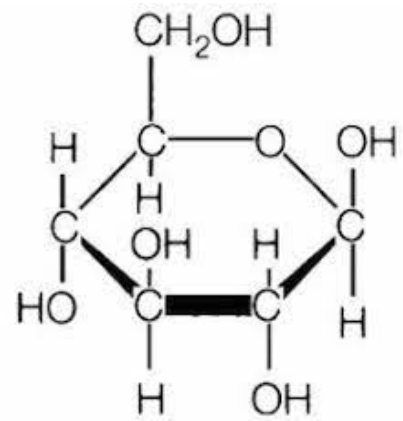
Organic compounds contain C-H bonds

- N[illegible]
- Fish/meats: no growth hormones, antibiotics
- Not genetically modified.

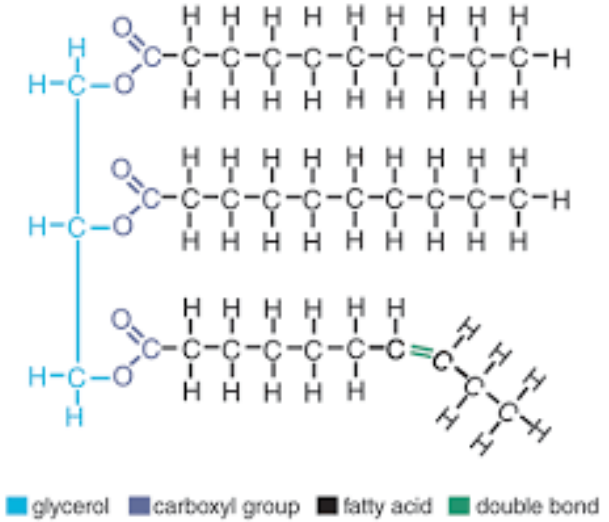
Organic matter



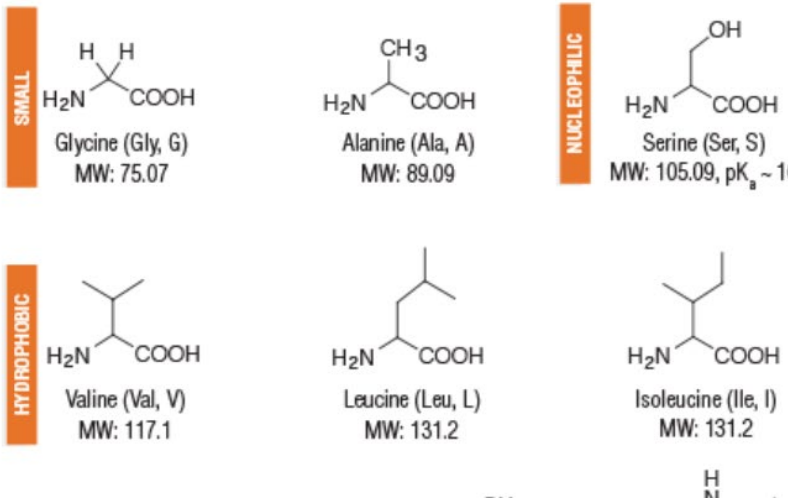
Organic compounds contain C-H bonds.



Glucose



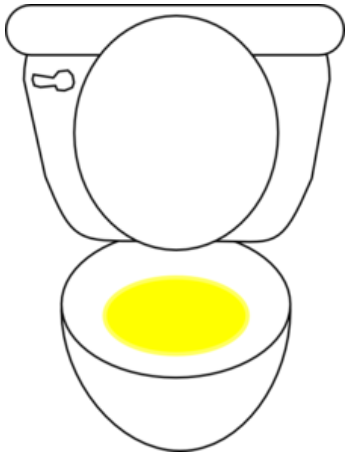
lipids



Some amino acids in protein

Organic compounds

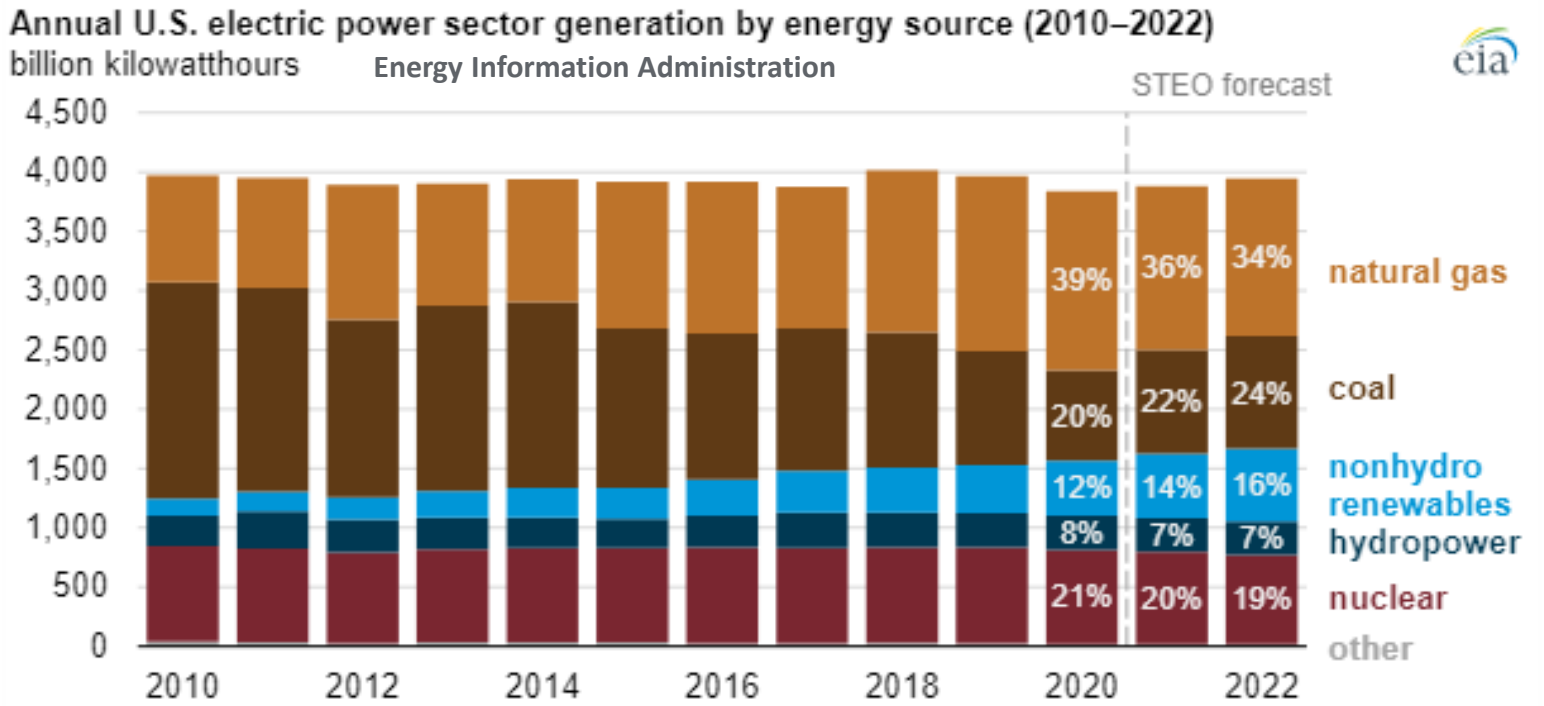
Organics
Organic matter



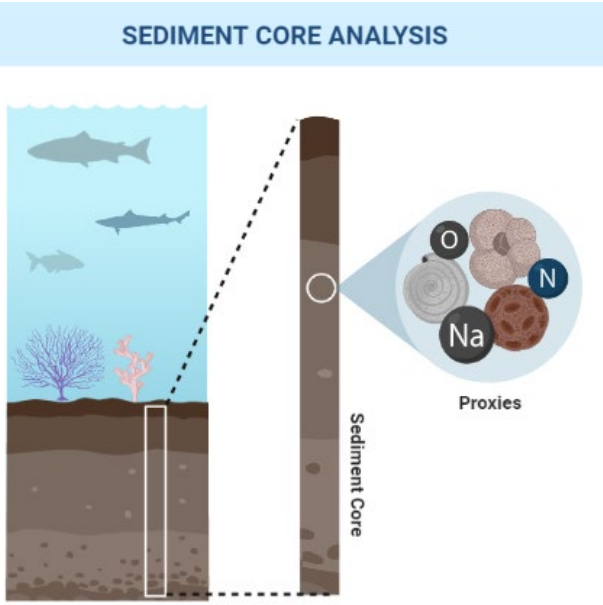
Recovery of resources: Methane gas, CH_4 from organic matters

- Methane is the main component: 70-90% of natural gas.
- Natural gas is a nonrenewable fossil fuel.

Organic matter → CO_2 + $\underline{CH_4}$

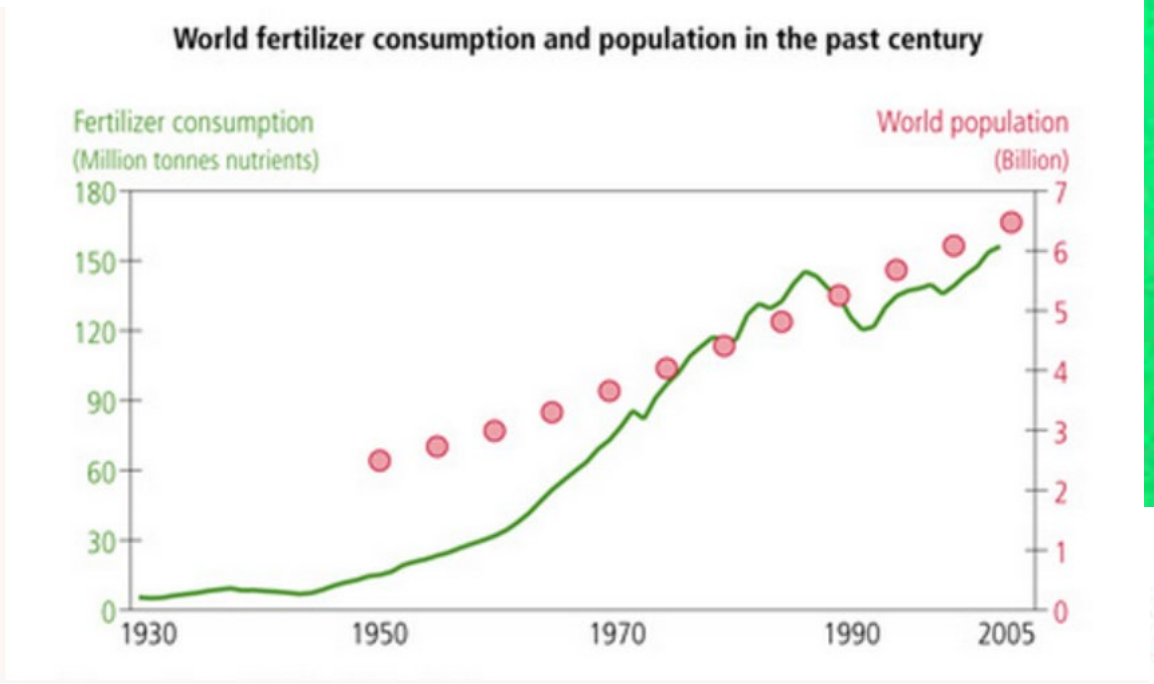


Under anaerobic conditions, organic matter → CO_2 + $\underline{CH_4}$



Microorganisms break down organic matter to methane gas under <u>anaerobic</u> conditions (no oxygen) →Renewable! Learn from nature!

Recovery of resources: fertilizer



The human population is predicted to reach 10 billion by 2050.

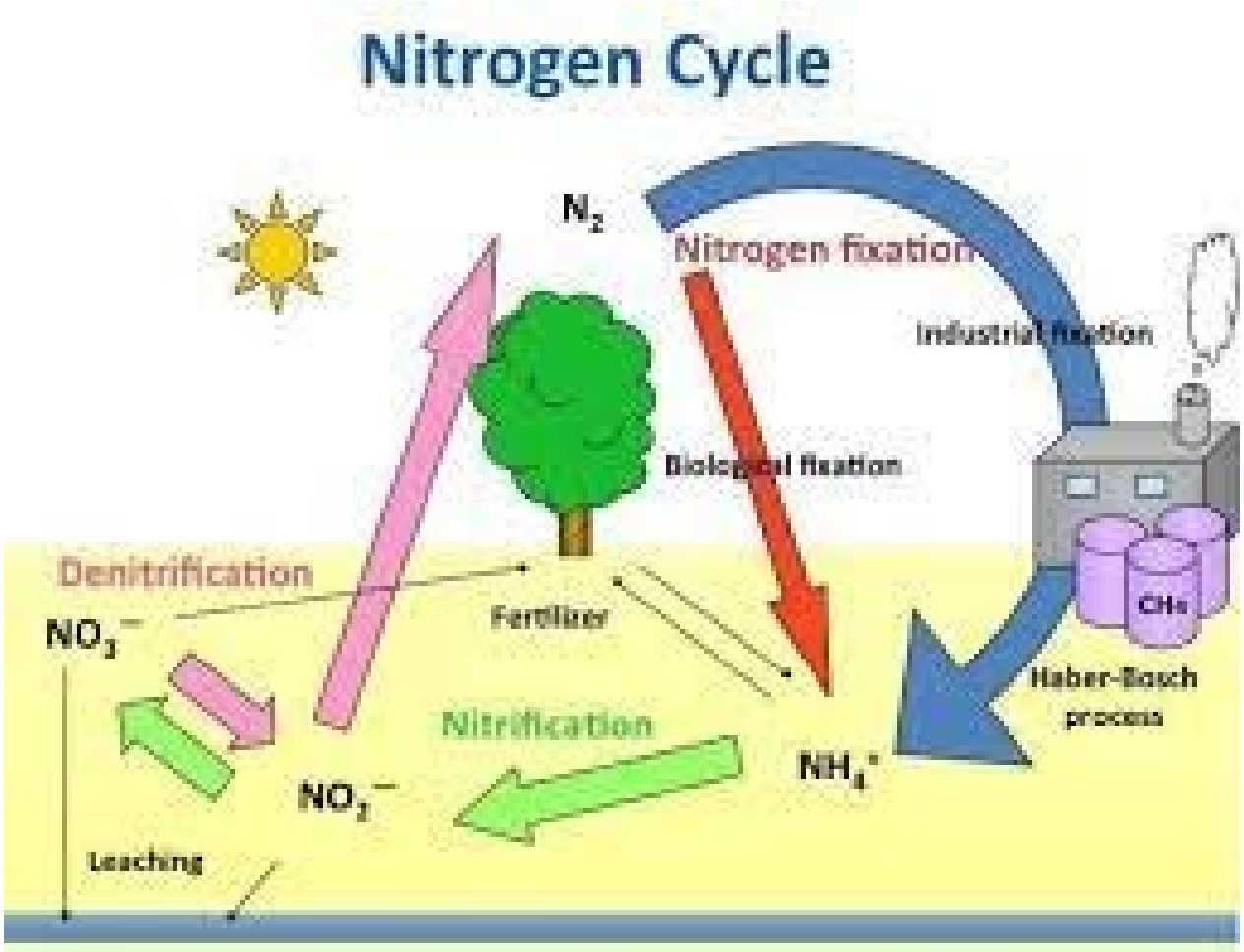
Plant nutrients: N and P

http://12.000.scripts.mit.edu/mission2017/fertilizers-2/

Synthetic fertilizer production

- Nitrogen fixation process: N_2 gas (78% of the air) → N-forms that can be used by living organisms (i.e., ammonia, nitrate, etc.)
- Natural process: done by microorganisms
- **Artificial process: Haber-Bosch process (fossil-fuel based)**

  N_2 + hydrogen →ammonia
- 80% of commercially produced ammonia: fertilizer
- Studies: 20~50% of fertilizer applied is taken up by crops.


Nitrogen Cycle
N_2
Nitrogen fixation
Industrial fixation
Biological fixation
Denitrification
NO_3^-
Fertilizer
Nitrification
NO_2^-
NH_4^+
Haber-Bosch process
Leaching

Environmental impacts: excess nutrients upsets healthy environmental system in natural water systems

Exponential algal growth

Hypoxia

"NOAA-supported scientists announced that the 2021 Gulf of Mexico "dead zone" is equivalent to more than four million acres of habitat potentially unavailable to fish and bottom species." EPA

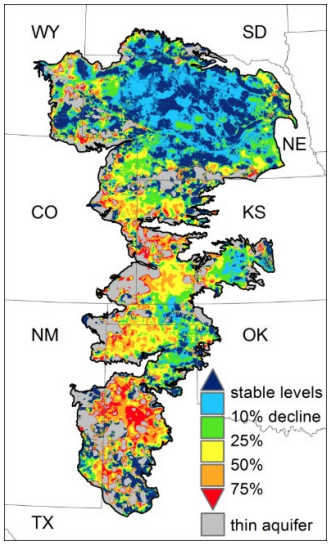
Alternative fertilizer:
Compost from waste, Inorganic fertilizer (struvite) synthesis from urine (part of natural N-cycle)

Recovery of resources: freshwater is a renewable but exhaustible resource.

- Stressed: when demand > 40% of available supply

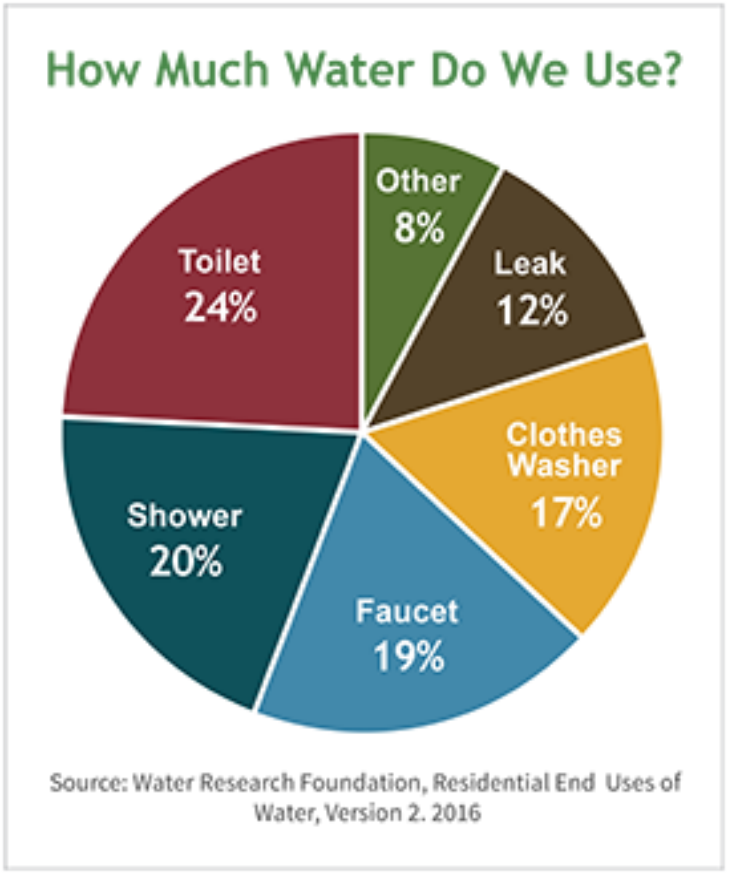
The Ogallala Aquifer

The net groundwater accumulation rate is -2.16 inch/ year.



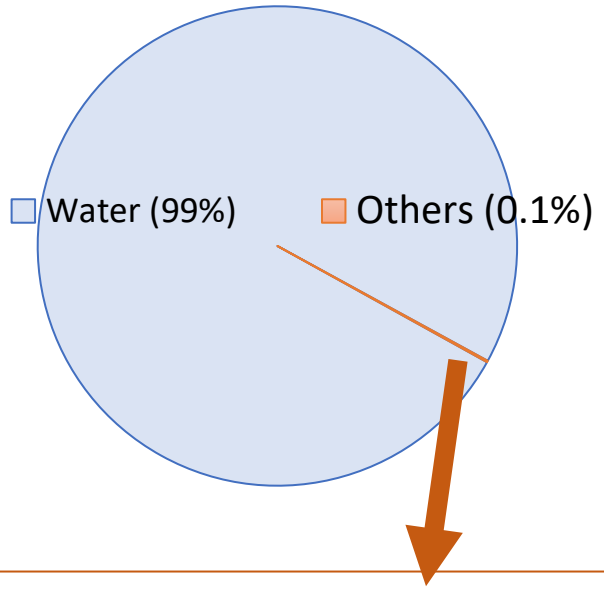
Reclaimed wastewater: Sewage to drinking water

Human waste: what's in there?



https://www.epa.gov/watersense/how-we-use-water

Domestic untreated wastewater: By weight



- organic matters (feces, urine, toilet paper, dirt, food, grease, hair, cleaning chemicals)
- microorganisms (including pathogens)

BOD (biological oxygen demand): how much organic matters are present in the water

<u>Organic matters</u>+ dissolved **O_2**→CO_2+H_2O+residue

- Analytical instruments: only can measure the concentration of an individual chemical compound in the water.

How much oxygen has been consumed?
→ indication of the amount of organic matter n the water.

Houston Public Works:

W/O O_2 (air)

Organic matter → CO_2 + $\underline{CH_4}$

- The largest water /wastewater utility in TX.
- 2.3 million people served.
- **277 MGD (million gallons per day) wastewater treated.**
- BOD_5 = 400 mg/L

(A good-sized bath holds 40 gallons, so a million gallons would be 25,000 baths) x 277

Raw wastewater compositions

Contaminants	Range, mg/L
COD	250 – 1,000
BOD5	110 – 400
Total Nitrogen (as N)	20 – 85
Organic	8 – 35
Free NH3	12 – 50
NO2-	0
NO3-	0
Total Phosphorus (as P)	4 – 15
Organic	1 – 5
Inorganic	3 – 10
Alkalinity (as CaCO3)	50 – 200
Grease	50 – 150

Metcalf & Eddy 3rd edition Wastewater Engineering

- Urine accounts for 1% of the total volume of the wastewater. (ex. 1% of 277 million gallons)
- <80% N load and <50% of P are from urine.

Animal waste: What's in there?

Beef waste characterization—as excreted

Components	Units	Beef cow in confinement [2/]
Weight	lb/d/1000 lb AU	104
Volume	ft^3/d/1000 lb AU	1.7
Moisture	% w.b.	88
TS	lb/d/1000 lb AU	13
VS	lb/d/1000 lb AU	11
BOD	lb/d/1000 lb AU	2.5
N	lb/d/1000 lb AU	0.35
P	lb/d/1000 lb AU	0.08
K	lb/d/1000 lb AU	0.25

https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=31475.wba

Animal waste: What's in there?

- Poultry waste characterization—as excreted

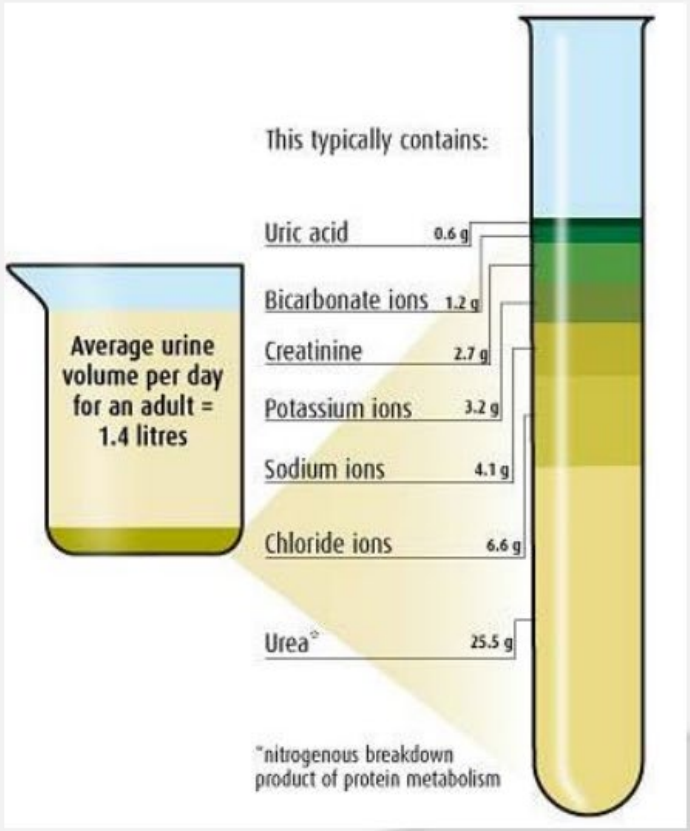
(b) Layer in units of per day per 1,000 lb animal unit

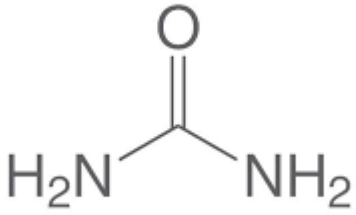
Components	Units	Layers [1/]
Weight	lb/d/1000 lb AU	57
Volume	ft^3/d/1000 lb AU	0.93
Moisture	% w.b.	75
TS	lb/d/1000 lb AU	15
VS	lb/d/1000 lb AU	11
BOD	lb/d/1000 lb AU	3.3
N	lb/d/1000 lb AU	1.1
P	lb/d/1000 lb AU	0.33
K	lb/d/1000 lb AU	0.39

Example 1: Can we use human urine as a fertilizer?

- Water 96%
- Urea 2%
- Uric acid
- Creatinine
- Ammonia
- Sodium
- Potassium
- Chloride
- Phosphate
- Sulphate
- oxalate

2%





urea

https://faculty.ksu.edu.sa/sites/default/files/472_bch_normal_constiturtion_of_urine.pdf

Example 1: Can we use human urine as a fertilizer?

- Why not? 16th century in Asia: Human excretes were commonly used as a fertilizer.
- Today:
  - Urine + feces mixture collection system
  - Presence of micropollutants *(natural hormones, pharmaceutical products, antibiotic resistance gene)*
  - Presence of pathogens

How farmers in Switzerland perceive fertilizers from recycled anthropogenic nutrients *(https://pubmed.ncbi.nlm.nih.gov/12926620/)*

- 467 Swiss farmers.
- 57% good/very good idea to use urine-based fertilizer
- 30% concerned about the fate of **micropollutants** in urine.

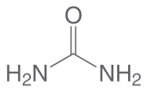
Example 1: Human urine as a fertilizer

- Direct use of urine as fertilizer: Urine storage for weeks to months.
- Chemically extract nutrients from urine: Struvite **is an effective fertilizer.**

$$Mg^{2+} + NH_4^+ + PO_4^{3-} + 6H_2O \rightarrow MgNH_4PO_4 \bullet 6H_2O$$

A ubiquitous microbial enzyme, urease

Urea + water → CO_2 + ammonia



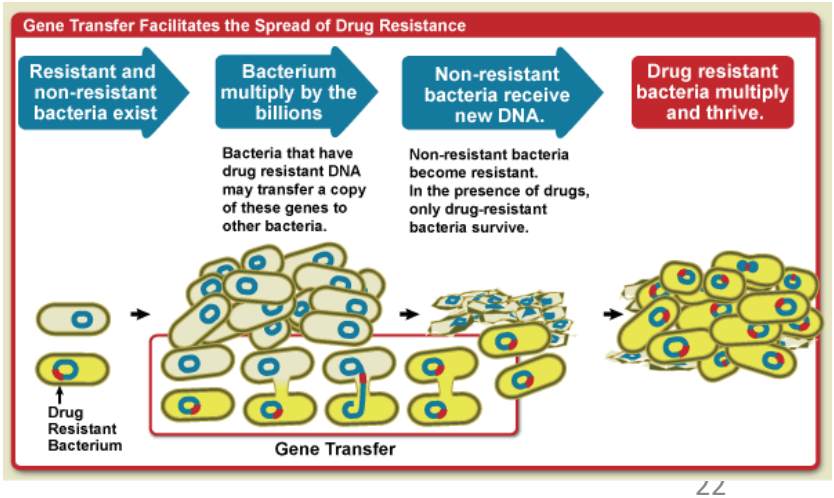
Production of ammonia raises pH of the stored urine solution to 9.0

Kills most of the pathogens.

"30% concerned about the fate of **micropollutants** in urine."

Example 1: Human urine as a fertilizer: Pollution transfer of micropollutants to crops/environment?

- Human hormones: The struvite contained no or very little **17β-estradiol,** commonly found natural female hormone in the environment.
- Urine storage: antibiotic-resistant genes were degraded, meaning, reduced risk of spreading antibiotic resistance in the environment.



Example 2: Can we generate energy, fertilizer, and freshwater from the sewage?

1) Municipal wastewater treatment
   a) Liquid → reclaimed water
   b) Solid → CH_4
   c) Solid → fertilizer
2) Sewage treatment system
   a) Solid → compost and fertilizer

Plant Process Schematic

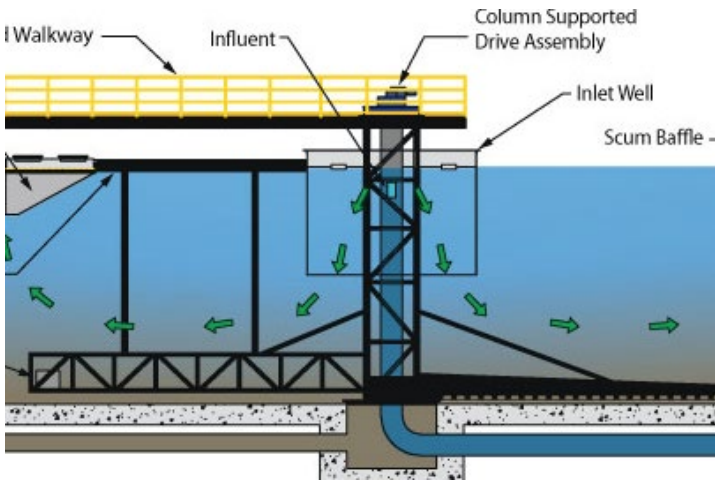
Central Valley Water Reclamation Facility

Primary Treatment: remove settleable and floatable solids

Water: Proceeds to Secondary treatment

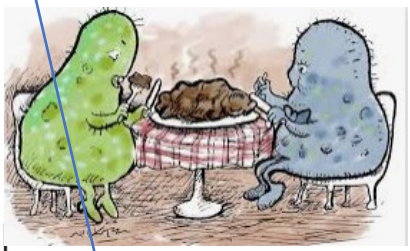
Solids:

- Bar screen removed items: sticks, plastics, large objects are disposed to landfills.
- Gravity settling mechanism removes <40% BOD and <65% suspended matter

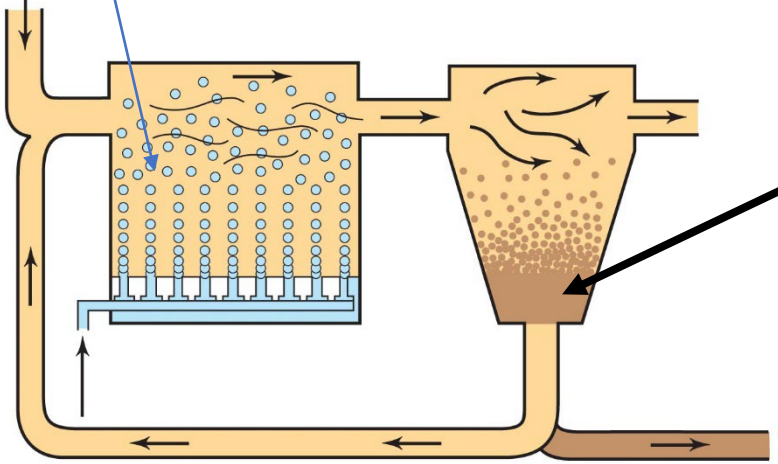


Secondary Treatment: BOD removal by microorganisms.

Organic matter + O_2 → CO_2 + water + more bacteria + metabolic byproducts



Some sludge is returned to the aeration tank to maintain actively degrading microbial community in the reactor.



The microbes settle out as "sludge" or "biosludge" by gravity

To waste

(b)

Disinfection of treated wastewater → return to river

- Chlorinated chemicals, UV lights, or Ozone
- Inactivated any remaining microbes.

Can we produce drinking water from sewage?

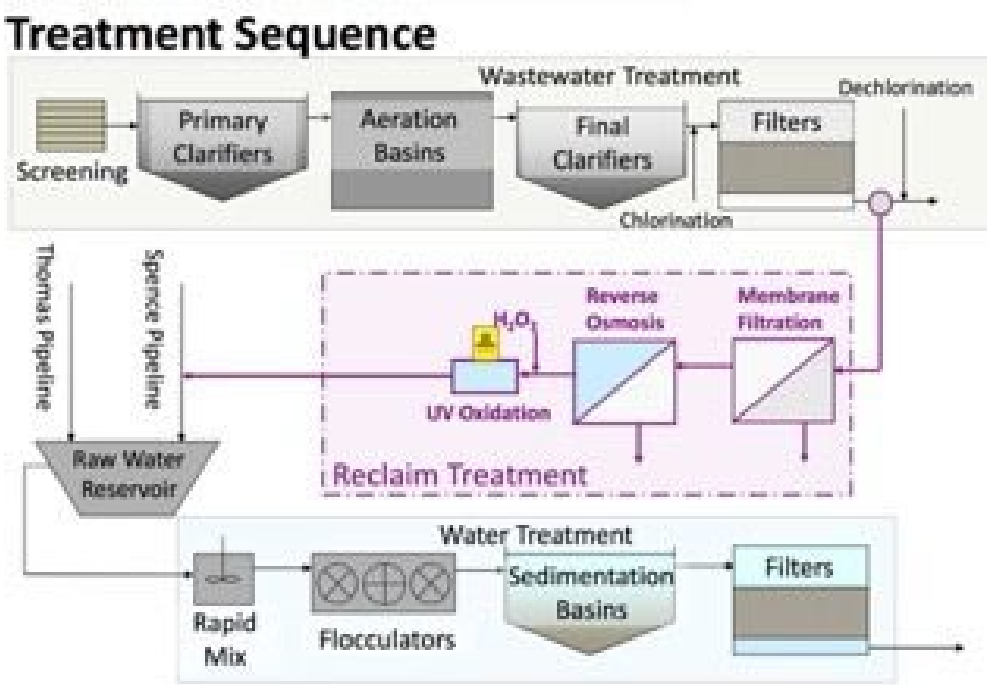
Sources/Usage: Public Domain.

Astronauts abord the International Space Station drink reclaimed urine.

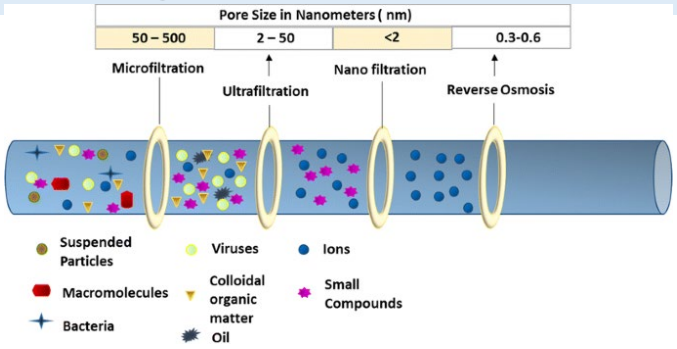
Credit: NASA

Bottles of NEWater, recycled sewage water that is given away in Singapore to help the public get over the "yuck" factor for what the nation hopes will become a major component of its water supply. *Elizabeth Weise*

Reclaimed Wastewater: Colorado River Municipal Water District (CRMWD), Odessa and Snyder, TX



Drinking water treatment facility



M.F.

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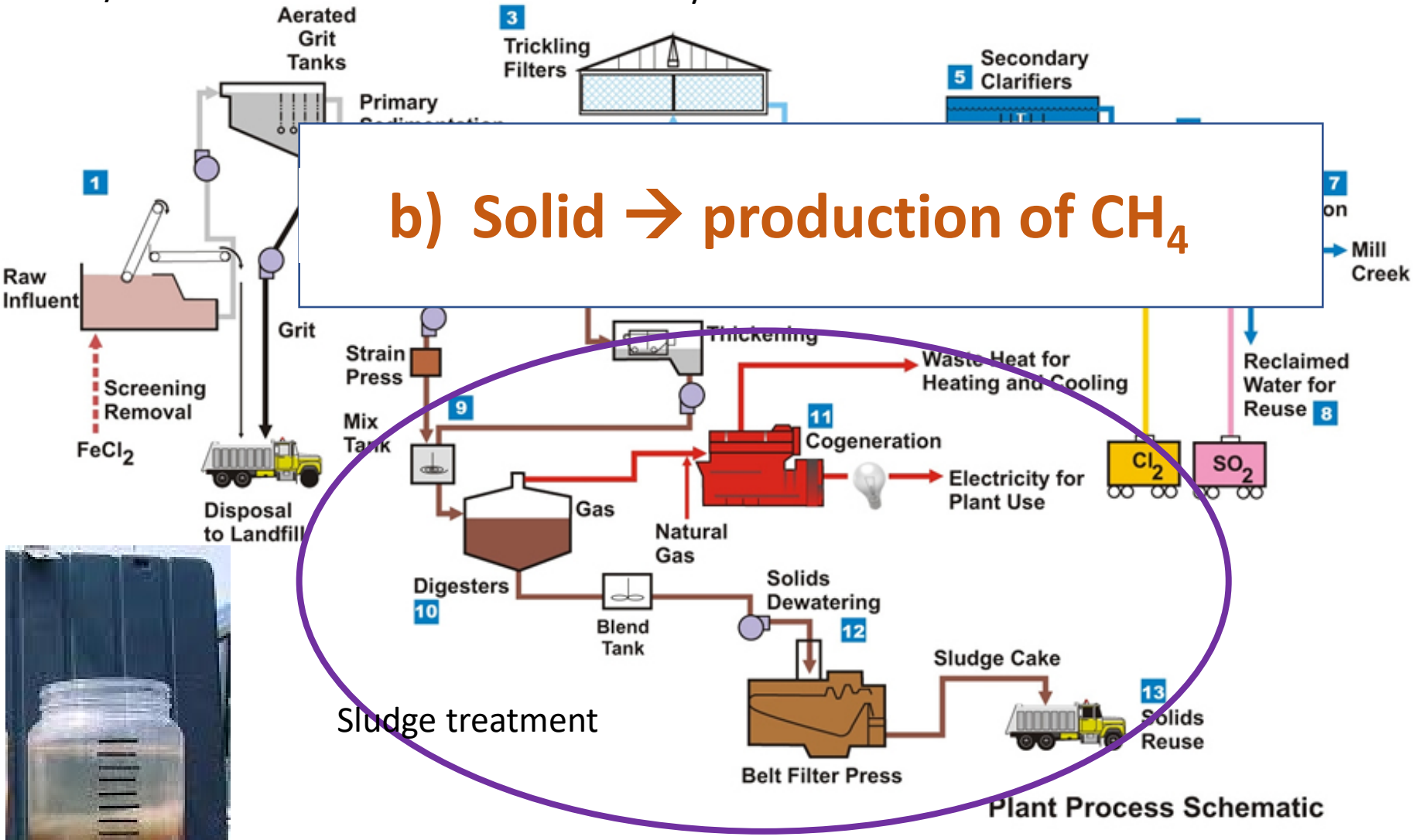
Reclaimed Wastewater: Colorado River Municipal Water District (CRMWD), Odessa and Snyder, TX

- Serves more than 600,000 Texans
- Reclaimed water:
  - Recharge groundwater
  - Supply industrial processes
  - Irrigate crops
  - Augment potable supplies

Primary treatment

Secondary treatment

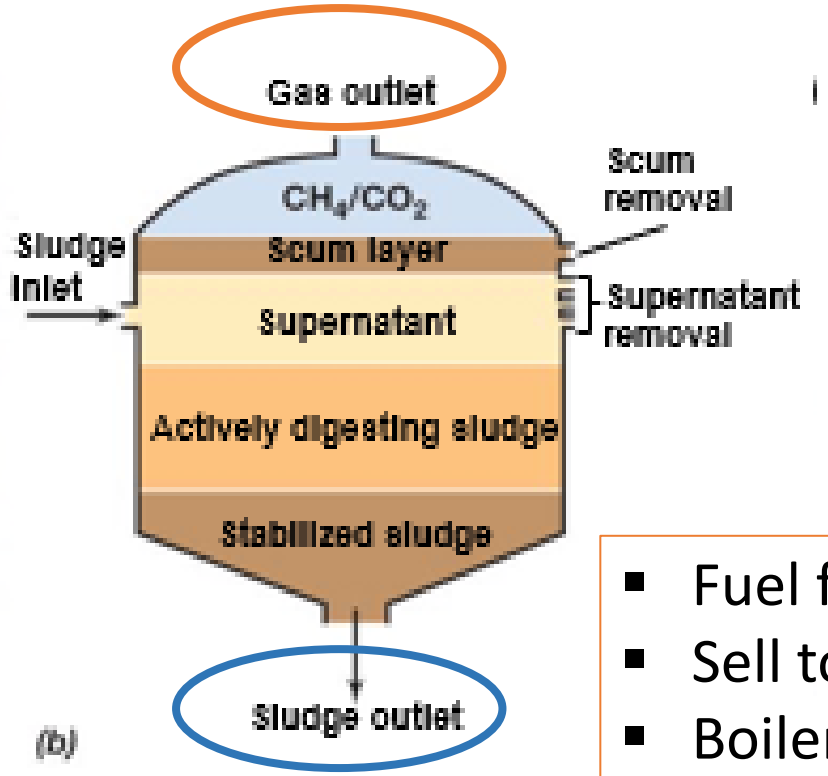


b) Solid → production of CH_4

Sludge (Biosolids) treatment: **anaerobic digester** to generate CH_4

Sludge (organic matter) + microorganisms→ CO_2 + $\underline{CH_4}$

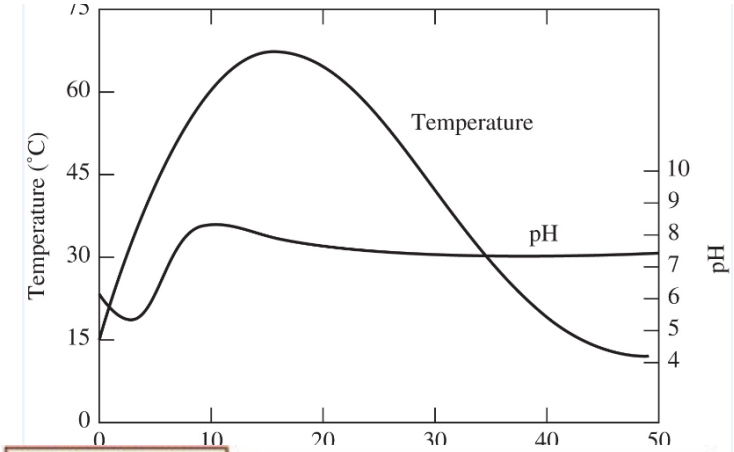
60% of the gas produced → CH_4

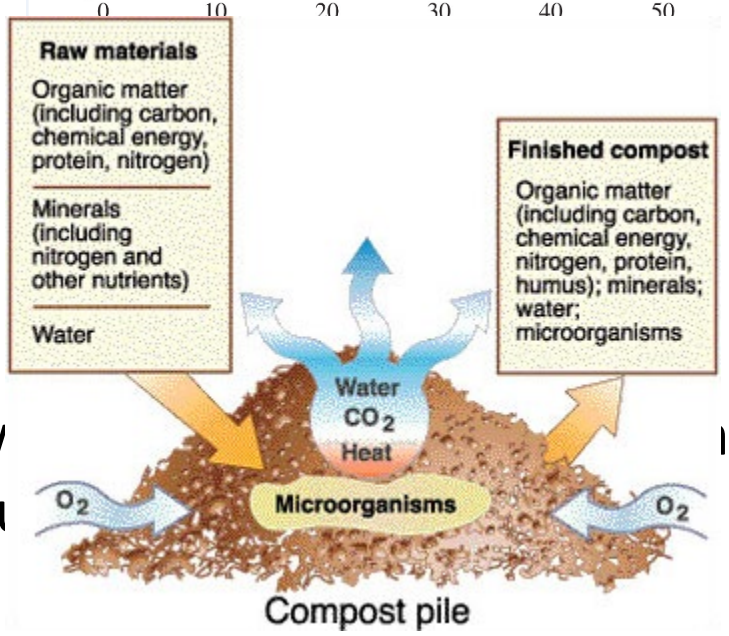


- Fuel for generators to power
- Sell to electric utilities (purify)
- Boiler fuel for on-site heating

Sludge (Biosolids) treatment: composting biosolids (dehydrated) from the digester

c) Solid → fertilizer (compost)





Successful composting:

High temperature can inactivate w ...s.

Adjust C/N ratio by adding other su

How effective is composting at killing pathogens?

Table 8 Temperature required to eliminate some pathogens

Microorganism	Temperature	Exposure time
Salmonella spp	55°C	1 hour
	65°C	15-20 minutes
Escherichia coli	55°C	1 hour
	65°C	15-20 minutes
Brucella abortus	55°C	1 hora
	62°C	3 minutes
Parvovirus bovino	55°C	1 hour
Ascaris lumbricoides eggs	55°C	3 days

Source: Jones and Martin, 2003

Heat exchanger?
Compost to heat water?

https://smallfarms.cornell.edu/2012/10/compost-power/

Example 2: Can we generate energy, fertilizer, and fresh water from the sewage/ municipal wastewater treatment?

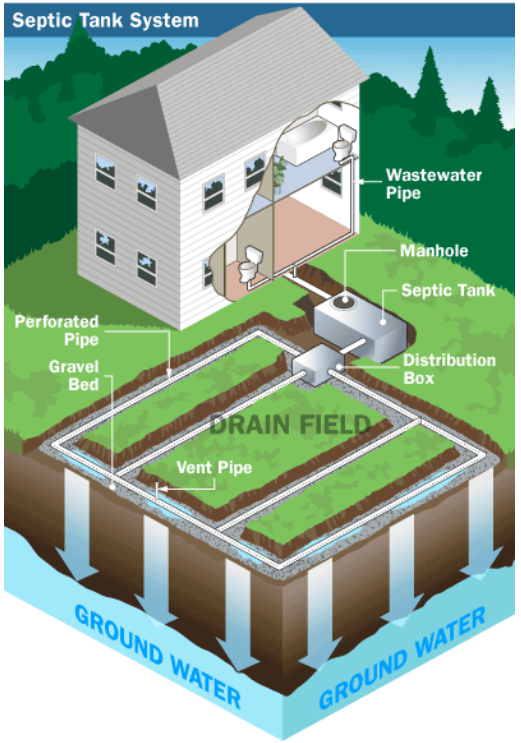
1) Municipal wastewater treatment
   a) Liquid → reclaimed water
   b) Solid → production of CH_4
   c) Solid → fertilizer

2) Sewage treatment system
   a) Solid → compost and fertilizer

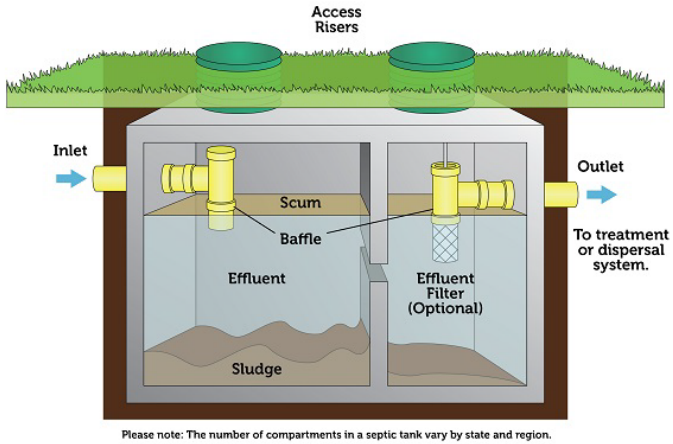
Example 2: Sewage treatment system

- 20% of the new homes built in TX have On-site Sewage Facilities (OSSF).
- Based on natural processes
  - soil absorption
  - microbial degradation
  - microbial uptake of nutrients
- Design consideration
  - soil texture
  - distance to groundwater
  - tank size and holding time
- Solid: biodegradation and physical removal

https://www.epa.gov/septic/types-septic-syst

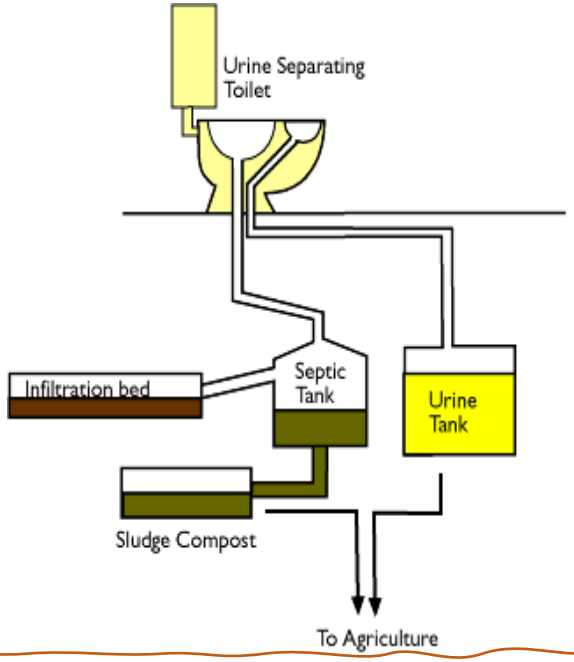


Septic Tank



Example 2: Sewage treatment system

- Graywater: irrigation
- Urine tank: fertilizer
- Solid: on-site compost



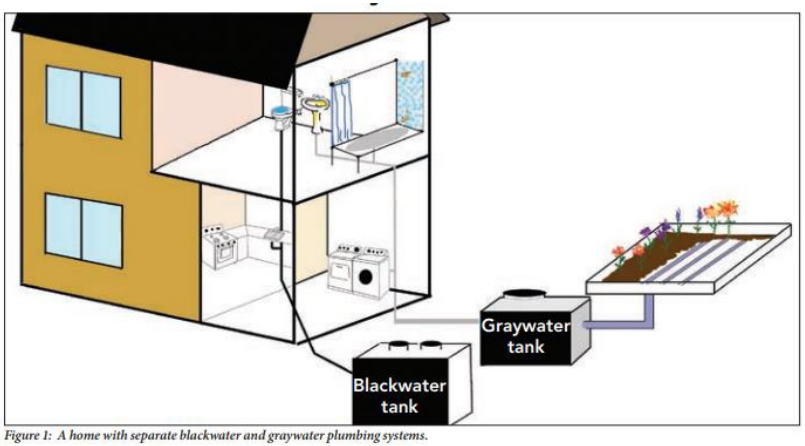


Figure 1: A home with separate blackwater and graywater plumbing systems.

https://agrilifeextension.tamu.edu/library/water/onsite-wastewater-treatment-systems-graywater-use-and-water-quality/

Example 3: Animal Waste Management

Animal waste: What's in there?

Beef waste characterization—as excreted

Components	Units	Beef cow in confinement [2/]
Weight	lb/d/1000 lb AU	104
Volume	ft^3/d/1000 lb AU	1.7
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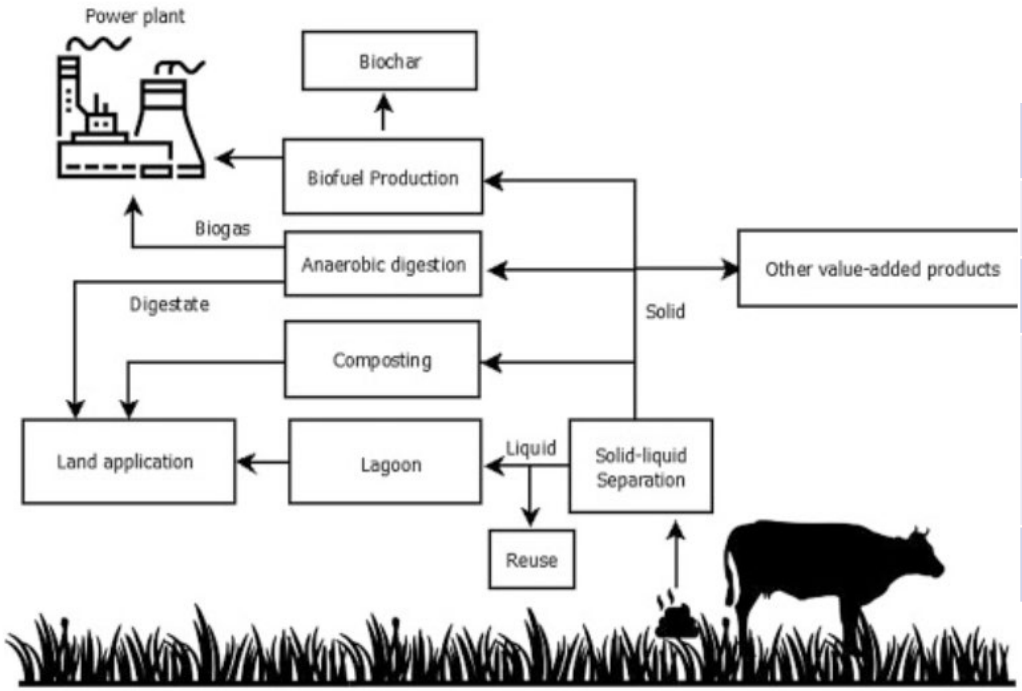
https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=31475.wba

Example 3: Animal Waste Management

- Collection of solid manure.
- Mechanical separation of solid and liquid.
- Flush the remaining manure with water.
- Open lots: Runoff from the surface.
- Liquid manure (less than 5% solid) is stored in the lagoon or other engineered containments.
- Land application as a soil amendment.

Example 3: Animal Waste Management: Compost and CH_4



https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/manure-management

What's Worth More: A Cow's Milk or its Poop?

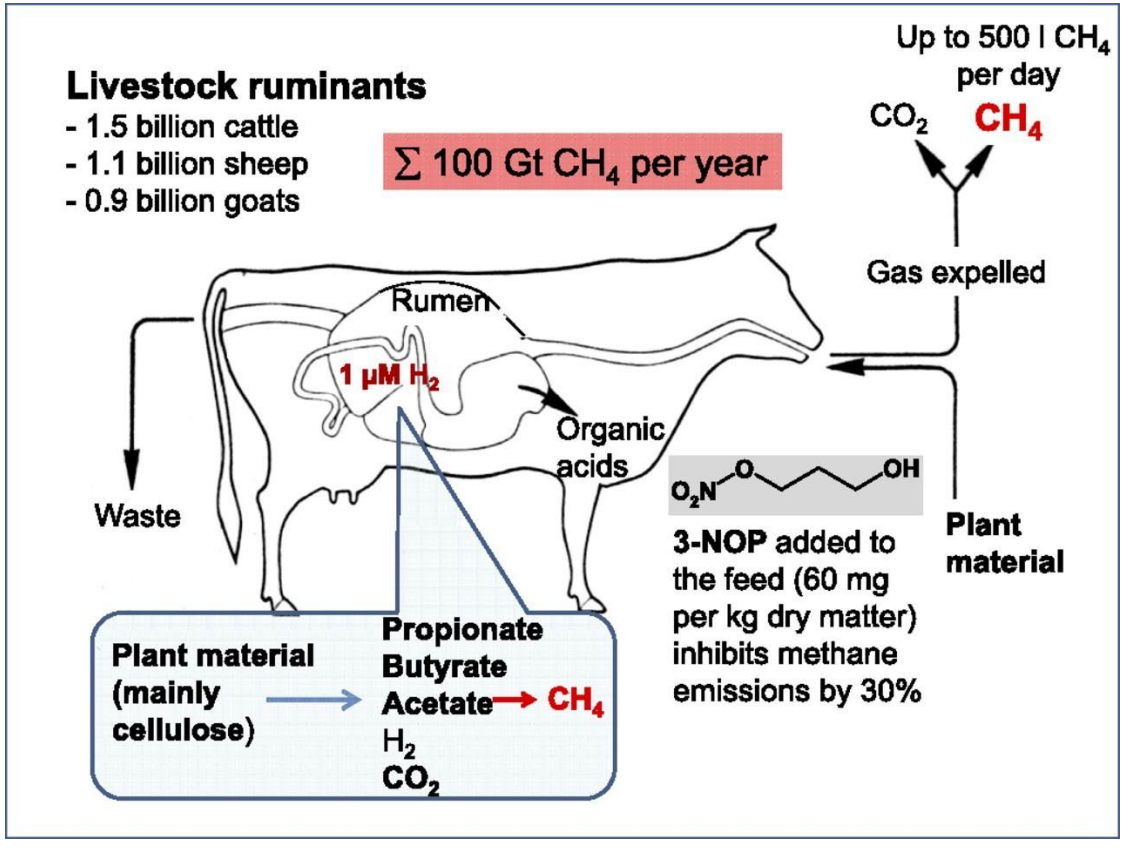
by Aaron Smith | February 03, 2021

Per 2,000 cow dairy	$ cost / cow
Digester maintenance	-294
Energy generation	+69
CA incentive (Low Carbon Fuel Standard)	+1,935/year
Net	+1,710

https://asmith.ucdavis.edu/news/cow-power-rising

Livestock ruminants: CH_4 emission

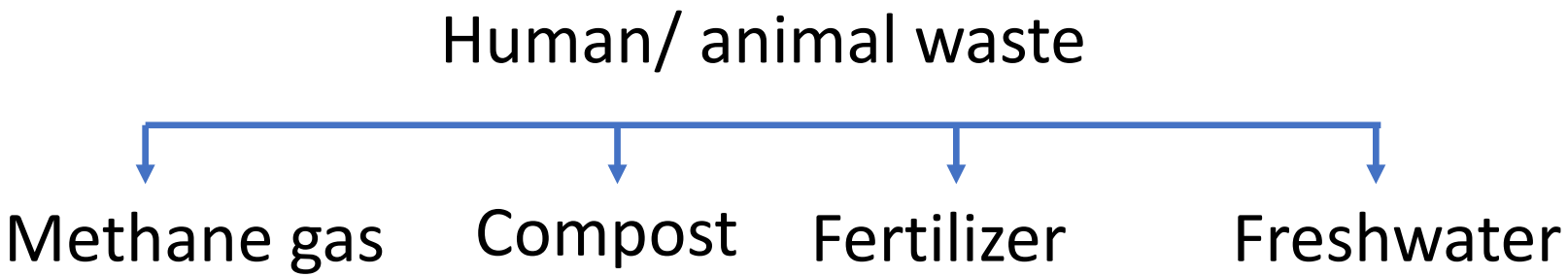
Methane formation in the rumen of a dairy cow



https://www.pnas.org/doi/10.1073/pnas.1600298113

CH_4 is 84 times more potent greenhouse gas over 20 years than CO_2.
CA farmer: increases number of cows → increases economical profits, but also increases CH_4 emission from cows. Pros. and Cons.?

Conclusions



Environmental benefits

- Reduce natural gas demand to generate electricity (renewable alternative energy source) → carbon cycle
- Reduce demand for synthetic fertilizer (natural gas-dependent process) → nitrogen cycle
- Reduce freshwater stress happening in many parts of the U.S. → water cycle
- May increase farmer's profit (increase GHG emission?)

Questions?

Keep it simple and straightforward!

Mukherji@uhcl.edu