
PSI Center for Energy and Environmental Sciences

# Program

EPFL

12.09. **Overview and expectations**
HW: Ch1: Integrated Solid Waste Management (incl. preface)

19.09. Ch1
HW: Ch2: MSW Characterization and Quantities

26.09. **Hammerdirt / Beach Litter Survey**
HW: Ch3: Waste Collection

03.10. Discussion of MFA, Ch2 and Ch3
HW: Ch4: Mechanical Processing

10.10. **BAREC (Ecublens)**
HW: MFA and part of Ch5: Separation

17.10. **BLUBOX (Moudon)**
HW: Ch6: Biological Processes
HW: Project ideas

**Vacations 21.-27.10.2024**

31.10. Discussion of Ch2, Ch3, Ch4
**Project Kick-off**
HW project proposal

07.11 **Ecorecyclage**
HW: Finalize project plan

08.11. **Submission of project plan**

14.11 Discussion of Ch 4, 5, Ch 6
HW Ch 7: Thermal Processes

21.11. **Holcim**
HW project

28.11. Discussion Ch 7 / Exam preparation
HW project

05.12. Exam preparation
HW project

12.12 **Examination** (Ch 1-7, excursions)
HW project / final report

19.12. **at noon Submission of video** //
… video watching… independently
**Debriefing sessions with each group**

20.12. **Submission of final report**

HW = Home Work, Ch = Chapter

# Overview – 14.11.2024

**14:15 Biological Processes**

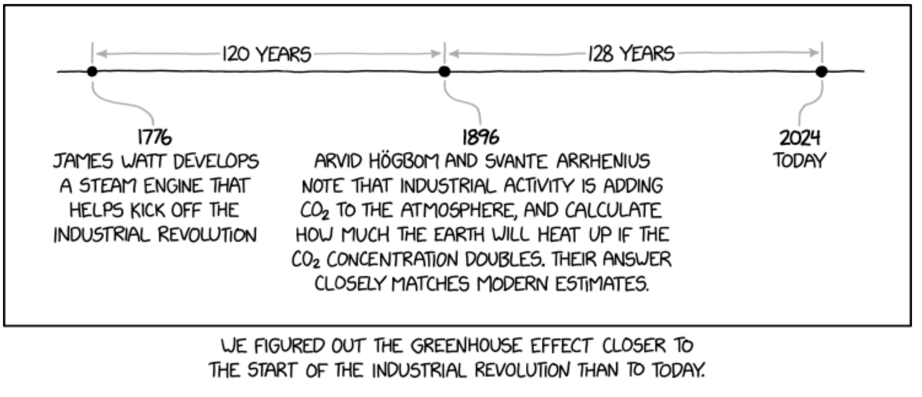
15:15 Mechanical Processes

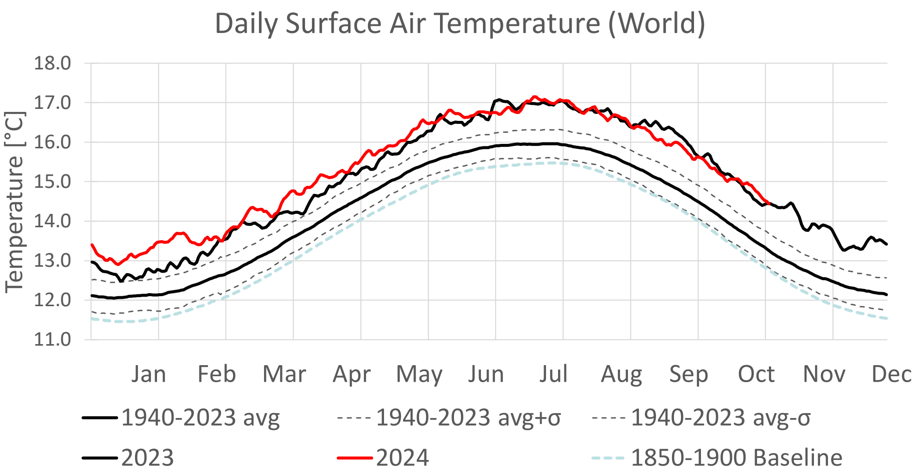
16:15 Separation Processes

17:15 Project work







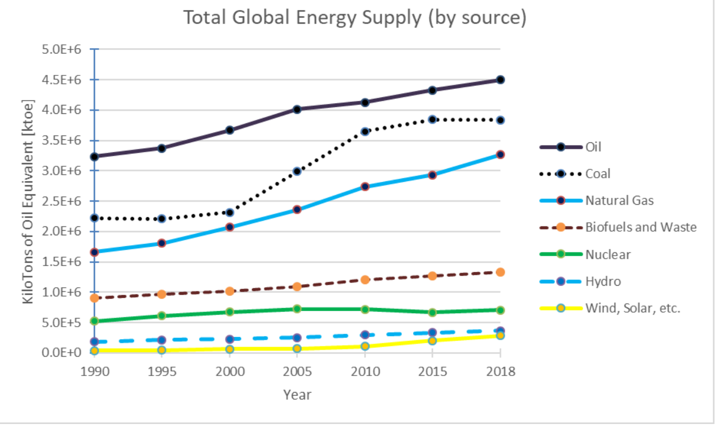



Dataset: ECMWF Reanalysis v5 (ERA5) downloaded from C3S



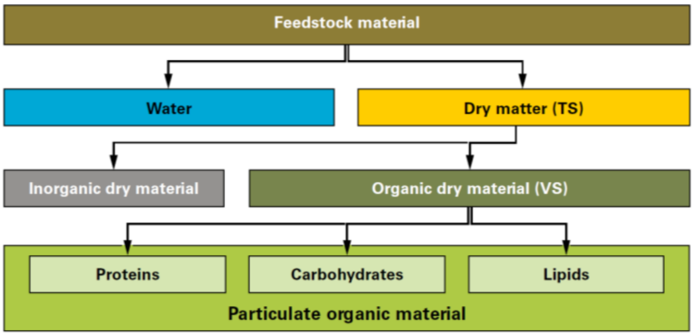


# Energy Scenario




Data & Statistics - IEA

## Classification of Feedstock




- Total dry matter content - typically referred to as **Total Solids (TS)** - only the organic biodegradable fraction contributes to biogas production
- This organic dry matter is also called **"Volatile Solids" (VS)**


Müller C. (2007). Anaerobic Digestion of Biodegradable Solid Waste in Low - and Middle Income countries. Overview over existing technologies and relevant case studies. Swiss Federal Institute of Aquatic Science and Technology (Eawag). Dübendorf, Switzerland.




## Valuable Sources from Different Feedstocks

| Municipal | Agriculture | Industry |
|---|---|---|
| • Organic fraction of municipal solid waste ("biowaste")<br>• Human excreta | • Manure<br>• Energy crops<br>• Algal biomass<br>• Agro-industrial waste | • Slaughterhouse waste<br>• Food processing waste<br>• Biochemical waste<br>• Pulp and paper waste |

| Substrate | TS (% of raw waste) | VS (% of TS) | Literature Source |
|---|---|---|---|
| Spent fruits | 25–45 | 90–95 | Deublein and Steinhauser (2011) |
| Vegetable wastes | 5–20 | 76–90 | Deublein and Steinhauser (2011) |
| Market wastes | 8–20 | 75–90 | Deublein and Steinhauser (2011) |
| Leftovers (canteen) | 9–37 | 75–98 | Deublein and Steinhauser (2011) |
| Overstored food | 14–18 | 81–97 | Deublein and Steinhauser (2011) |
| Fruit wastes | 15–20 | 75–85 | Gunaseelan (2004) |
| Biowaste | 25–40 | 50–70 | Eder and Schulz (2007) |
| Kitchen waste | 9–37 | 50–70 | Eder and Schulz (2007) |
| Market waste | 28–45 | 50–80 | Eder and Schulz (2007) |

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# "Aerobic" vs. "Anerobic" Treatment

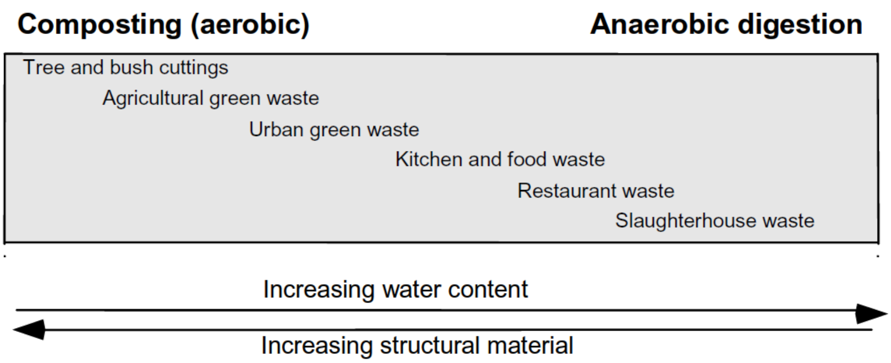


**Fig. 4.4.** Suitability for aerobic or anaerobic processes [29]



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# Aerobic and Anaerobic Degradation Pathways

The two basic metabolic pathways for the decomposition or degradation of wastes are *aerobic* (with oxygen) and *anaerobic* (in the absence of oxygen).

[complex organics] + oxygen $\rightarrow CO_2 + H_2O + NO_3^- + SO_4^{2-}$ + other products

energy poor

[complex organics] + water $\rightarrow CO_2 + CH_4 + H_2S + NH_4^+$

energy rich

## Methane Generation by Anaerobic Digestion

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right)H_2O \rightarrow$$

$$\left(\frac{4a+b-2c-3d}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d}{8}\right)CO_2 + dNH_3$$



## MSW an estimate: $C_{99}H_{149}O_{59}N$

a = 99, b = 149, c = 59 and d = 1

$$C_{99}H_{149}O_{59}N + \left(\frac{4(99)-149-2(59)+3(1)}{4}\right)H_2O \rightarrow$$

$$\left(\frac{4(99)+149-2(59)-3(1)}{8}\right)CH_4 + \left(\frac{4(99)-149+2(59)+3(1)}{8}\right)CO_2 + NH_3$$

$$C_{99}H_{149}O_{59}N + 33H_2O \rightarrow 53CH_4 + 46CO_2 + NH_3$$

1 mole of this waste gives 53 moles of Methane

2295 g of this waste gives 848 g of Methane

1 kg of this waste gives 369.5 g of Methane

517.3 L $CH_4$ per kg waste

19MJ/kg Waste

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## MSW an estimate: $C_{99}H_{149}O_{59}N$

- But realistically, only around 258 liters of methane per kg of refuse can be obtained, as in total waste contains organic plus inorganic, and wet refuse is generally assumed to be 50% biodegradable organic.
- The only carbon that can participate in the production of gas is from decomposable materials, such as food waste and paper. Other organics, most importantly plastics, do not decompose to produce gas.
- two ways of generating methane are:

1. to capture the gases produced in landfills or
2. to digest it in an anaerobic digester



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## Microorganisms Responsible for Anaerobic Decomposition

***Acid formers*** that ferment the complex organic compounds to more simple organic forms, such as acetic and propionic acids. (facultative or hardy organisms)

***Methane formers*** that convert the organic acids to methane.

- These organisms are strict anaerobes
- have very slow growth rates
- sensitive to temperature and pH changes (need >pH = 6.8)

Two different groups: ***mesophilic*** group is operating best around 30 to 38°C and ***thermophilic*** group is operating best around 50 to 58°C.

## Process Parameters

In addition to temperature and residence time, other variables are important:

- the maintenance of total anaerobiosis
- maintain a neutral pH level (never below 6.2)
- the provision of adequate nutrients (such as nitrogen) is required. If the C/N ratio of the waste is not sufficient for full decomposition, and another source of N is needed, such as sewage sludge rich in nitrogen. The C/N ratio of 20:1 as a minimum is required for active anaerobic decomposition. (Raw primary sludge has a C/N ratio of about 16:1)





## Methane Extraction from Landfills

- Landfills are very large anaerobic digesters.
- However, landfills are not optimized for gas production.
- Some communities have tried to create a bioreactor landfill. A bioreactor landfill is operated to rapidly transform and degrade organic waste.
- The increase in waste degradation and stabilization is accomplished through the addition of liquid to enhance microbial processes.

# Composting

Composting differs from the previously discussed anaerobic process in that it is an aerobic process, and the end-product is the partially decomposed organic fraction.

- Natural process
- High acceptance

[complex organics] + oxygen ⟶ $CO_2$ + $H_2O$ +$NO_3^-$ + $SO_4^{2-}$ + [other less complex organics] + [heat]

70°C

- The concentration of dead and living organisms in compost can be as high as 25%.
- The elevated temperatures destroy most of the pathogenic bacteria, eggs, and cysts.
- If the mixture is too dry, the microorganisms cannot survive, and composting stops.
- Too much moisture turns the system towards an anerobic situation.



# Field-edge composting

Die Feldrandkompostierung ist eher selten anzutreffen; sauber gepflegte Feldrandmieten gelten auch als Stand der Technik.

AWEL 2015

# Windrow Composting

- long parallel piles “windrows”
- hight 1.2-2m
- passively aerated
- shredded and/or screened source-separated

Mobile aerator for windrows.





# Actively Aerated Systems

aerated static piles / positive and negative aeration systems

## Control of Composting

Temperature
Moisture
Odor

air must pass through the cover which will remove some odors

under roof

inside

closed tunnels





## Amount of Moisture in Compost

$$M_p = \frac{M_a X_a + 100 X_s}{X_s + X_a}$$

where

$M_p$ = moisture in the mixed pile ready to begin composting, as percent moisture

$M_a$ = moisture in the solids such as the shredded and screened refuse, as percent moisture

$X_a$ = mass of solids, wet tons

$X_S$ = mass of sludge or other source of water, tons (This assumes that the solids content of the sludge is very low, a good assumption if waste activated sludge is used, which is commonly less than 1% solids.)

## Calculate the amount of moisture to be added

**EXAMPLE 6-2**

Ten tons of a mixture of paper and other compostable materials has a moisture content of 7%. The intent is to make a mixture for composting of 50% moisture. How many tons of water or sludge must be added to the solids to achieve this moisture concentration in the compost pile?

Solid Waste Engineering, CENGAGE 2016



## Question

6-5. Suppose you are a city engineer. An advertisement appears in a trade journal for a new in-vessel composting system that produces methane. Your city manages, who has no technical training, asks you to find out more about this system. You decide to write a letter to the company, Bioscam Inc. What questions would you ask?

# Final Thoughts

Using **biological processes** to **produce** useful products such as **methane** and recovery **nutrients** is increasing.

We recognize that the **use of non-renewable fossil fuels** for our energy use **is not** in keeping with the principles of **sustainable** development and contributes to the impact of greenhouse gas.

Composting also contributes to nutrient recovery. For example, **phosphorous** is a valuable limited resource and **should be reused for agricultural applications and not lost in landfills.**