Lecture 1: Introduction

Waste management

Waste management includes

- the collection and transport of waste
- recovery of waste
  - Separation
  - Further use of materials
  - Use of energy content
- disposal of waste
  - Rendering the waste harmless
  - Permanent deposition
- supervision of such operations
  - Regional environmental centres
  - Municipal environmental authority
  - **Yourself!**
- after-care of disposal sites

Waste Policy in Finland

- **Is in line with the EU waste policy**
- **Sets the wider perspective to waste management actions and legislation in Finland**

Prevention: The production and harmful impacts of wastes should be reduced and wherever possible prevented at source.

The Polluter Pays: The producers of wastes take responsibility for the costs of waste management.

Producer Responsibility: Manufacturers and importers of certain product types must bear the responsibility for the management of their products when they become wastes, instead of waste producers.

The Precautionary Principle: Potential problems related to wastes and waste management should be anticipated and avoided.

The Proximity Principle: Wastes should be disposed of near to their source.

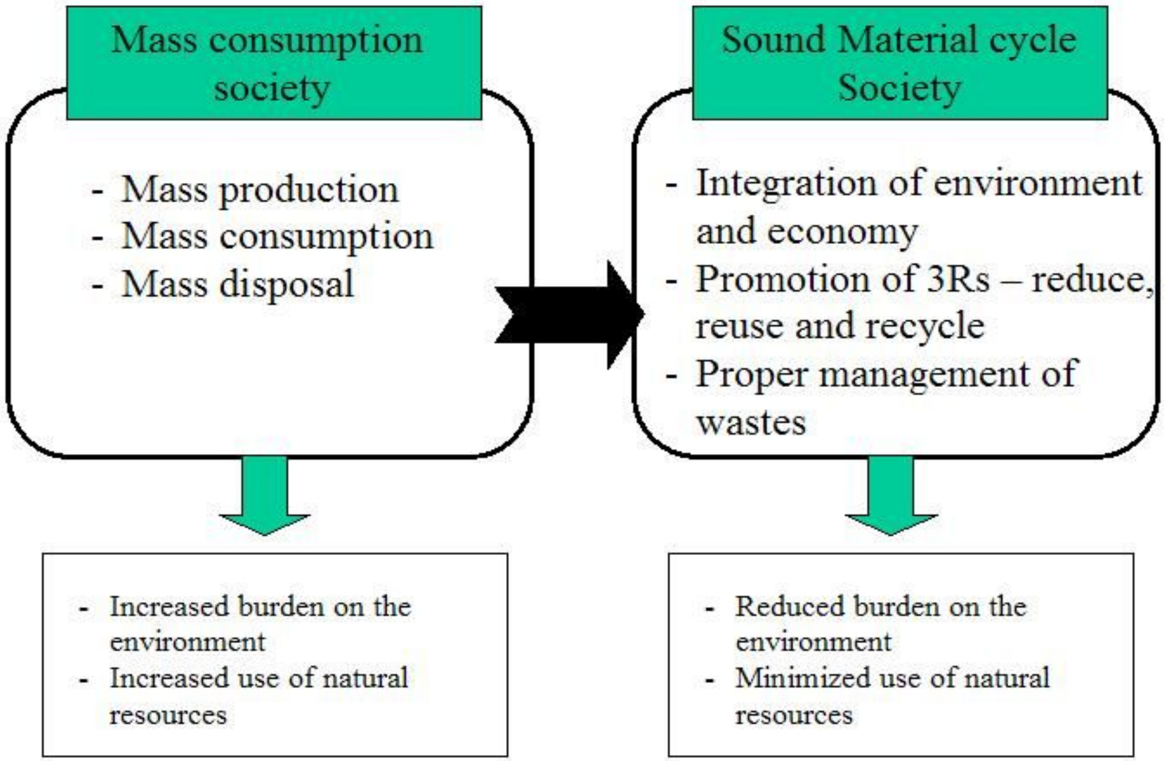
The Self-sufficiency Principle: The EU and member states should remain self-sufficient with regard to the disposal of wastes.

The 4 R concept

Sound use of natural resources according to sustainable development guidelines

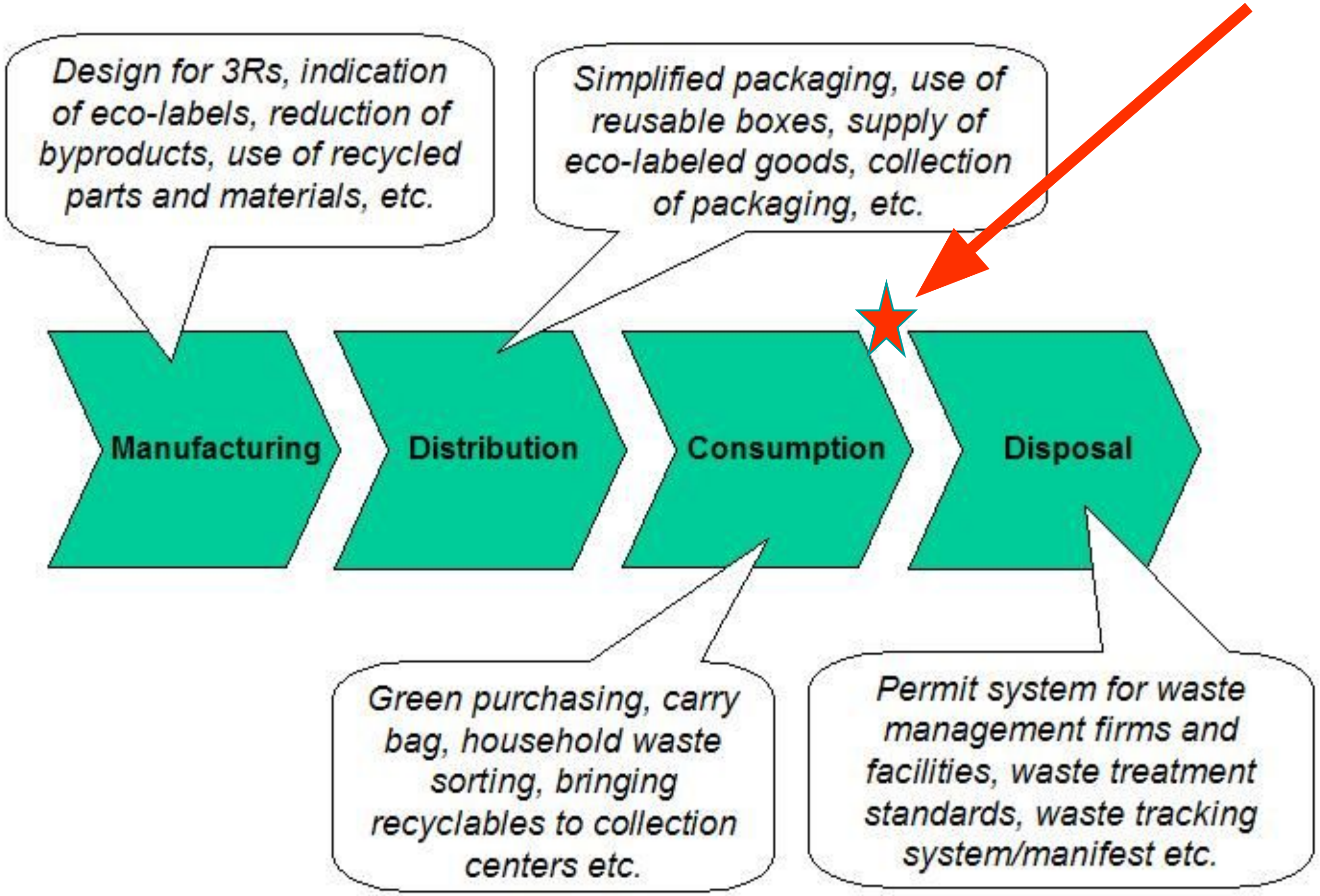
The 4R concept
Included in the Finnish
Waste policy

- Reduce
- Reuse
- Recycle
- Recover



Practising the 4 R concept

- Reducing waste requires activities in the whole product chain and planning of durable products.



Lecture 2:
Collection and transport

Practises in Household Waste Collection

Waste collection is organised by:

- Waste producer or property holder (Finnish Waste Act, Section 7)
- Garden waste, food waste and toilet waste can be composted on the property
    - rules how to do it
- Information to be given to the authority

Waste transport

- Waste holder shall take care that transport is organised (WA, section 8)
- Waste transporter has to take the waste to a facility specified by waste holder or authority (WA, section 9)
- Municipality is responsible for organising waste transport (WA, section 10)
    - for all household wastes including septic tank and cesspit sludges
    - for enterprise wastes comparable to household wastes, if situated on a housing property
    - for public operators
    - Transport organised by municipality itself, or using services of a company
- Waste transport scheme = systems and activities organised by a municipality for waste transport. Waste holder shall subscribe to waste transport scheme.

Waste Act

Municipal waste management regulations *(WA, section 17)*
Municipalities can issue local general regulations on more detailed implementation of the provisions of Ch.3 in WA and of Government general regulations issued under them.

Regulations may concern:

1) waste collection, sorting, storage, transport, dealing, recovery or disposal and the technical requirements for them
2) measures required to prevent hazard or harm to health or the environment
3) supervision of waste management.

Goverment can issue general regulations concerning waste management implementation (WA section 18)

Municipal waste management in Mikkeli (example)

Mikkeli and neighbouring municipalities founded a company (Metsä-Sairila) to organise waste management

Metsä-Sairila is responsible for all tasks of municipalities in waste management excluding

- Authority tasks like acceptance of local regulations and charges (payments)
- Authority decisions

Responsibilities of Metsä-Sairila

- Recycling
- Hazardous wastes
- Composting of separately collected bio waste and sludge
- Planning, developing, coordination and information

- Also treatment facilities; enlargement ; after care of landfill site.

How waste management is implemented

Waste transport schemes for household wastes and similar other wastes:
In densely populated area: Property owner makes an agreement with waste transporter (contractual waste transport scheme)

Sparsely populated area: Subscribing to waste transport scheme (announcement to Metsä-Sairila)
Possibilities

- Waste collection sites.
    - About 60 in the region. Annual charges.
- Collection at the property
    - Agreement with a waste transporter
    - Forbidden to use of collection sites
- Two or more properties may combine their efforts and share a waste bin

Waste collection

Requirements for waste bins:

- Durable (weather and damage)
- Closed, sealed (rats, birds)
- Large enough
- Easy to empty
- Low noice when emptying

Classification of bins

- Single use bags / reusable bins
- Surface waste bins / deep collection bins
- Waste bins (120 – 750 litres)
- Waste containers (4 - 12 m^3)
    - Stationary
    - Hauled
- Hauled dumpsters (5 - 35 m^3)

Household waste collection

Private household

Biowaste has to be collected separately or composted at home.

Typical private household system includes at least

- bin for mixed waste
- bin for biowaste

Other, recyclable waste is taken to collection sites.

Housing company waste

Mixed waste

- large bins to be emptied
- To reduce the volume of waste
  - Compresser or baler

- Also large containers used as storage for waste
  - Truck haules the container to waste station to be emptyed
  - Requires plenty of space to haul the container on the truck

If more than 5 apartments:

- separate collection of also paper and and cardboard

If more than 18 apartments:

- waste bins in addition for glas, metal and liquid carton

Color symbols

- Green□ paper Grey □ mixed waste
- Brown □ biowaste Yellow: liquid cartons

Public waste collection sites

Waste collection at public sites is done at places, where

- Amount of waste is high
- Emptying is done seldom

Necessary to

- Have large bins
- Moderate temperatures around the year
- Odor has to be prevented

Typical places eg.

- Remote places
- Recreation areas
- Parking/resting areas
- Public buildings (schools…)

Public waste collection sites

Modern solution is often deep collection bins (MOLOK)

- Most of the structure is hidden in the ground
- The wastes are in a bag that is lifted up and emptied into a truck
- Benefits
  - Small space demand
  - Emptying is easy
    - less space demanding
    - Possible even by boat
  - Hygienic for biowaste – temperatu stays low even in summer
  - Quite fire safe

Logistics in waste transport

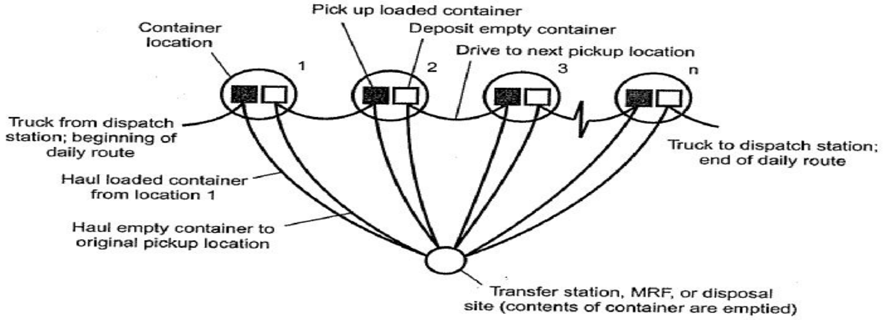
The waste transport has to be planned economically

The collection system depends on the equipment.

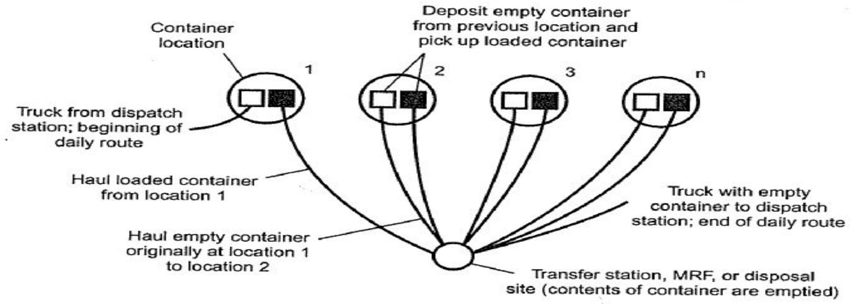
TABLE 7.4 Systems for the Collection of Solid Waste

Schematic of operational sequence	System description
(a) Hauled container system (conventional mode)	Containers used for the storage of wastes are hauled to an MRF, transfer station, or disposal site, emptied, and returned to their original location.
(b) Hauled container system (exchange container mode)	Containers used for the storage of wastes are hauled to an MRF, transfer station, or disposal site, emptied, and returned to a different location in the exchange mode of operation. The exchange mode works best when the containers are of a similar size. In the exchange mode, the driver must begin the collection route with an empty container on the vehicle to be deposited at the first collection site.
(c) Stationary container system	Containers used for the storage of wastes remain at the point of generation, except when they are moved to the curb or other location to be emptied. The collection vehicle is driven from pickup location to pickup location until it is loaded fully.

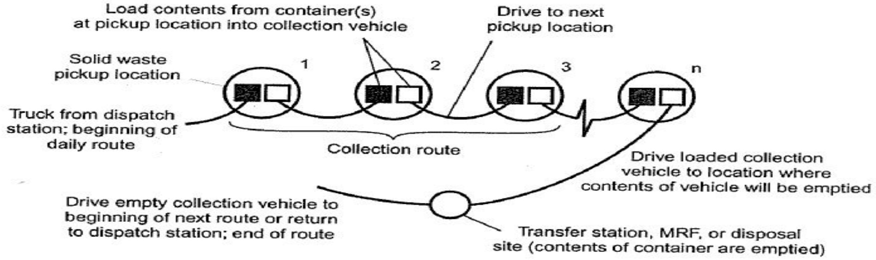
(a) Hauled container system (conventional mode)



(b) Hauled container system (exchange container mode)



(c) Stationary container system



Waste collection trucks for option C

FIGURE 7.2 Typical example of mechanized collection vehicle with mechanical articulated pickup mechanism used for the collection of domestic source separated and comingled waste placed in a dual compartment container (see insert) (courtesy Heil Environmental Industries, Ltd.). The large containers equipped with wheels are brought to the curb by the homeowner. In some locations, helpers are used to bring the loaded containers to the curb, and the homeowner is responsible for returning the container to its storage location.

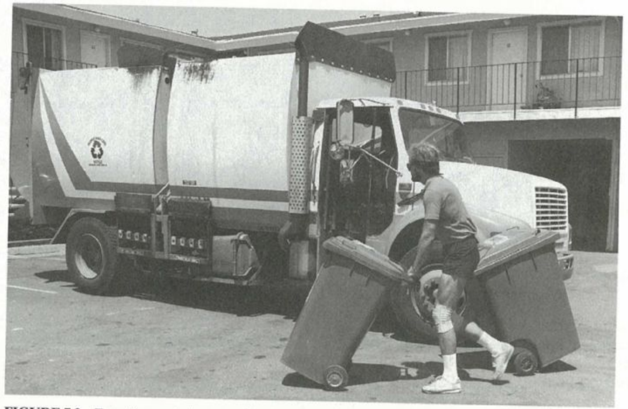
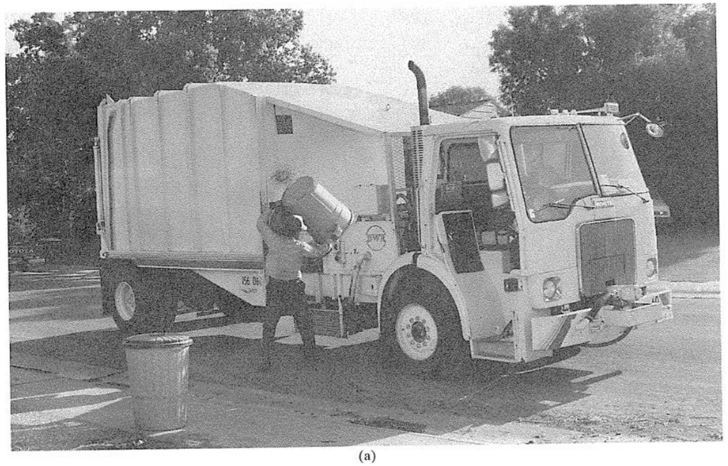


FIGURE 7.3 Emptying containers used for both commingled and source-separated wastes at an apartment complex. In the situation shown in the photo, the collector is responsible for bringing the loaded containers to the collection vehicle to be unloaded.

7.6



(a)

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Logistics and transport routes

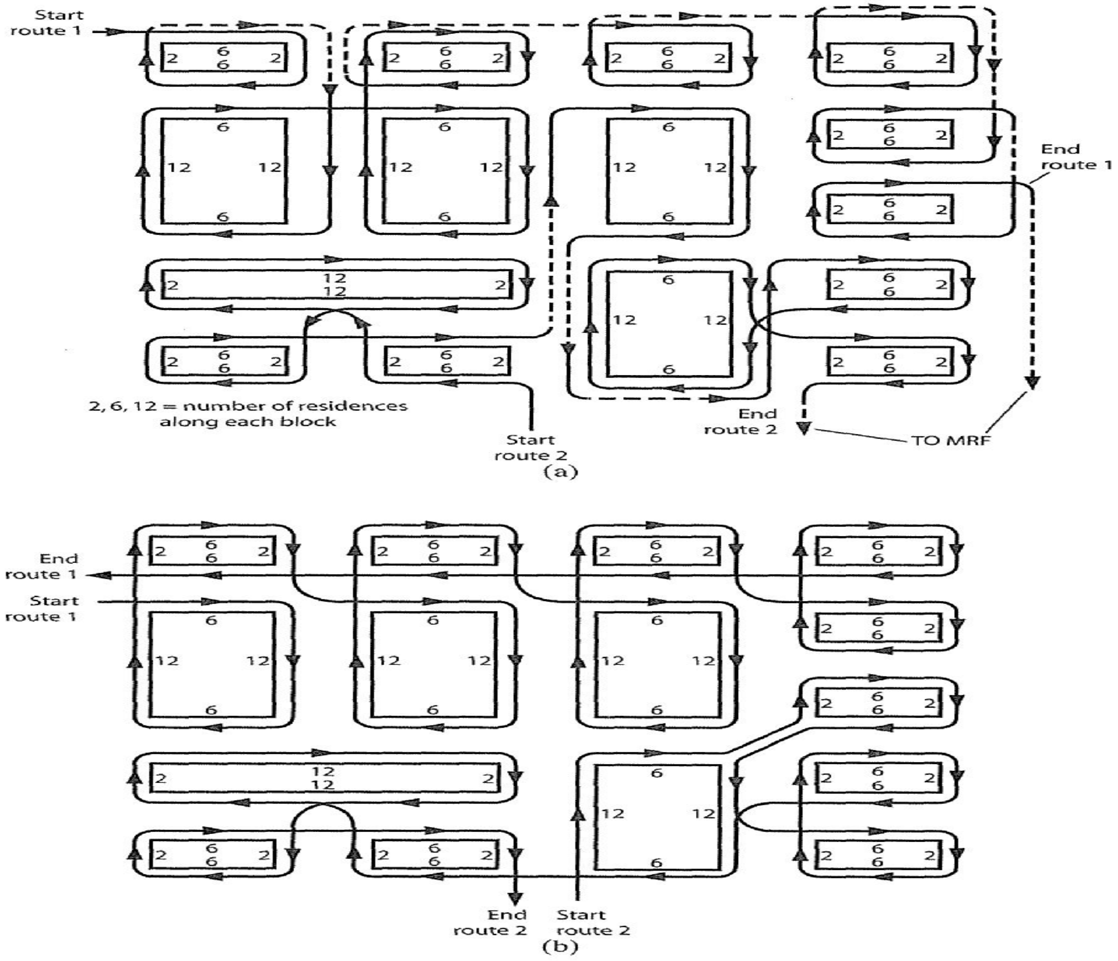


FIGURE 7.15 The effectiveness of the collection routes can be assessed by the amount of route overlap. (*a*) Route layout with overlap shown by the dotted lines. (*b*) Route layout without overlap.

Cost of waste collection and transport

The cost in € is affected by

- Amount of waste generated
- Size of the bin how often it has to be emptied (notice regulations!)
- Price per emptying
- Price for transport
- Original investment

LCA, Life Cycle Analysis The environmental ”cost”

- Emissions during the collection
- Emissions during the transport
- Total LCA of waste management should include also emissions from eg. landfill or composting

Lecture 3: Waste sorting

Waste types

Waste should be sorted for recovery

- In Finland sorting is done basicly at source
- In many countries mechanical sorting stations

Waste to landfill should not contain any reusable, recyclable, recoverable waste or hazardous waste or organic carbon that may result greenhouse gas emissions:

- Biowaste
- Paper, cardboard
- Glass, metal, electrical waste
- Wood, plastics….

Mixed municipal waste (MMW) quality

- Depends on single waste producers
- Contains also hazardous waste from households

Landfills are often situated by waste centres where all kinds of waste are recepted for further treatment or transfer

Waste centre in Lahti

Sorted waste is collected at a waste centre

- Private people and companies bring their special wastes to the centre
- Waste is sorted into containers or dumpsters
- Recoverable
  - Wood, paper, cardboard, metal, glass, energy waste
  - No charge for < 1 m^3
- Soil and rocks
- Garden waste
- Preserved wood
- Landfill waste
- Electrical and electronic waste

Kujala, Lahti
Waste sorting centre Pilleri

Recyclable materials sorted at source

Waste paper collected separately often at other facilities

Waste metal

- Tin cans, aluminium trays and foil,
- empty paint tins and aerosol flasks, bicycle frames

Waste glass

- Glass bottles and jars
- Coloured and clear glass separately.
- **No** window or mirror glass,
- no heat -resistant glass, porcelain, plastic, light bulbs

Construction waste

- Demolition waste
- Wood separately
- NOTE: Asbestos is a hazardous waste and should only be handled by authorised staff.

Biowaste

- **Biowaste is organic, biologically degradable waste suitable for composting**
- **Solid, non-toxic waste**
  - Food waste
    - Peels of fruit, vegetables and rootcrop
    - Egg shells
    - Coffee and tea leaves with filter bags
  - Other kitchen waste
    - Kitchen towels and paper napkins
  - Flower soil and plant residues
  - Chopped wood and saw dust (not preserved)
  - Biowaste bag of paper or corn starch

Waste for energy recovery

In general paper or plastic based waste

- Food packagees of plastic (viili and joughurt packages)
- Plastic bags, boxes, wraps, bottles and buckets
- Plastic foams crushed (pillows) or eg whole mattress (in min. 4 pieces, cover removed)
- Cartons, drawing papers
- Styrox underlaying and boxes
- Used paper and plastic cups, plates
- Slightly dirty carton packages like pizza or ice cream boxes
- Wood pieces, chipboards (also painted, max. 50cm x 50 cm

In single houses and other small properties also:

- paper and cardboard drink and detergent packages (no aluminium lining),
- Cardboard biscuit and cereal packages
- Flour bags, egg and fruit boxes
- Kitchen paper and paper napkins
- Cardboard boxes, paper and gift wraps
- Garden and farming plastics (bale plastics and strawberry plastics)

Waste for landfill

- **Waste not possible to use for recovery**
  - PVC-plastics, 03-marked plastics and other unidentified plastic toys and packages, tubes, lines raincoats and cloths
  - Transparencies for overhead slides, plastic folders, plastic cards
  - packages containing aluminium
    - Coffee bags, aluminium covers, chipspackages
  - Hygiene products (eg. baby diapers)
  - Textiles: clothes, rugs, socks, ribbons
  - Shoes, rubber, leather and artificial leather products
  - Mirrors, porcelain, ceramics, window glass
  - Dust bags of vacuum cleaners, lamp bulbs, tobacco residues, chewing gums
  - Food containing packages and big bones

- **In single houses and other small properties also**:
  - Aluminium lined liquid cartoons

NOTE: almost everything can be incinerated.

Material recovery facility

MSW is not sorted at source in all countries

- Even if sorted, mixed waste contains recoverable wastes
- Sorting is done at material recovery facilities (MRF)
- Sorting possibly done only if economical value high enough
- Buyback centre: in some places, private people bringing in the recyclable material,are payed for it
- MRF planned for flexible and safe traffic

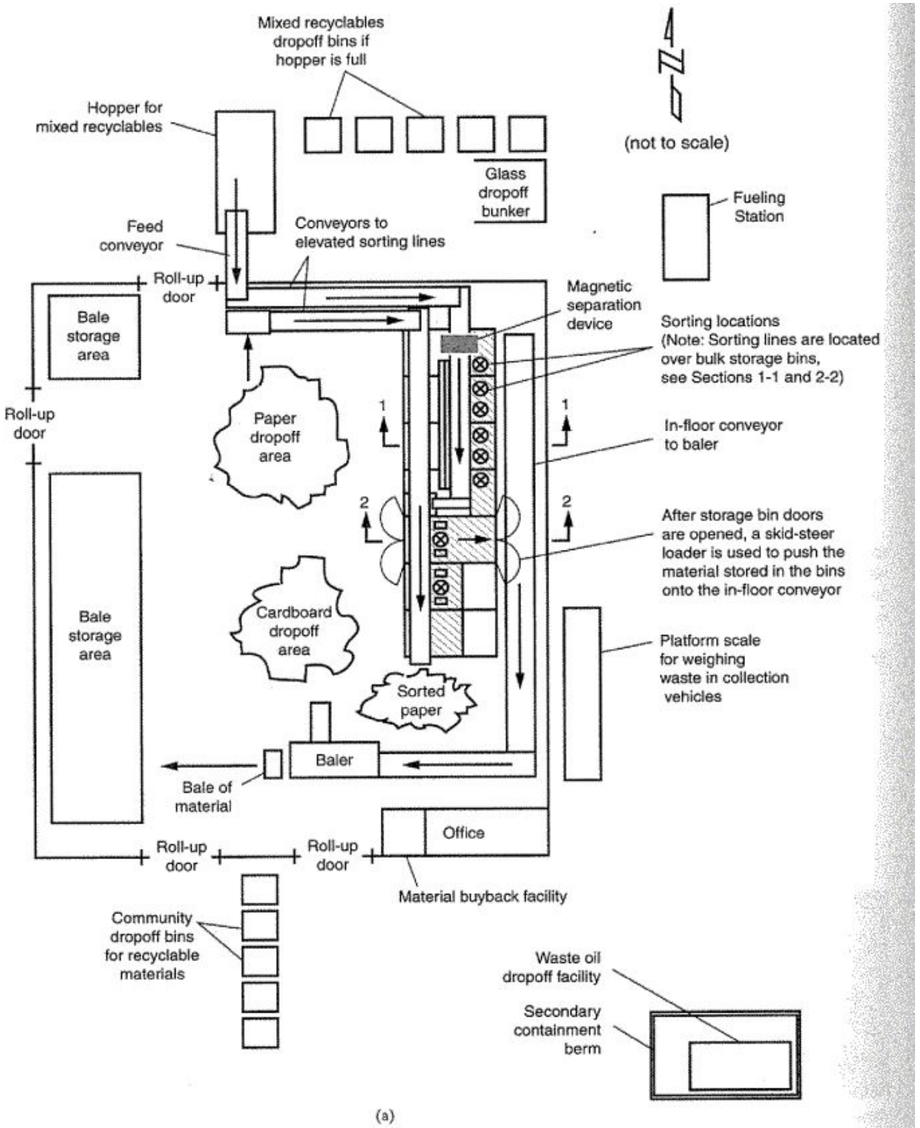


FIGURE 8.8 Layout of MRF for processing of source-separated materials: (*a*) plan view of facility. In some facilities, moving floors are used to transfer the stored material to the cross conveyor leading to the baler.

Material prices in USA 2002

TABLE 8.9 Buyback Prices for Recycled Materials at an MRF as of January 1, 2002

Material	Fully segregated, $/lb	Commingled, $/lb
Aluminum	0.760	0.74
Glass	0.051	0.040
Bimetal	0.16	Segregated only
Plastic		
PET	0.41	0.35
HDPE	0.25	0.15
PVC	0.26	Segregated only
LDPE	0.88	Segregated only
PP	0.52	Segregated only
PS	1.74	Segregated only
Other	0.16	Segregated only

MRF facility

- Commingled recyclable material is sorted into usable fractions in MRF
- Manual or automated sorting

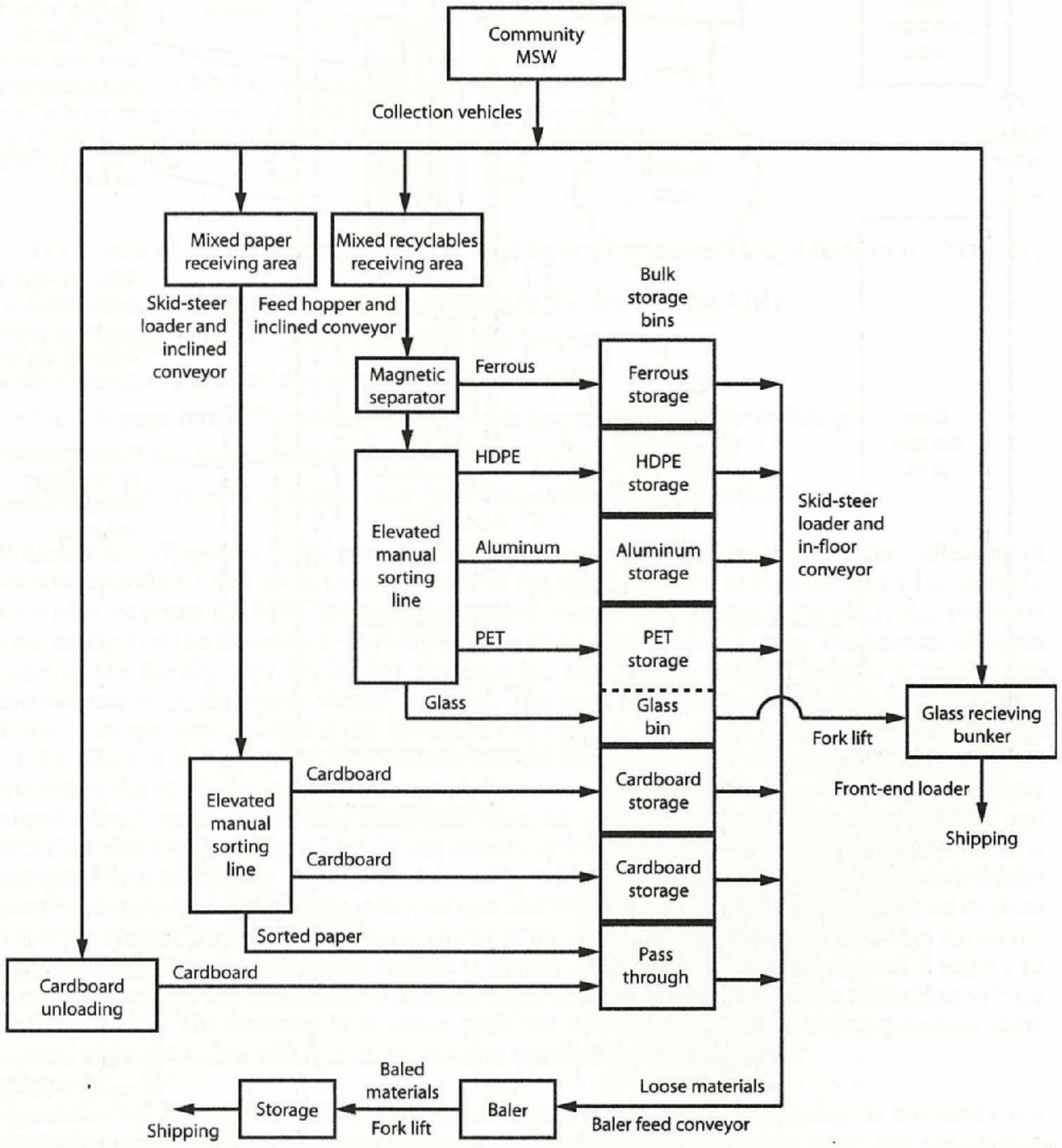
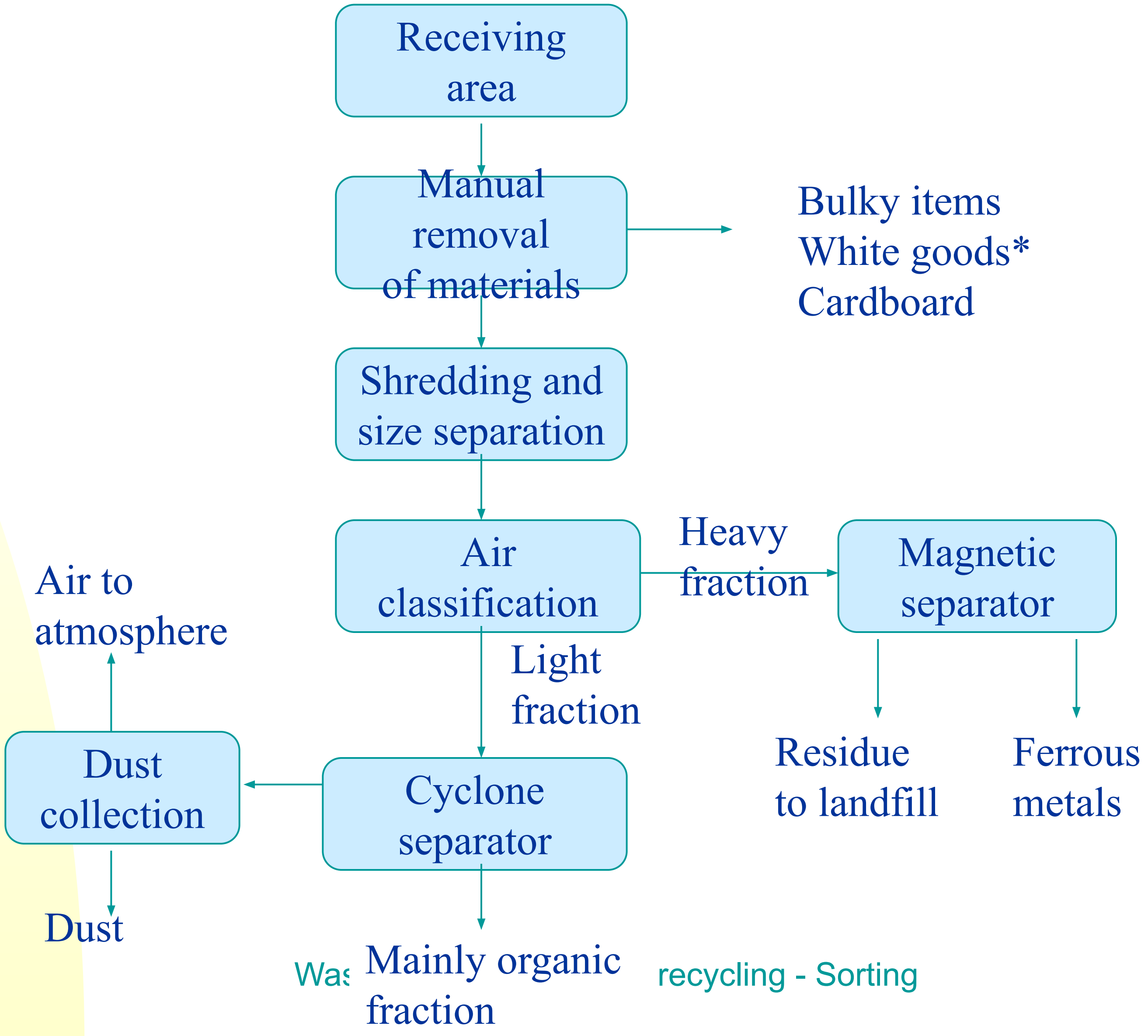


FIGURE 8.7 Material flow diagram for source-separated recyclables.

Processing of and recovery from mixed municipal waste

- **Manual sorting** (big items, material sorting)
- **Size reduction** mechanically
  - Hammermills
  - Shear shredders (Al, tires, plastics)
  - Tub grinders for yard wastes
- **Size separation**
  - Sizing of shredded yard wastes
  - Preparing MSW for shredding
  - Removing glass from shredded waste
- **Materials handling** (conveyers,storage bins, trucks, fork lifts)
- **Magnetic field separation**
- **Automated sorting**
- **Densification**
  - Baling for cardboard, paper, plastics, aluminium cans

Main steps in material classification



Size Reduction

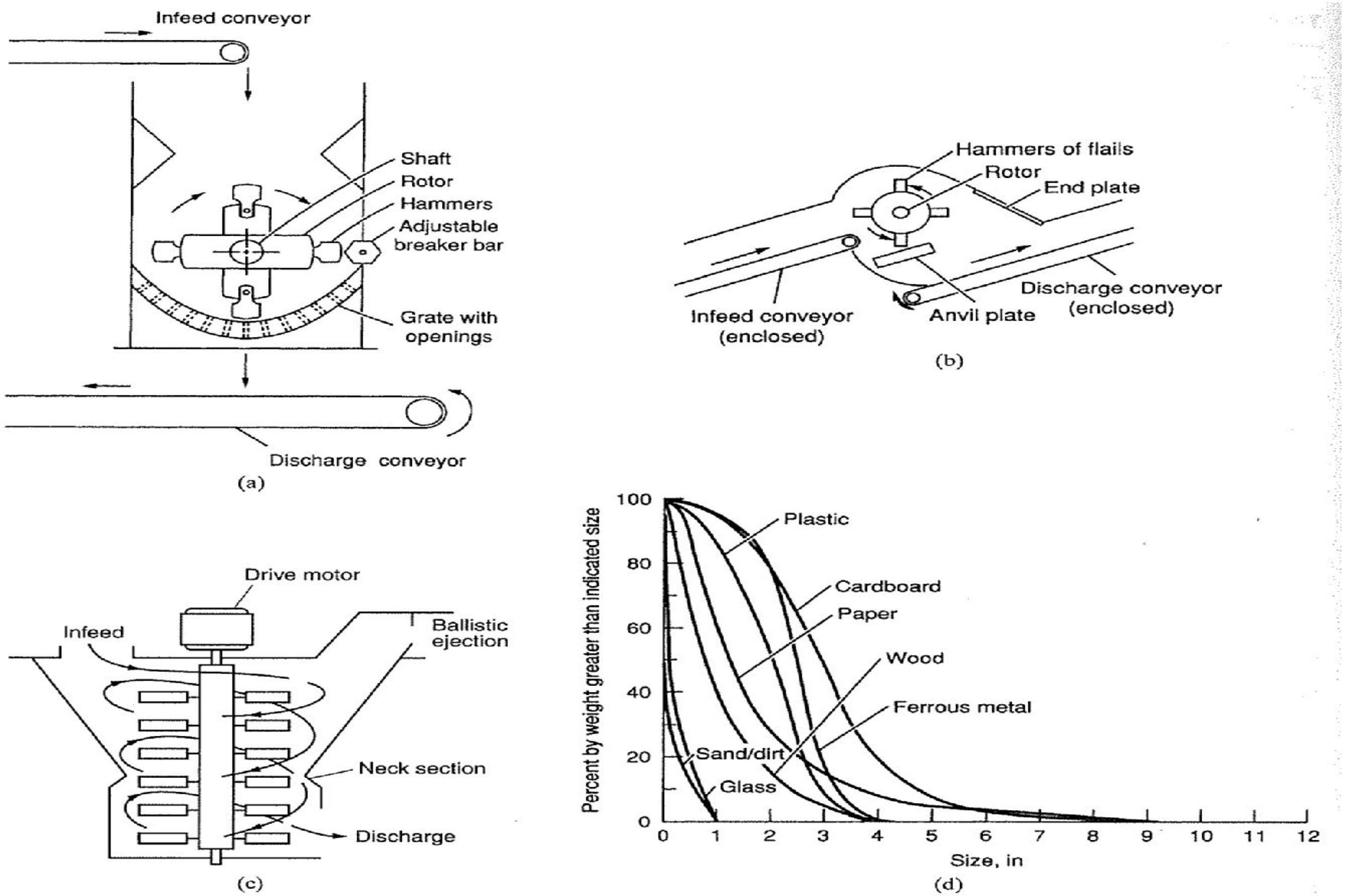


FIGURE 8.26 Types of high-speed impacting equipment used for size reduction of solid waste: (*a*) horizontal-shaft hammermill, (*b*) vertical-shaft hammermill with ballistic ejection, (*c*) horizontal-shaft flail mill, and (*d*) size distribution of various waste components after processing in a hammermill. *(From Tchobanoglous et al., 1993.)*

Size separation

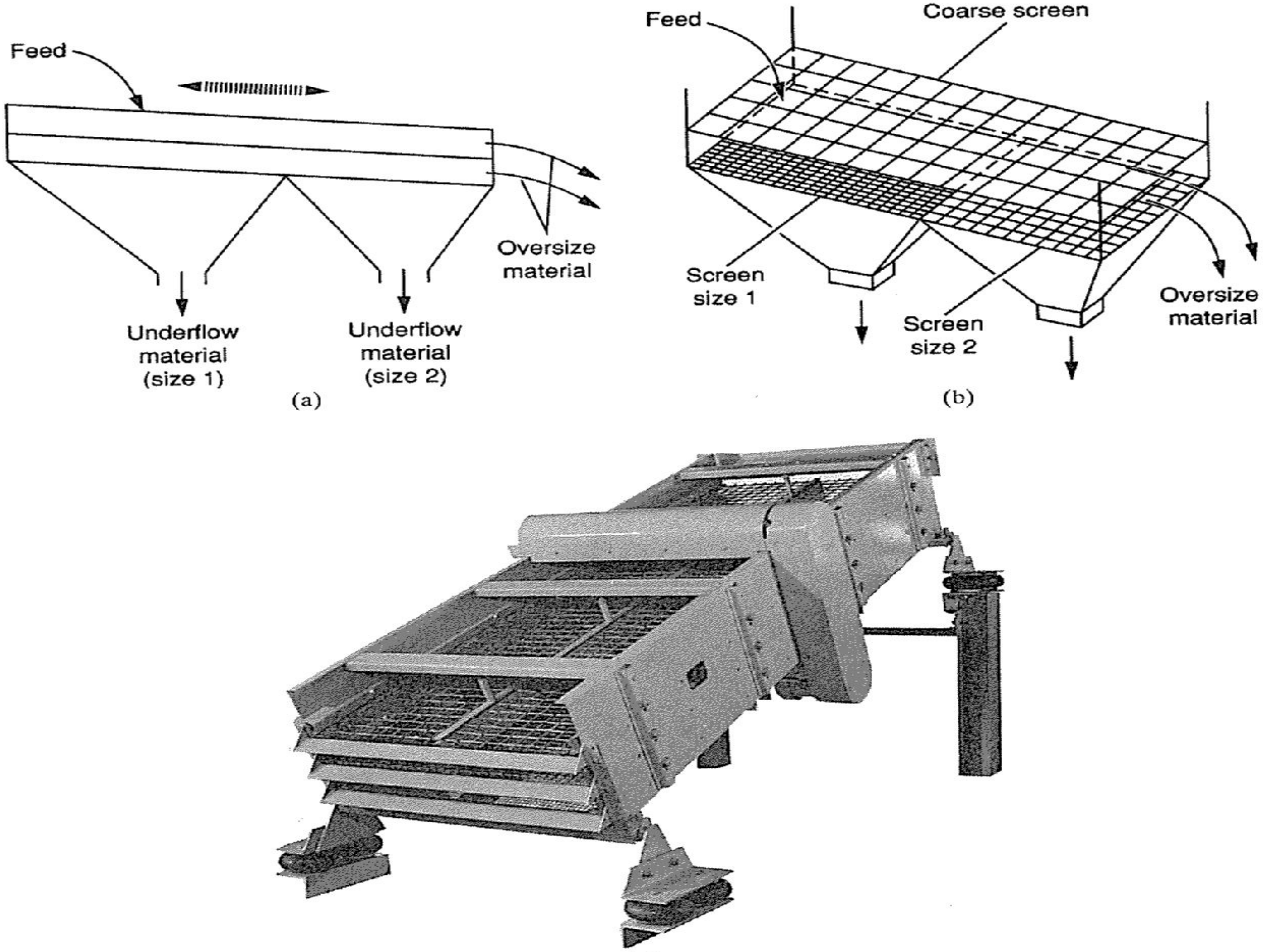


FIGURE 8.28 Views of vibratory screen used for the size separation of waste components: (*a*) profile diagram, (*b*) perspective diagram, and (*c*) typical vibratory screen (see also Figure 8.21*c*). *(From Tchobanoglous et al., 1993.)*

Size separation

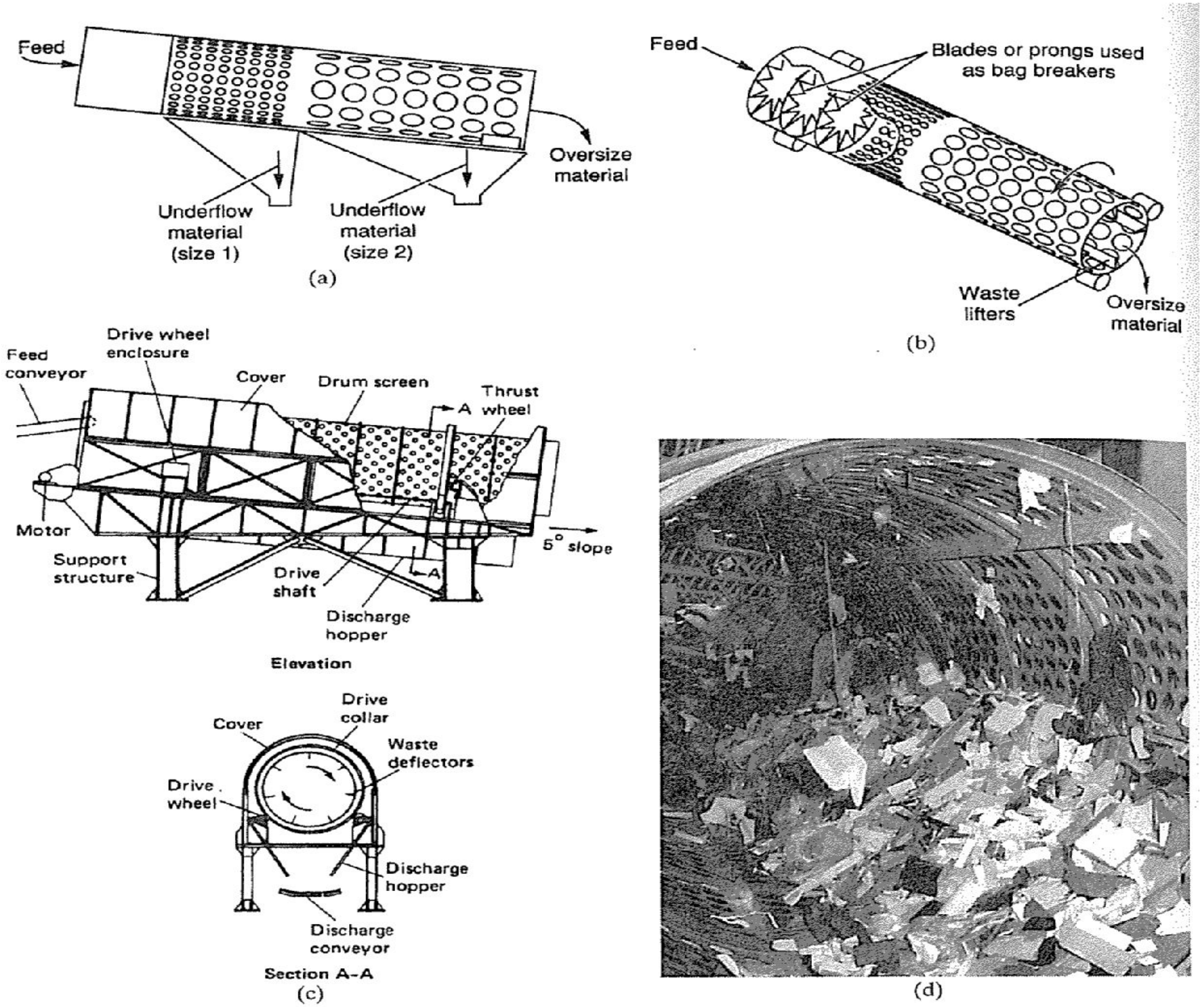
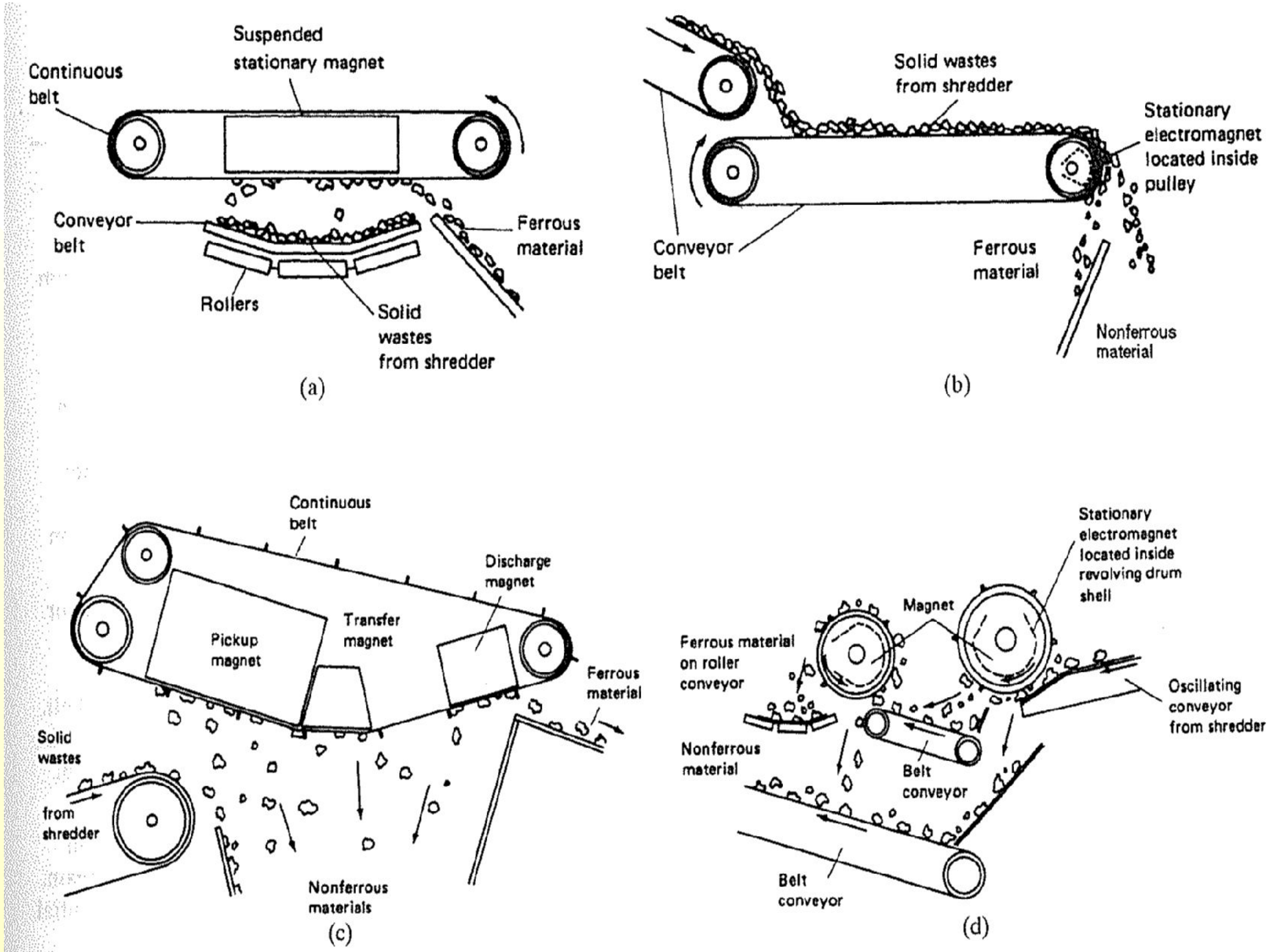


FIGURE 8.29 Views of trommel (rotary) screen used for the size separation of waste components: (*a*) profile diagram, (*b*) perspective diagram, (*c*) diagram detailing components of trommel screen, and (*d*) typical trommel screen in operation. *[Figures (a), (b), and (c) from Tchobanoglous et al., 1993; Fig. (d) from Triple/S Dynamics Systems, Inc.]*

Magnetic separation



Air classifier

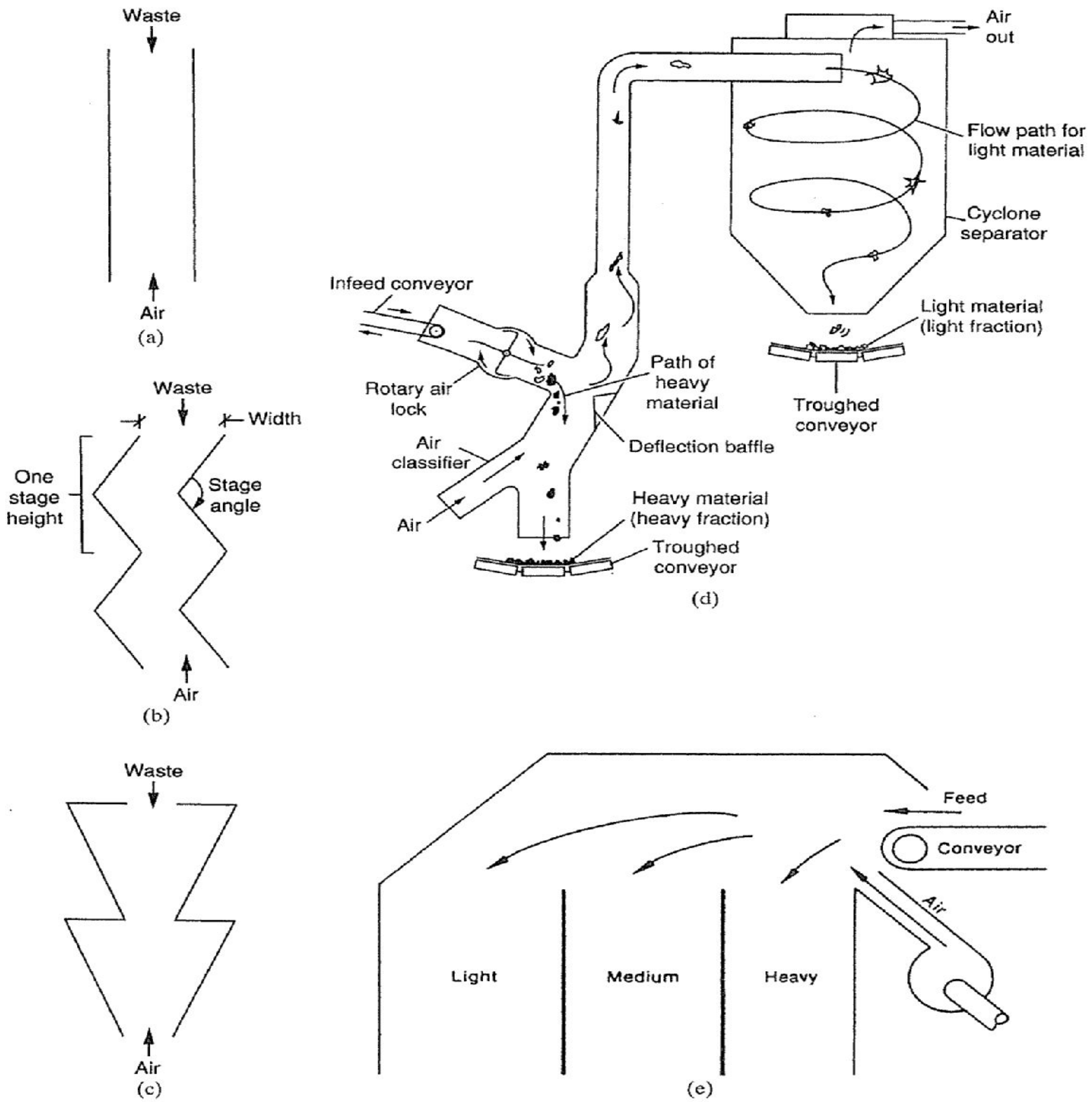


FIGURE 8.32 Air classifiers used for the separation of waste components: (*a*) vertical column air classifier, (*b*) zigzag air classifier, (*c*) stacked triangle, (*d*) typical air classification system, and (*e*) diagram of an air knife classification system.

Automated sorting system with sensors

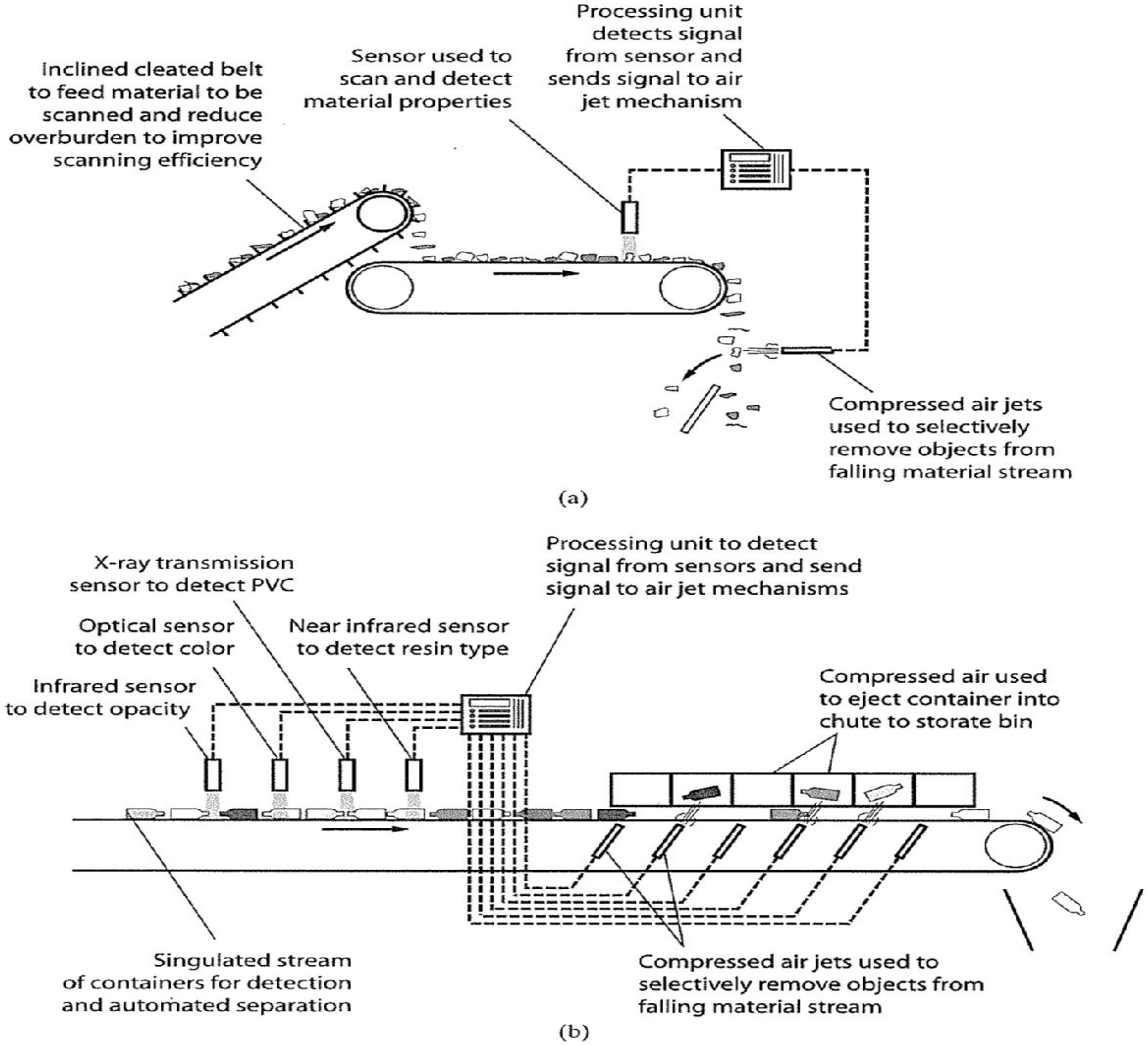
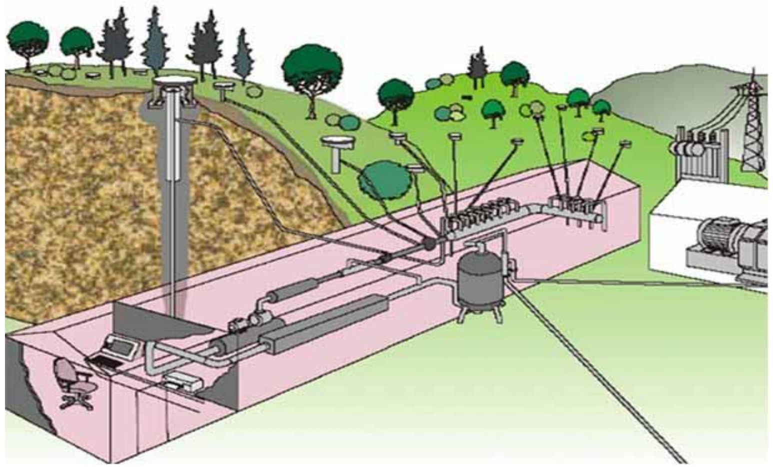


FIGURE 8.34 Systems for automated separation of solid waste components: (*a*) binary sorting device, and (*b*) an array of sensors for material identification.

Lecture 4: Landfill

Gas collection and utilization system

- Gas collection system contains
  - Gas extraction wells/trenches
  - Pipelines
  - Compressor or blowing station
    - Leads gas to flare or generator for electricity production
  - Instrumentation and electrical equipment
- The gas is led to a burner –
  - with just a flame/flare
  - With a generator to produce electricity
- 1 m^3 gas contains 4 – 5kWh energy
  - 2 m^3 corresponds 1 l of oil
- 150m^3 gas is formed /1 ton waste
  - Will be less in the future – WHY??



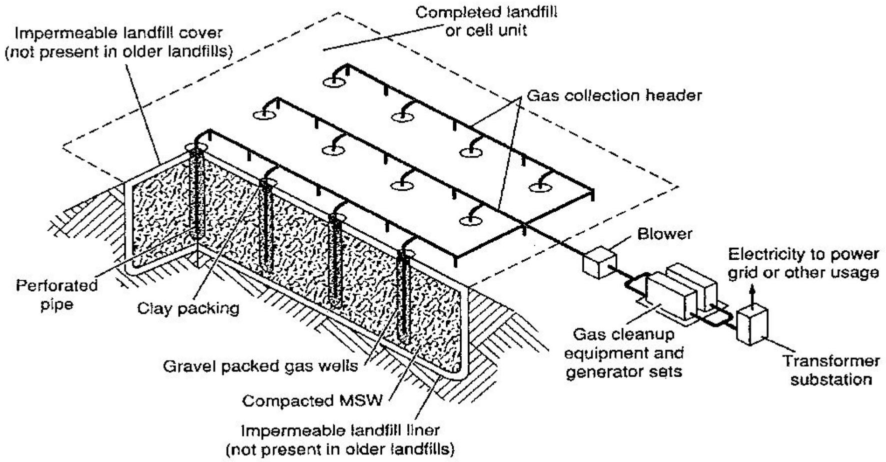


FIGURE 14.9 Landfill gas recovery system using vertical wells.

Planning of a landfill

Siting is a problem: ”not in my back yard”

- Land use plans and regulations
- Distance form close-by
  - residential areas
  - water resources
  - recreation areas
- Haul distance
- Size of available land area
- Soil conditions and topography
- Geologic and hydrogeologic conditions
- Surface-water conditions

- Screening of potential sites using several criteria in screening

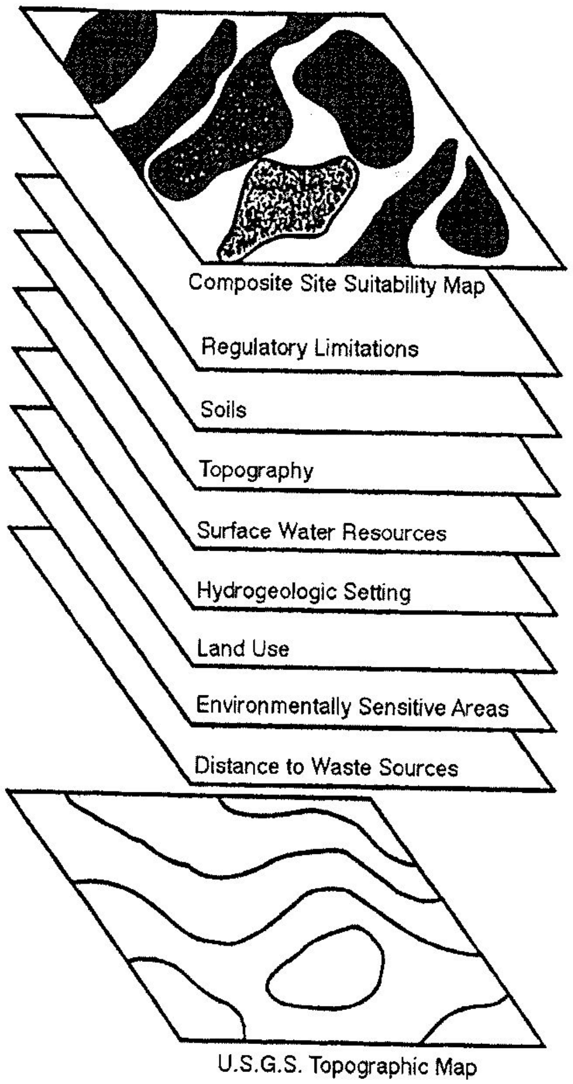


FIGURE 14.4 Overlay maps of various site criteria used in the screening of potential landfill sites. *(From Barlaz et al., 1989.)*

Gas formation in anaerobic processes

- Micro-organisms come from daily soil cover, sludge, recycled leachate
- **Phase I** - Initial adjustment
  - Aerobic bacterial decomposition starts
- **Phase II** – Transition phase
  - Anaerobic conditions develop
  - NO_3^- + SO_4^{2-} □□ $\mathbf{N_2}$ + $\mathbf{H_2S}$
  - Organic acids and CO_2 formation □ pH decreases
- **Phase III** – Acid phase
  - Bacteria activated □ significant amounts of **acids** and $\mathbf{CO_2}$
  - pH ≤ 5
  - Heavy metals solubilize
  - Essential nutrients into the leachate

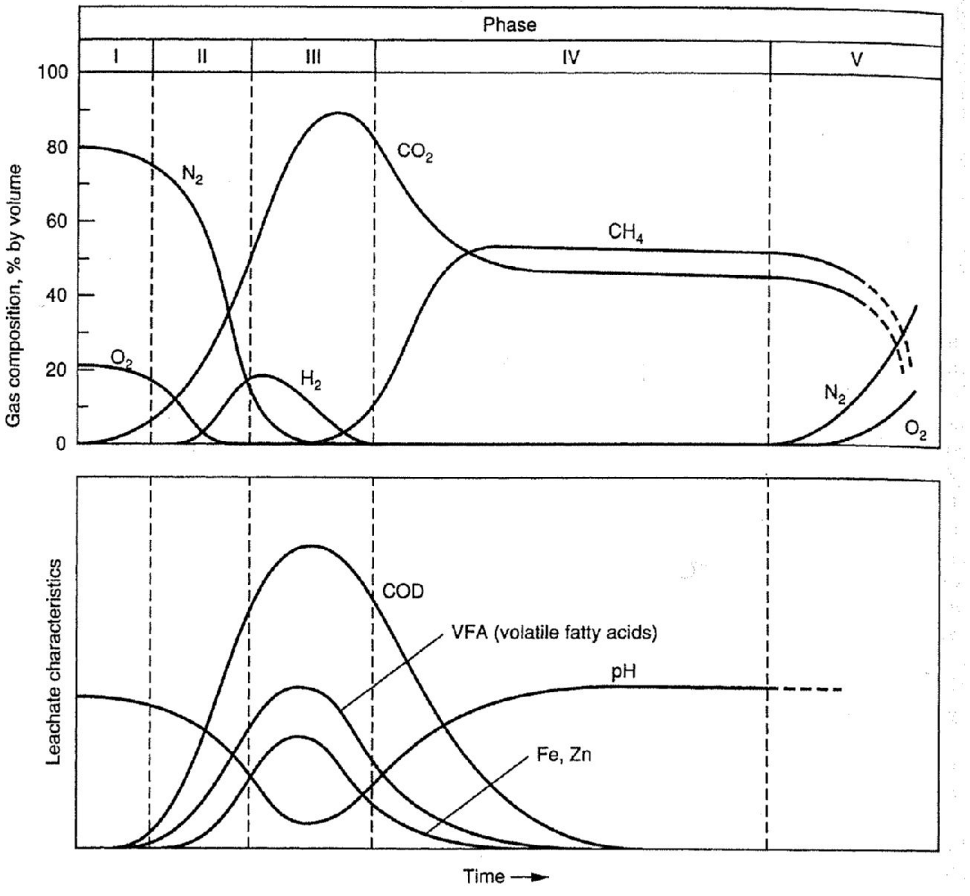


FIGURE 14.6 Generalized phases in the generation of landfill gases (I—Initial Adjustment, II—Transition Phase, III—Acid Phase, IV—Methane Fermentation, and V—Maturation Phase). *(Adapted from Farquhar and Rovers, 1973; Parker, 1983; Pohland, 1987; and Pohland, 1991.)*

Gas formation…

- **Phase IV** – methane fermentation phase
  - Bacteria transforms acetic acid and hydrogen gas

    into methane and carbon dioxide

    □ **CH_4 + CO_2**
  - pH will rise to 6,8 – 8
  - BOD, COD and conductivity are reduced in the leachate
  - Heavy metal concentration reduced in the leachate
- **Phase V** – maturation phase
  - Readily available organic matter has been converted into CH_4 and CO_2 Moisture sinks through the waste
  - Some organic matter is converted
  - Some CH_4 and CO_2 are formed
- **Total reaction**
- Organic matter + H_2O + nutrients □
  new cells + resistant organic matter + CH_4 + CO_2 + NH_3 + H_2S + heat

Formation of leachate

- Amount of leachate varies and depends on eg. season and weather
- Average amount is 7 – 16 m^3 /ha*d
- In a closed, well covered landfill 3-4 m^3/ha*d
- Volume can be reduced by
  - Plants growing on closed parts of a landfill
    - Willow 20-30%, grass 5-20%
  - Watering the surface of the landfill (evaporation)

- The leachate contains
  - Biodegradable components
  - More nitrogen and less phosphorus than municipal waste waters
  - Dissolved metals and salts (especially from ash)
    - Cd, Co, Cr, Cu, Fe, Ni, Mn, Pb, Zn –also As
    - Concentrations often lower than allowed for drinking water
  - Organic compounds
    - Chlorinated hydrocarbons, toluene, xylene, phenol, PCB
    - Concentrations are not high

Leachate

Quality of leachate depends on
the phase of the biological processes

Leachate can also be circulated
in the waste layers nutrients and
humidity to the microbes

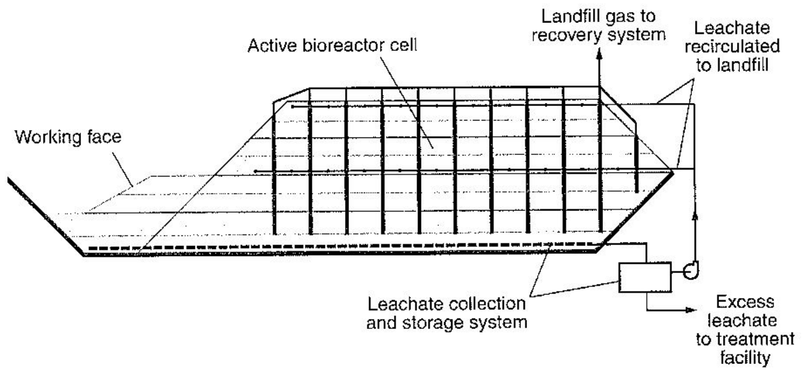
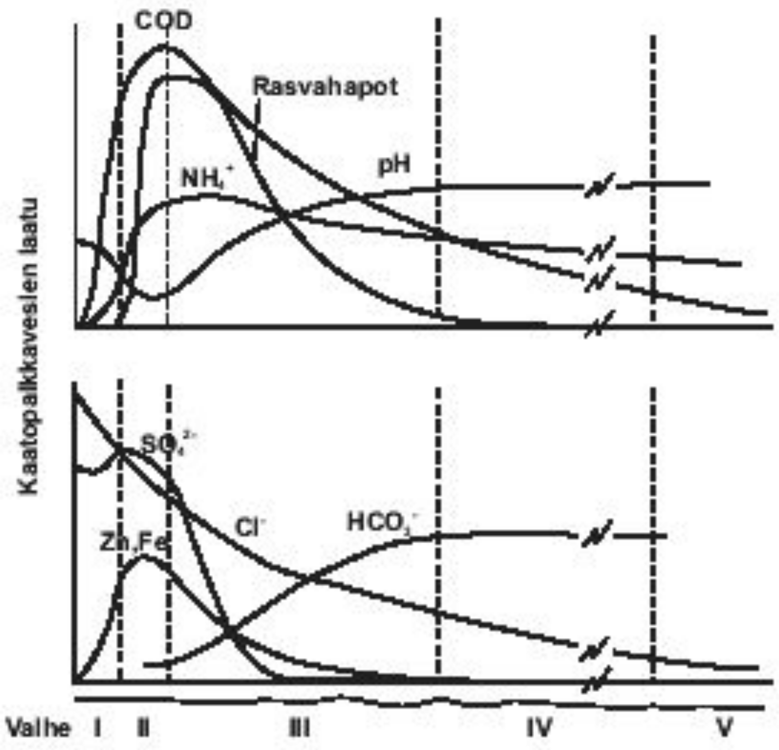


FIGURE 14.3 Bioreactor landfill with leachate recirculation and landfill gas recovery. *(Adapted from Solid and Hazardous Waste Education Center, University of Wisconsin–Madison, 2000.)*



Construction of a landfill before filling it

The landfill has to be specially founded

- Road construction
- Land construction and quarrying
- Re-inforcement of the bottom soil
- Waterproofing the bottom and walls
  - the landfill is segregated from the bottom soil with chemically and physically durable liner
  - prevents the ground water pollution
- Collection system for leachate and surface water
  - no water runs off uncontrolled
- Gas collection system
  - no gaseous emissions should be released
- Buildings (office, storage, reception..)

Filling

- Filling system depends on topography
- Waste is placed onto the landfill in cells
- Waste is crushed and compacted
- Cells are covered daily with soil

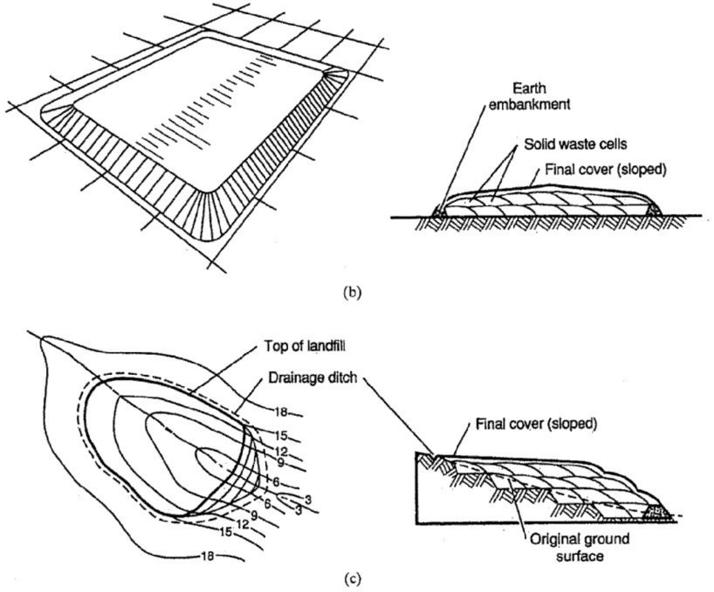
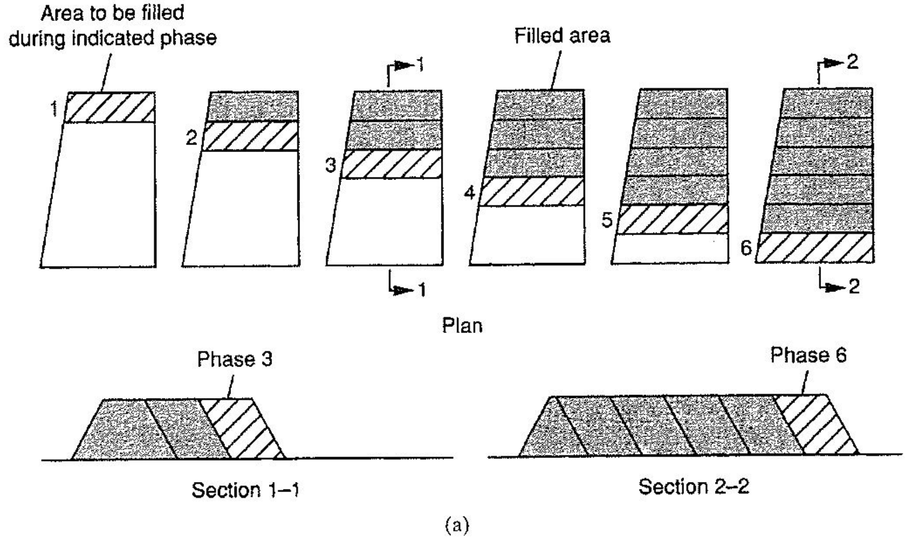


FIGURE 14.2 Commonly used landfilling methods: (*a*) excavated cell/trench; (*b*) area; (*c*) canyon/depression.



Waste layers in a landfill

a)

- Bottom layers are built
- Leachate collection pipes are installed

b)

- Waste is added as cells and layers of cells
- Daily layers are covered with soil
- Gas collection pipes are installed, surrounded with gravel

c)

- Final top layer is built

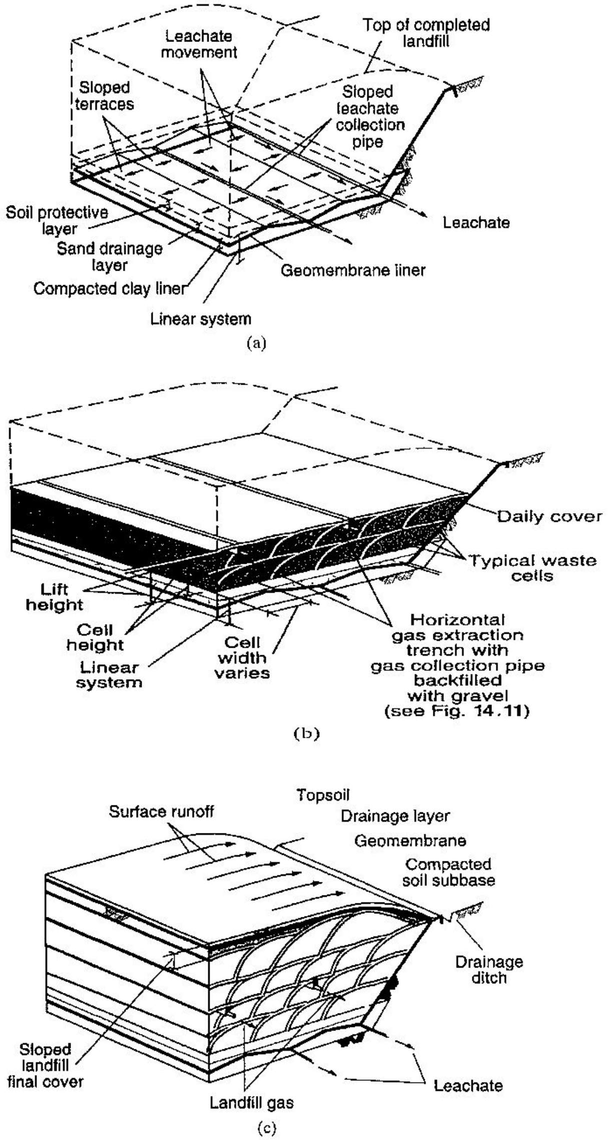


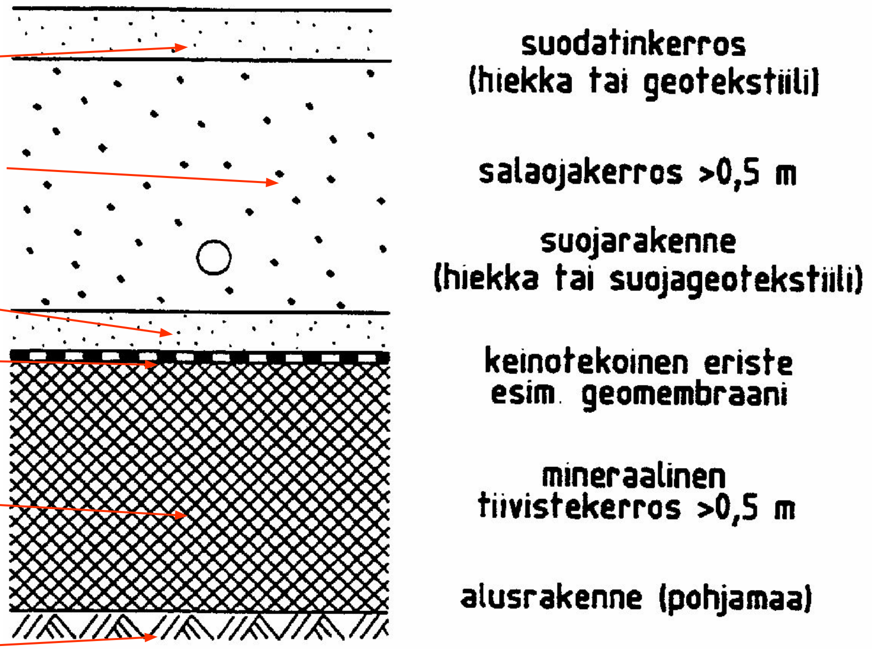
FIGURE 14.1 Cutaway views of a sanitary landfill: (*a*) after geomembrane liner has been installed over compacted clay layer and before drainage and soil protective layers have been installed; (*b*) after two lifts of solid waste have been completed; and (*c*) completed landfill with final cover installed.

Landfill Bottom Structure

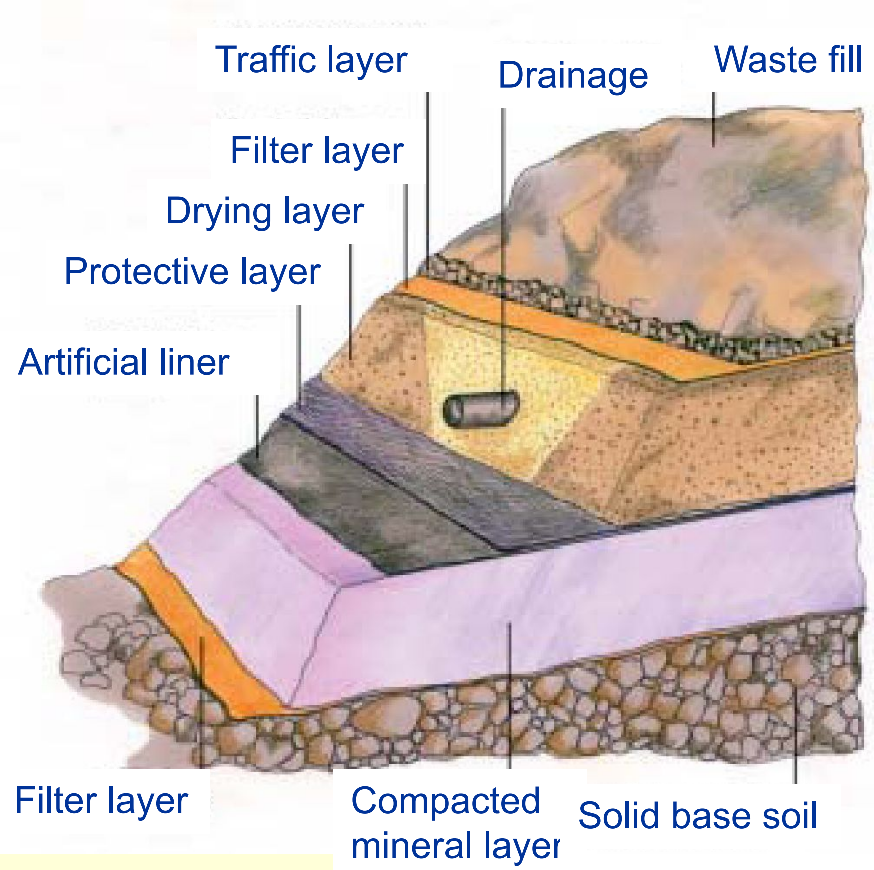
Soil quality is important

Structure contains several layers from top to the bottom:

- Waste layers
- Filtering material layer
  - Sand or geotextile
- Leachate collection pipes in soil layer (>0,5m)
- Protection layer
  - Sand or geotextile
- Artificial liner
  - Eg. Geomembrane
- Compacted layer of special mineral material or artificial separator >0,5m
- Natural bottom soil forms sturdy base



Landfill bottom structure



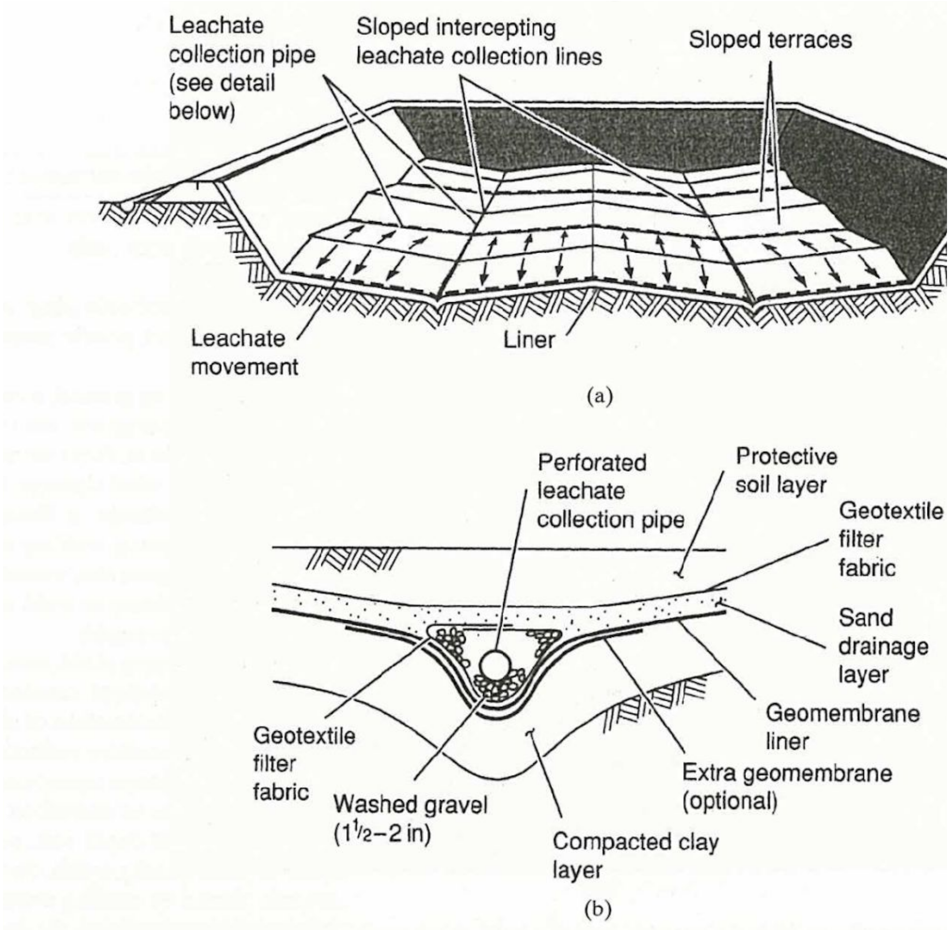


FIGURE 14.23 Leachate collection system with graded terraces: (*a*) pictorial view; (
ical leachate collection pipe.

Required bottom layers

- Bottom layers
  - Base soil has to be bearing
  - Water permeability and thickness of bottom layers
    - Hazardous waste
      - $K \leq 1{,}0 \cdot 10^{-9}$ m/s, layer ≥ 5 m
    - Regular waste
      - $K \leq 1{,}0 \cdot 10^{-9}$ m/s, layer ≥ 1 m
    - Permanent waste
      - $K \leq 1{,}0 \cdot 10^{-7}$ m/s, layer ≥ 1 m
  - Minimum compacted layer
    - hazardous waste 1 m
    - regular waste 0,5 m
  - If K-values are higher than given thicker compacted layer required

An example of bottom liners and leachate tubes

Lecture 5:
Composting (part 1)

Definitions

- Composting = aerobic biological decomposition of the biodegradable organic fraction of MSW under controlled conditions to a state sufficiently stable for nuisance-free storage and handling and for safe use in land applications
- Composting is a natural process that can be enhanced with technical methods
- Composting can reduce
  - The amount of waste in landfills
  - The nutrient and CH_4 emissions from landfills
- Composting can produce
  - Organic part of soil for land applications
  - Heat and gaseous products (mainly CO_2)
- Composting is operated
  - Municipally
  - In a household or housing company

The four phases of decomposition = composting

1) Latent phase (ambient temperature – 22°C, a few days)

- Micro-organism (bacteria, fungi, and other microbes) responsible for composting acclimatize, infiltrate and colonize in the waste
- Start breaking down the soluble (readily degradable) organic material → Produce heat

2) Growth phase, mesophilic (22 - 40°C, 2-12 days)

- Micro-organisms grow and reproduce
- High respiration
- Elevation of temperature → mesophilic temperatures

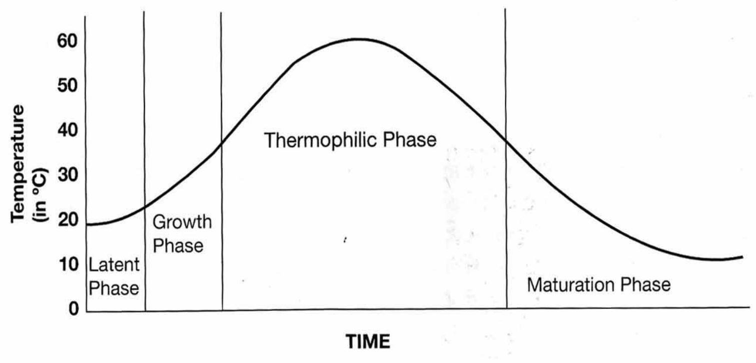
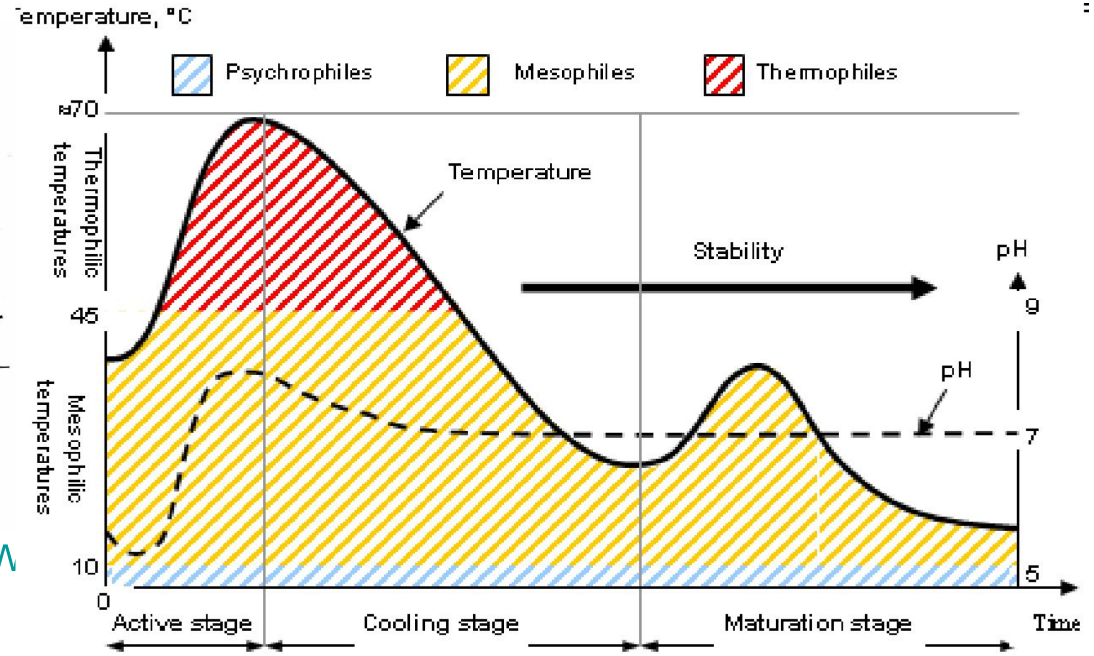


Figure 5.1. Temperature and the phases of composting



The five phases of decomposition = composting

3) Thermophilic phase (40 – 60^oC, days or months)

- High temperature pathogens sterilized
- Decomposes eg.proteins and fats, cellulosa, hemicellulosa
- At the end temperature drops to ~ 40^oC

4) Cooling period

5) Maturation (curing) phase (40^oC – ambient,several months)

- Slow process
- Temperature drops slowly to ambient
- Organic chemicals humic compounds
- Residual ammonia nitrite (NO_2^-) nitrate (NO_3^-)

Factors affecting the decomposition in the compost

Temperature

- Depends on the microbial activity in the compost
- High temperature (>40^{o}C)
  - Enhanced breakdown of proteins, fats and even complex carbohydrates like cellulose and hemicellulose
  - Reduction of pathogenes if 40^{o}C for 5 days and 55^{o}C min 4hrs
  - If 60-65^{o}C micro-organisms will dye
    - Aeration will cool down the compost

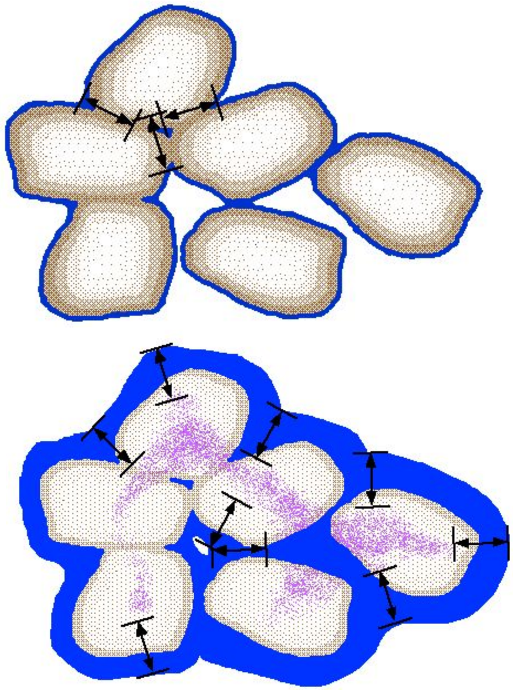
- If cooling down too early
  - Mixing will bring a new temperature peak

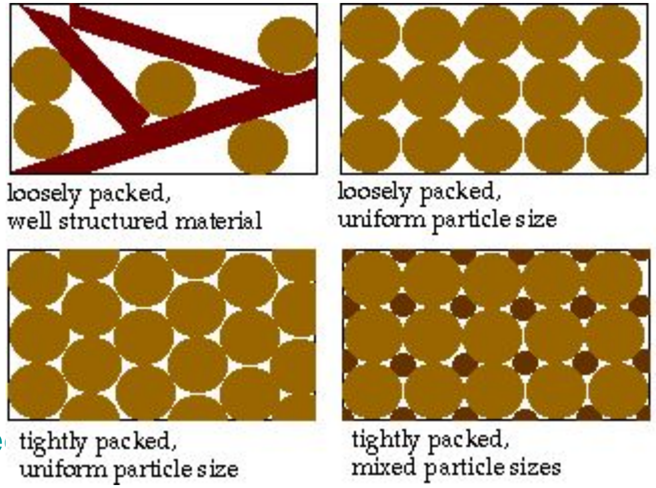
Factors affecting the decomposition in the compost

- **Particle size**
  - Small particles: large surface microbial activity increases
  - Too small particles: too compact
    - Air circulation is prevented
    - Decreases microbial activity
  - Large wood chips are used as bulking agent (air circulation easier)
    - Less available carbon in large chips
- **Aeration**
  - Oxygen necessary for microbes
    - Metabolism and respiration
  - Oxygen oxidizes organic molecules in the waste
  - Biological activity
    - Oxygen is used up
    - If < 5% oxygen anaerobic processes odor
  - Aeration with pipes, forced air flow, mixing

Factors affecting the decomposition in the compost

- Moisture optimum 50-60%
  - Microbial activity in thin films of water around organic particles
  - Low (<30%)
    - Bacteria becomes inactive
  - High (>65%)
    - Nutrient starts leaching
    - Anaerobic pockets between particles
      - fermentation
      - odor
  - Heat and air flow evaporate water significantly
- Porosity
  - Loosely packed material contains oxygen for the reactions





Factors affecting the decomposition in the compost

Composition of the mixture

- C : N ratio optimum 25:1 - 30:1
  - Reduced during the process as C CO_2 into the air
  - If C:N ratio much higher (less nitrogen)
    - microbial population remain small
    - nitrification not complete
    - disturbs proper maturation of the compost
- Too easily available nitrogen (eg if fertilizers added)
  - Microbes cannot use it
  - ammonia emissions (odor)
  - nitrate in the leachate
- C:N ratio depends on the feedstock
  - Mixing different feedstock good C:N ratio
  - Nitrogen addition: manure, sludge
  - Carbon addition: eg. woody material, finely ground

Materials and elements in composting

Material	Moisture
Peaches	80%
Lettuce	87%
Dry dog food	10%
Newspaper	5%

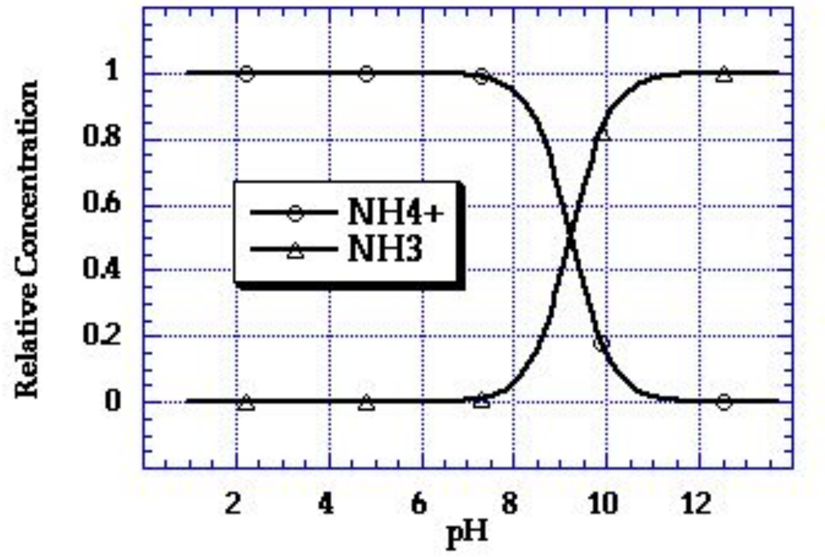
Material	C : N	
Wood and sawdust	500:1	High carbon materials
Paper	170:1	
Bark	120:1	
Leaves and the foliage	60:1	
Horse manure	25:1	High Nitrogen materials
Cow manure	20:1	
Grass clippings	19:1	
Sewage sludge (digested)	16:1	
Food wastes	15:1	

Often
Dry = high carbon content
Wet = High nitrogen content

Factors affecting the decomposition in the compost

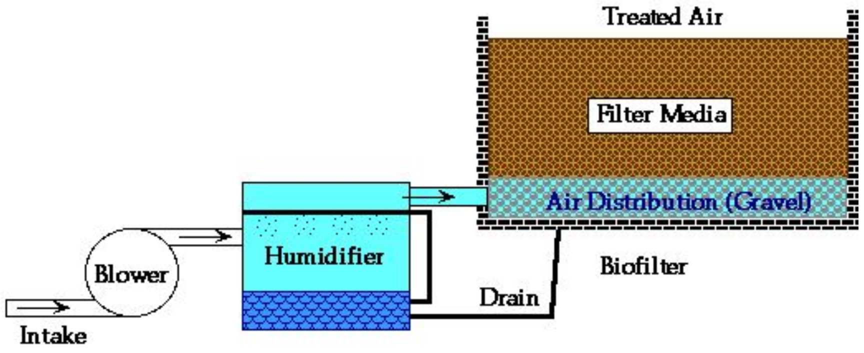
- pH
  - The equilibrium NH_4^+ □ $NH_3 + H^+$ depends on pH
    - At pH = 9 □ equilibrium
    - If pH is higher □ ammonia released
    - Too high variation in pH – kills the microbes

- pH of certain stages or processes
  - Feedstock appr. pH 5,5
  - Rotary drum pH 5
  - Tunnel compost pH 5,5-6,5



Factors affecting the decomposition in the compost

- Odors are caused if
  - Feedstock is stored anaerobically previous to the composting
  - In compost: low oxygen or anaerobic conditions cause odorouos compounds
    - Reduced sulfur compounds (eg. H_2S)
    - Volatile fatty acids
    - Aromatic compounds and amines
  - High pH ammonia
- Odor prevention/treatment
  - More oxygen into compost
  - Biofiltration in the outer compost layers
  - Biofiltration of outgoing air
    - Moist organic material
      - Compost, soil, bark, peat…
    - Adsorb and degrade molecules biologically



Properties affecting composting

Property	Unit	Optimum	Other information
Nutrient balance	C/N-ratio N/P-ratio C/P-ratio	20-35 5-20 75-150	-can be high if carbon source doesn´t decompose easily - High P content is not necessray, but is in favour of the nitrogen binding bacteria
Organic matter content and quality			-enough energy has to be released -suggested ratio between decomposable matter and water 1:10
pH		5- 10	-at the limits the composting process starts slower -high pH at the beginning□ nitrogen vaporizes as ammonia⇒ nitrogen loss
Humidity	p-%	50 – 60	-can be high if porosity is high and turning and mixing of compost is efficient
Porosity			-difficult to maintain oxygen content high enough in a dense and easily densified waste
Medium grain size	mm ∅	10 – 75	- Big enough to maintain aerobic conditions - Higher in a windrew compost than in a reactor
Poisonous components			- Seldom prevent composting but eg organic components may slow down composting

Lecture 6: Digestion

Basics of digestion

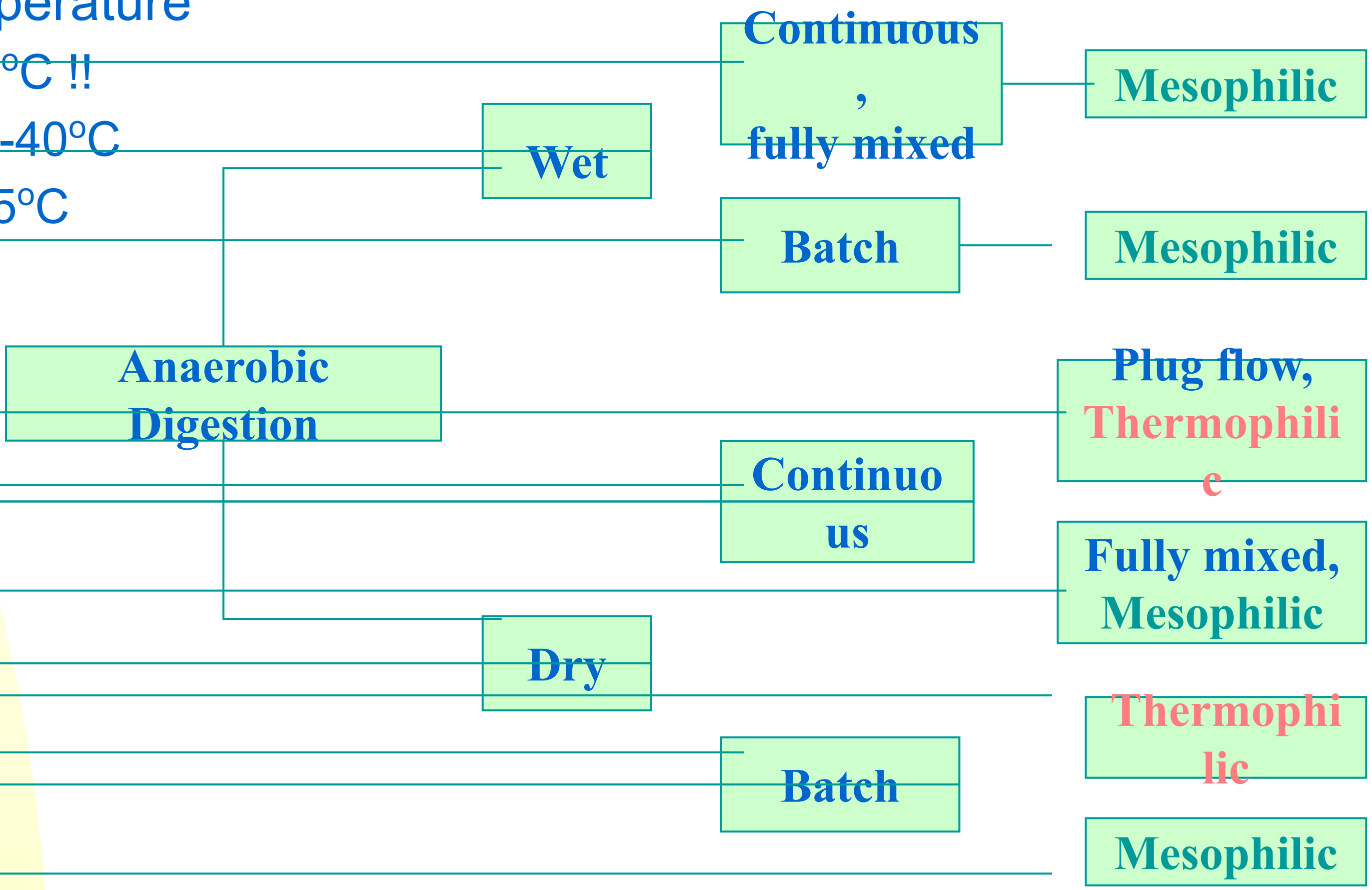
- **Treatment** for biological waste that cannot be disposed of at a landfill
  - 2006 biodegradable waste could be placed to landfills 75%
  - 2016 only 35%
    - other methods have to be developed

- **Digestion facilities in** Finland
  - Mainly at waste water plants for sludge treatment (~ 15 facilities)
  - A few facilities for municipal bio-waste treatment (Stormossen, Laihia)
  - A few industrial waste facilities
  - A few large facilities for farm waste (Close to Turku, Juva….)
  - Several facilities for farm waste treatment
  - The facilities in Finland produce over 25 mill. m^3 biogas
  - Biogas can be used for energy production or fuel for vehicles

- **Facility sizes** vary from private farm reactors (< 100 m^3) to Helsinki Water reactor (10 000 m^3)

Classification of anaerobic processes

- Wet process: total dry solids (TDS) 5 -15%
- Dry process: TDS 15-50%
- Process temperature
    - Cold:5-20°C !!
    - Warm: 20-40°C
    - Hot: 50-65°C



Digestion process

Biological reactions in the digestion are similar to those in anaerobic landfill

Hydrolysis: fermentative bacteria hydrolyze complicated organic compounds into soluble organics more available for the next stage

- Enzymes produced by hydrolytic bacteria decompose and liquefy carbohydrates, cellulose, proteins and fats
- Rate limited: decomposing the complex compounds like cellulose
- Rate governed by
  - Substrate availability
  - Bacterial population density
  - Temperature and pH

Acidogenesis (acidogenesis and acetogenesis): products of the hydrolysis are further processed by bacteria

- Main products: acetic, lactic and propionic acids
  - Acetic acid is produced from monomers
  - Volatile fatty acids (VFA) are produced from protein, fat and carbohydrate components
- Some gases (CO_2, H_2) and methanol are produced
- pH falls
- Products depend on feedstock, bacteria species and environmental conditions

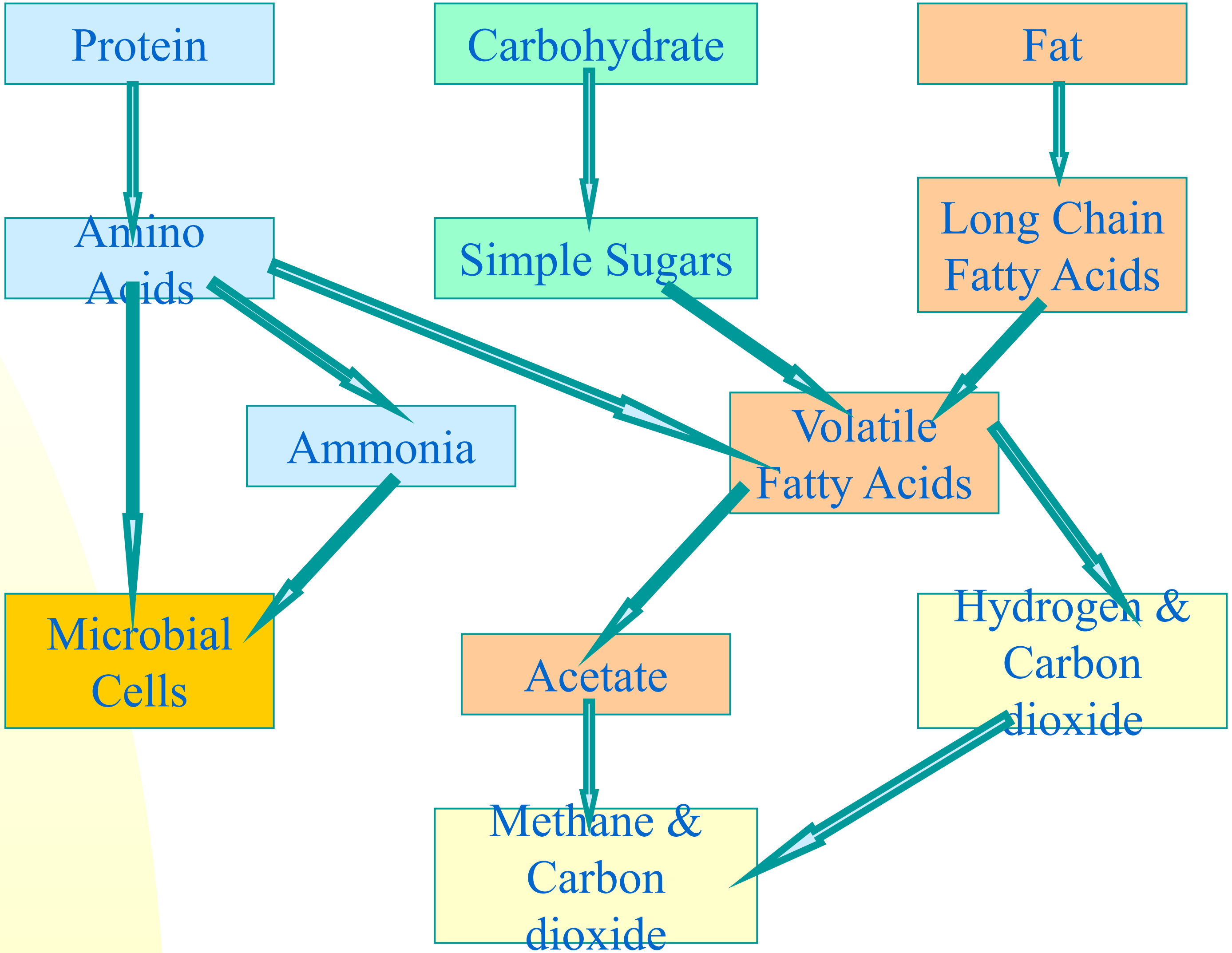
Digestion process

Methanogenesis: methane - forming bacteria produces methane from the products of previous stage (HAc, MeOH, CO_2, H_2)

- Acetic acid + acetate → 75% of CH_4
  - $CH_3COOH \rightarrow CH_4 + CO_2$
- Methanol and hydrogen can be used, too
  - $CH_3OH + H_2 \rightarrow CH_4 + H_2O$
- Carbon dioxide and hydrogen produce methane, too
  - $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

- Converting volatile fatty acids into methane maintains higher pH
  - pH stays at 6,6 – 7,0 (mild acidic)
  - Problems arise if pH <6,4
  - Volatile fatty acids would be harmful for fertilizer use of the final product

Substrate dissimilation in anaerobic process



Gas formation in anaerobic processes

See anaerobic processes in landfills for more detailed description

- **Phase I**
  - Atmospheric levels of N_2 and O_2
- **Phase II**
  - N_2 falls to 10%
  - Oxygen is depleted
  - Fatty acids and CO_2 formed
- **Phase III**
  - CO_2 falls to 40%
  - CH_4 rises to 60%
- **Phase IV**
  - Plateau: CO_2 40% and CH_4 60%
- **Phase V**
  - CO_2 and CH_4 production to ~0

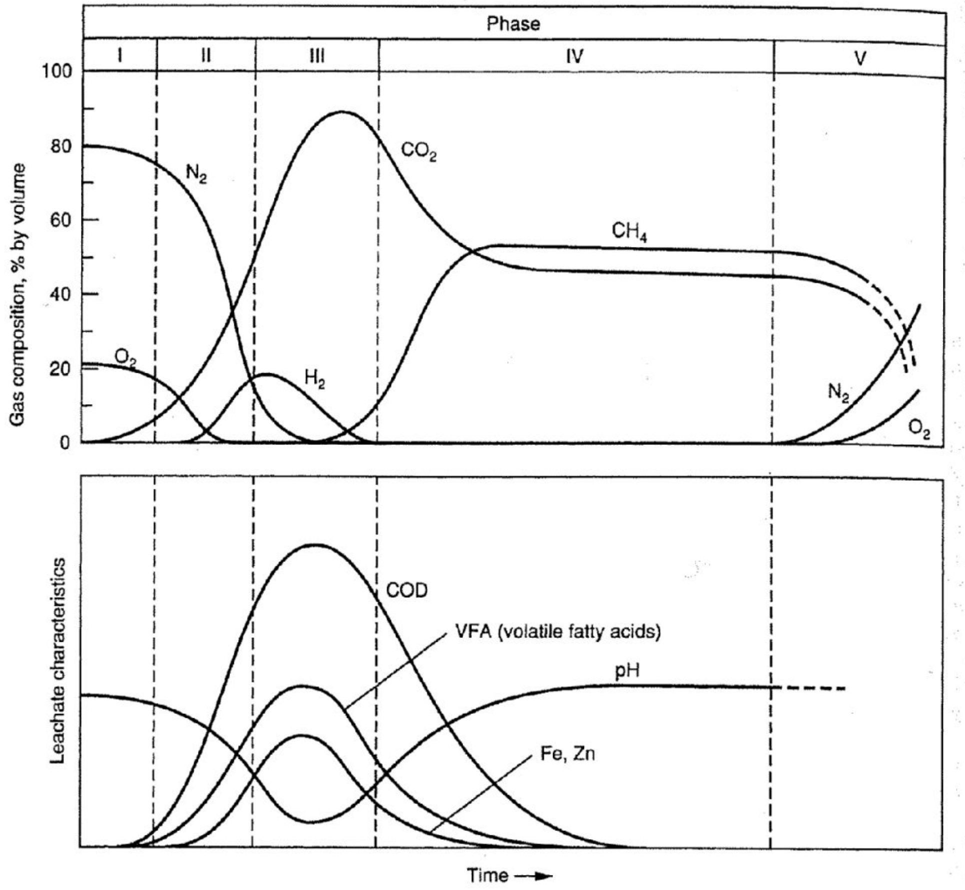


FIGURE 14.6 Generalized phases in the generation of landfill gases (I—Initial Adjustment, II—Transition Phase, III—Acid Phase, IV—Methane Fermentation, and V—Maturation Phase). *(Adapted from Farquhar and Rovers, 1973; Parker, 1983; Pohland, 1987; and Pohland, 1991.)*

Lecture 7:
Waste incineration (part 2)

7.10 Thermal treatment methods of waste

(VDI, 2000)

Incineration = complete burning (oxygenation)

Gasification = partial oxygenation

Pyrolysis = thermal decomposition in anaerobic conditions

	Pyrolysis	**Gasification**	**Incineration**
Temperature/C	250-700	800-1600	850-1400
Pressure/bar	1	1 - 45	1
Atmosphere	Inert/N_2	O_2/H_2O	Air
Air coefficient (stoich.)	0	<1	>1
Process products Gas phase Solid phase	 H_2, CO, HC, N_2 Ash, coke	 H_2, CO, CH_4, N_2 Slag	 CO_2, H_2O, O_2, N_2 Ash

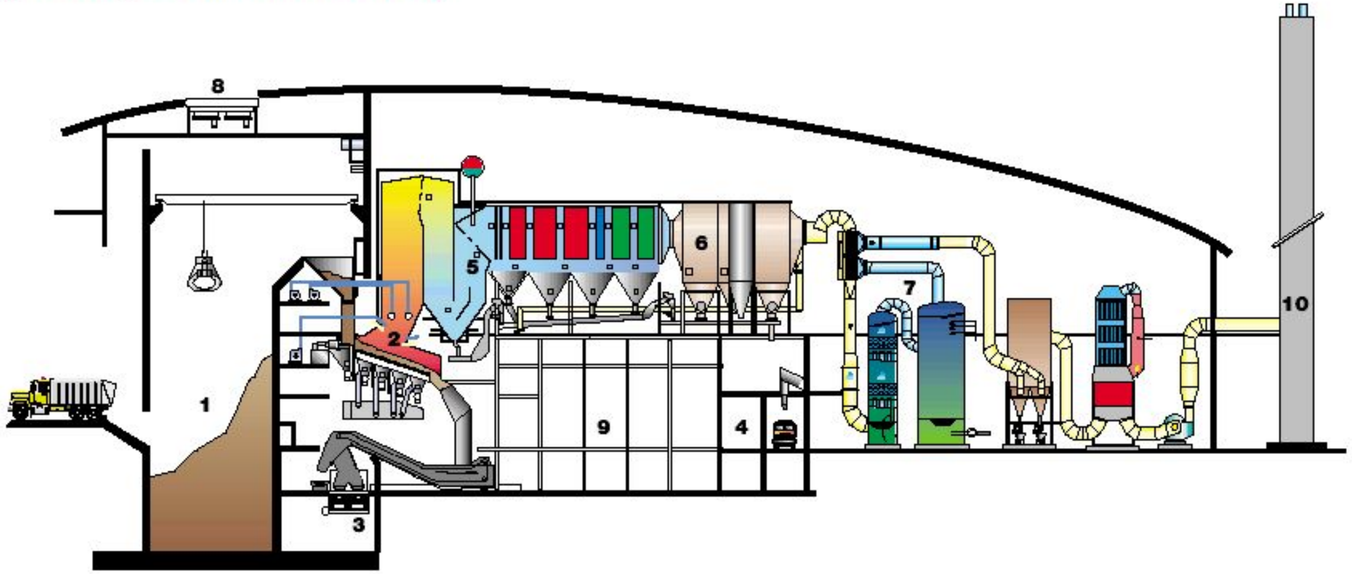
Different versions of processes have been developed. Part of them are used also as large scale processes.

7.10.2 Municipal waste incineration plants – basic structure

(VonRoll Environmental Technology Inc. brochure 2001)

Grate incineration plant shown in picture.

Cross section of modern grate combustion system
(Nuremberg, to be commissioned in 2001).



1 Waste pit
2 Grate combustion system (water-cooled)
3 Slag discharge
4 Fly ash loading station
5 Steam generation
6 Electrostatic precipitator
7 Flue gas purification
8 Heat exchanger
9 Electrical and Control Center
10 Stack

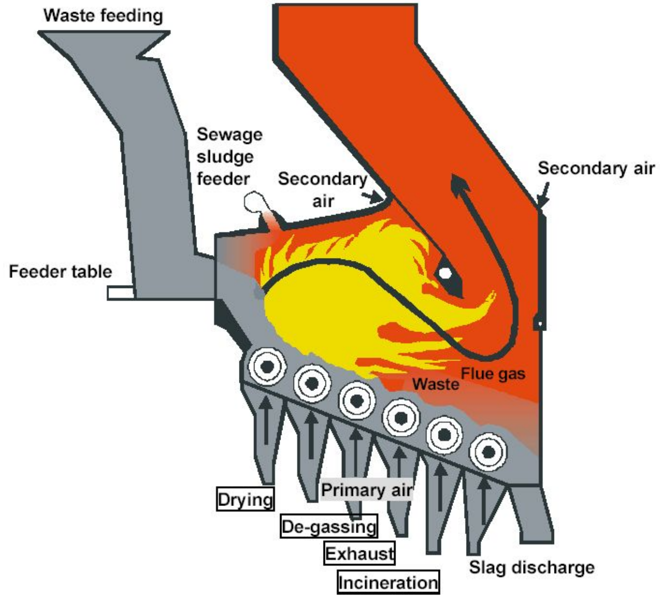
1 Jätebunkkeri
2 Arinapolttokammio (vesijäähdytteinen)
3 Pohjatuhkan poisto
4 Lentotuhkan lastausasema
5 Höyrynkehitys
6 Sähkösuodatin
7 Savukaasun puhdistus
8 Lämmönvaihdin
9 Ohjauskeskus
10 Savupiippu

Grate firing

Grate firing basics

- Fuel in suitable size is spread onto solid or moving grate, where burning takes place
- The grate :
  - Transfers the fuel to the furnace
  - Mixes and separates fuel particles from each other
  - Transfers the residual, ash out of the furnace
- Sections, where the fuel is dried, pyrolysed and the residual coke are burned.
- Primary air is fed form underneath the grate and the secondary air on top of it
- Waste consists often of volatile components

   burning above the grate



Grate firing (cont)

Different air flows in grate firing conditions vary

Air flow cools down the grate and prevents slagging

The direction of the air

- Delay in the furnace longer in counter current air
- Flammability better in counter current air flow
- Medium format is often a compromise
    - Good mixing and turbulence of air and flue gas flow

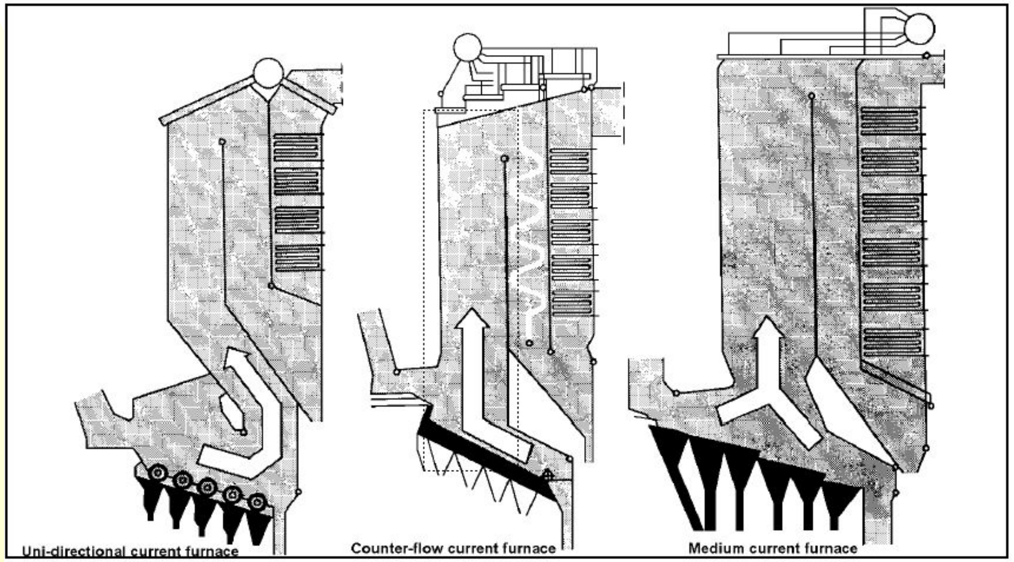


Figure 4.6: Various Types of Incineration Air Feeding
Source [1, UBA, 2001]

Grate firing (cont)

Grates of different design (BREF)
- Continuous feeding: roll, chain
- Discontinuous feeding: counter current
- Cooling: small with air flow; big with water coolers

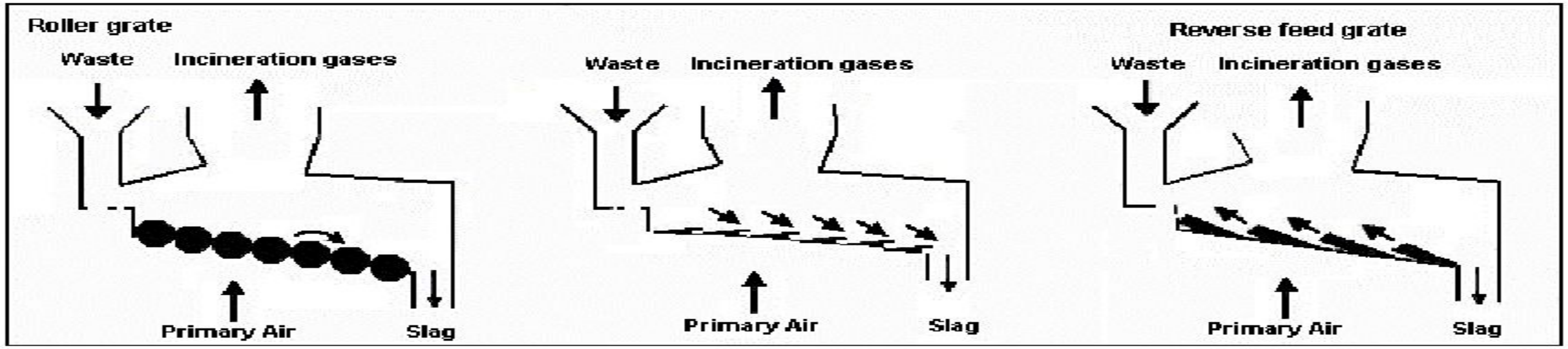


Figure 4.3: Different Grate Types
Source [1, UBA, 2001]

Grate structure (VonRoll Environmental Technology Inc. brochure 2001)

Grate firing (cont)

The grate removes the slag (bottom ash) to a container below the furnace (BREF)
- Often water cooled
- The container is emptied and the water is separated

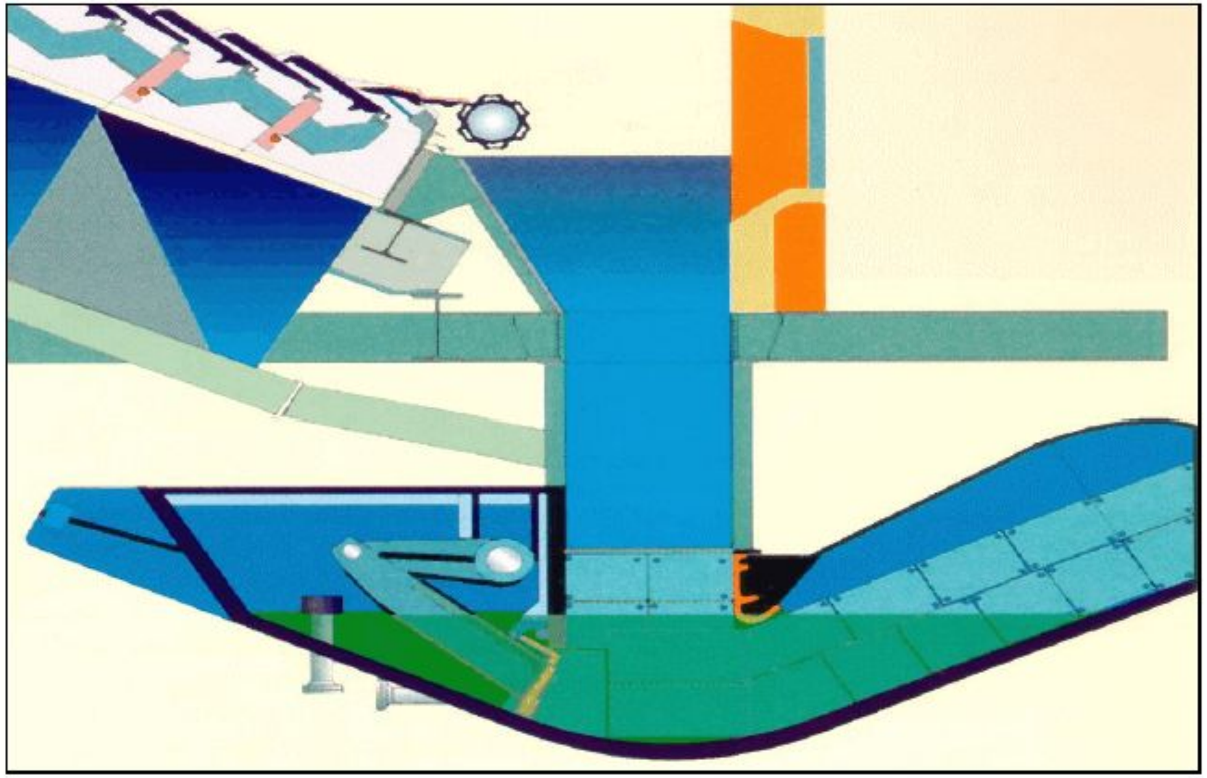
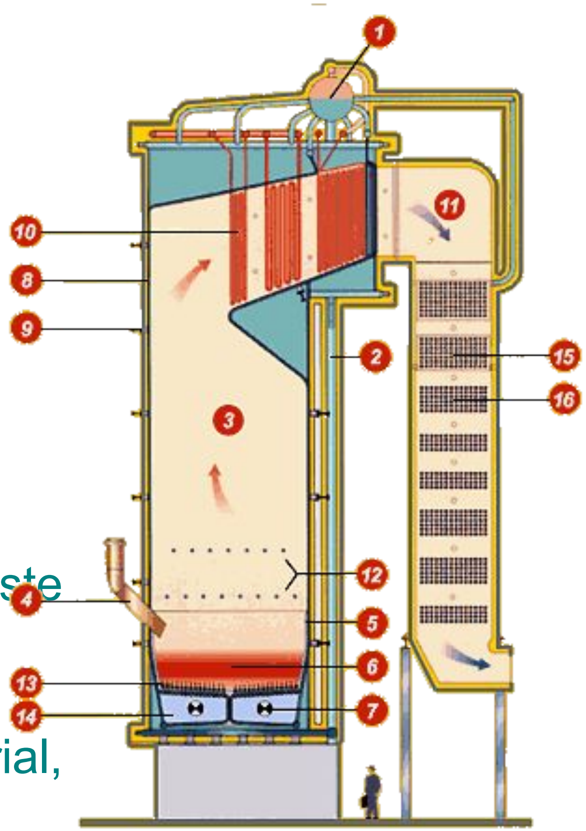


Figure 4.4: Diagram of an ash remover at a grate incinerator
Source [1, UBA, 2001]

Fluidised bed incineration

Fluidised bed incineration has been used for tens of years for homogeneous fuel

- coal (dust), sludge, biomass (wood)
- sorted waste is required for waste incineration
  - homogeneous recycled fuel
- well managed and reliable incineration method
  - flue gas cleaning is cheaper



Principle of fluidised bed incineration

- inert bed material (sand, ash) floats in the reactor
- air is fed from beneath floats the mass
- bed material has to be heated before feeding the waste (oil or gas burners are used)
- waste has to be finely structured, max. 50 mm
  - feeding among or above the fluidised bed material,

- turbulence is important mixes the fuel, bed material and air

Fluidised bed incineration (cont)

- The purpose for using the bed material is to
  - enhance the mixing of air and the fuel
  - Balance temperatures in the furnace – cutting down the peaks
  - Promote heat exchange
- Fluidised bed incineration is suitable also for wet fuel

Examples of fluidised bed combustion

- https://www.youtube.com/watch?v=cmm5R_km4Kk
- https://www.youtube.com/watch?v=T6IcdLfV3G4
- https://www.youtube.com/watch?v=KcR62W2z8KE

Fluidised bed incineration (cont)

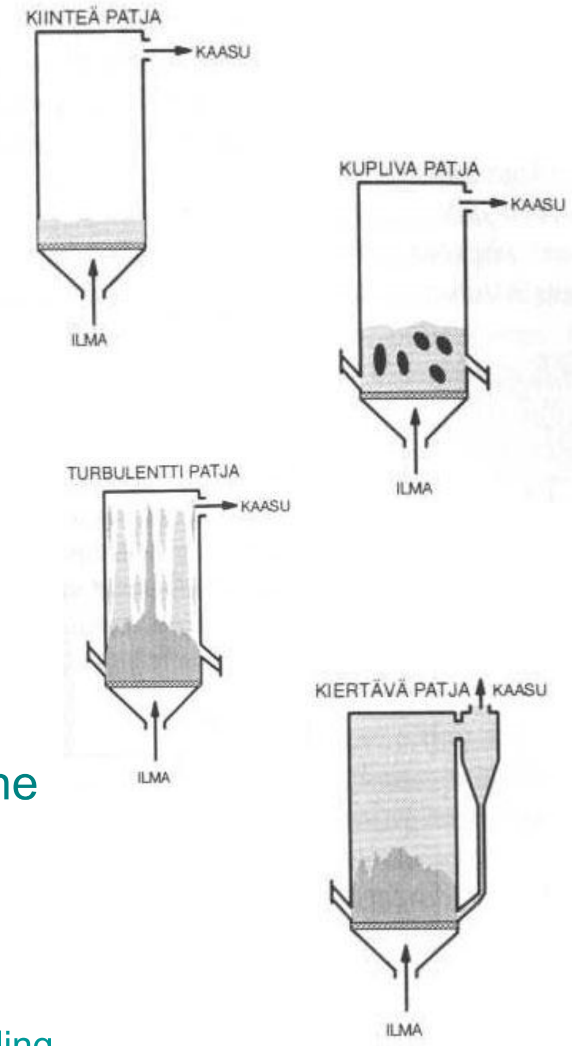
Fluidised bed reactors are classified with turbulence caused by the air flow

1) Fixed bed
- divides air flow evenly

2) Bubbling bed
- air is bubbled through the bed material
- the bed has a clear surface

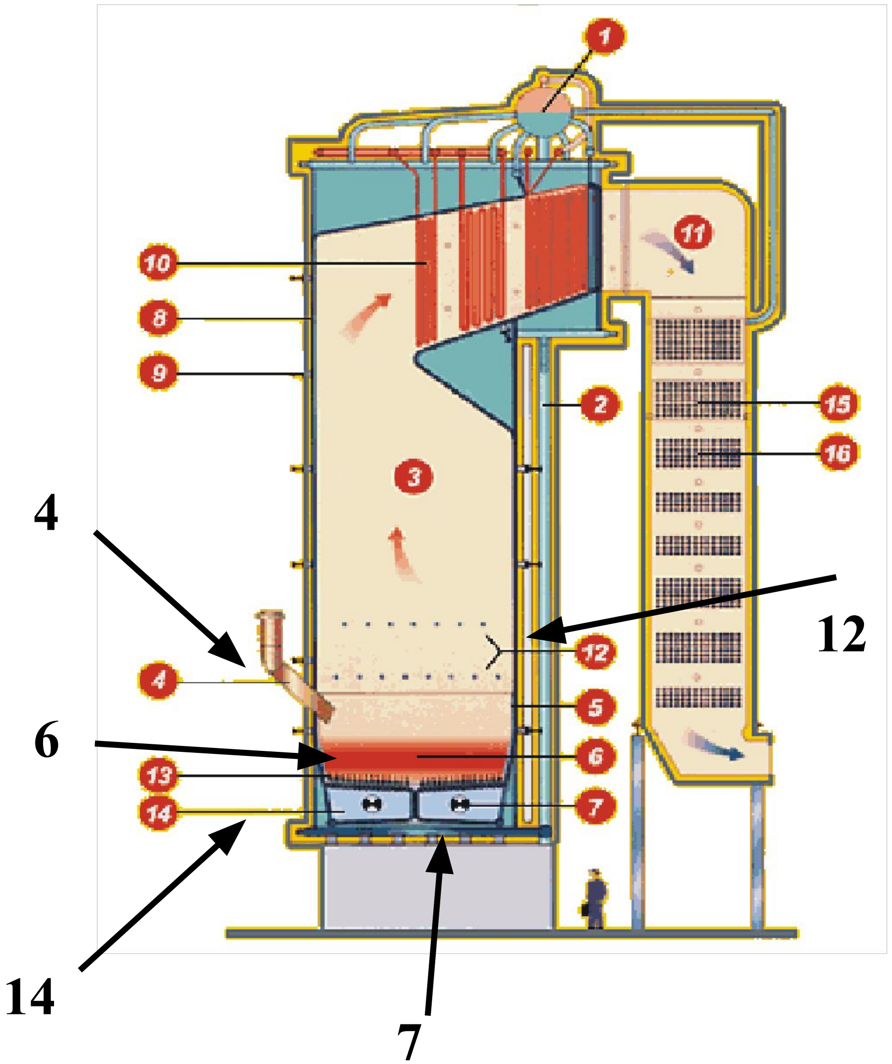
3) Turbulent bed
- air makes the bed material float in the furnace
- temperature is balanced by the bed material

4) Circulating bed
- bed material is floating out of the furnace with the flue gases
- returned back with flue gases in the cyclone
- higher flow balances further the temperature



The structure of the fluidised bed system

1. Steam container
2. Pipes for water
3. Furnace
4. Fuel into furnace
5. Safety surface
6. Sand layer
7. Burners for heating the sand
8. Gas tight water pipe walls
9. Supporting structures
10. Superheaters
11. Flue gases from the furnace
12. Nozzles for over-air
13. Grate and air nozzles for fluidising the sand
14. Air into the furnace
15. Preheaters of the water
16. Preheaters of the air



Fluidised bed techniques

Common

- The bed material has high energy content (once heated, holds the temperature)
- Efficient mixing of fuel and air
- Suitable also for moist fuel and high ash content fuel
- High efficiency of burning

Technical data

- Temperature 800-900 °C
- Possibility to adjust load from 40 % to 100 %
- Power 3 - 420 MW
- Energy efficiency 70-90%
- Usability typically 98 %

Fluidised bed techniques (cont)

Small emissions

- Moderate temperature:
  - Thermal formation of NO reduced
  - Fuel –NO still formed
- alkaline bed material can be used to bind sulfur emissions in the furnace
- Less oxygen (flue gas circulation)
  - N_2O-emissions higher

Solid wastes (differences partly dependable on fuel quality)

- Less bottom ash 10%
  - Fly ash 90%
- Bottom ash contains more volatile metals than in grate firing

  less metals in flue gases
- The ash quality more homogeneous
- Less sintering of ash

Minor need for repair

- Minor fouling if not much Cl, K, Na, Al in the waste

7.10.3 Pyrolysis and gasification

Optional methods for waste incineration developed already from the 1980’s.

Commercial systems exists, but different methods in industrial scale are at different stages of development.

The target is

- to add inorganic waste collection
- change the waste into process gas
- minimize the cleaning costs of the flue gas by reducing their volume

The methods decompose

- the components of the waste → chemical raw materials
- different stages in burning processes → different fuels

The methods used are

- Temperature and pressure control
- Special reactors
- Often combined with incineration

Pyrolysis and gasification (cont)

Smouldering

- Gas formation from volatile waste particles
- 400-600 ^{o}C

Pyrolysis

- Decomposition of waste by heat produces gas
- Energy content of gas 5 – 15 MJ/m^3
- 600-800 ^{o}C (also given 400-700 ^{o}C)

Gasification

- Gasification of coal to coke
- Volatile compounds separated from the solid waste
- Additional components: oxygen or water vapour
- Gas= process gas ($CO + H_2$)
- 800-1000 ^{o}C

Combined technology: burning included

- In combined technology the coke from pyrolysis and the gas are burned

In Europe

- Combustible non sorted municipal waste (RDF): a few pyrolysis sites in Germany for MSW treatment (2003)
- Others for treatment of recycled fuel separated at source (REF)

Gasification

Several processes suitable for municipal waste, dried waste water sludge or hazardous waste are ready or being developed.

Gasification often combined to pyrolysis

- gases are burned at a power plant

Fuel feeding (waste)

- content and particle size limited
  fine particles expected requires often pretreatment
- hazardous waste (liquids, paste, fine grade) directly fed to the gasifier

Various processes

- concurrent gasifier
- cyclone gasifier
- fluid bed gasifier
- packed bed gasifier

Pressurised and atmospheric gasification plants exist.

Gasification (cont)

Example of gasification of wet waste; moisture 60%

- gasification air is blown from the bottom □ bed material is floating
- waste for gasification is fed above the air feed
- while falling, the waste particles are
  - dried and pyrolysed □ gas, coke, tar
  - residual coke falls down in air stream
- coke is burned □ hot CO ja CO_2 gases
- gas flows upwards □ endothermic reactions
- Particles are separated in a cyclone □ returned to oxygen flow

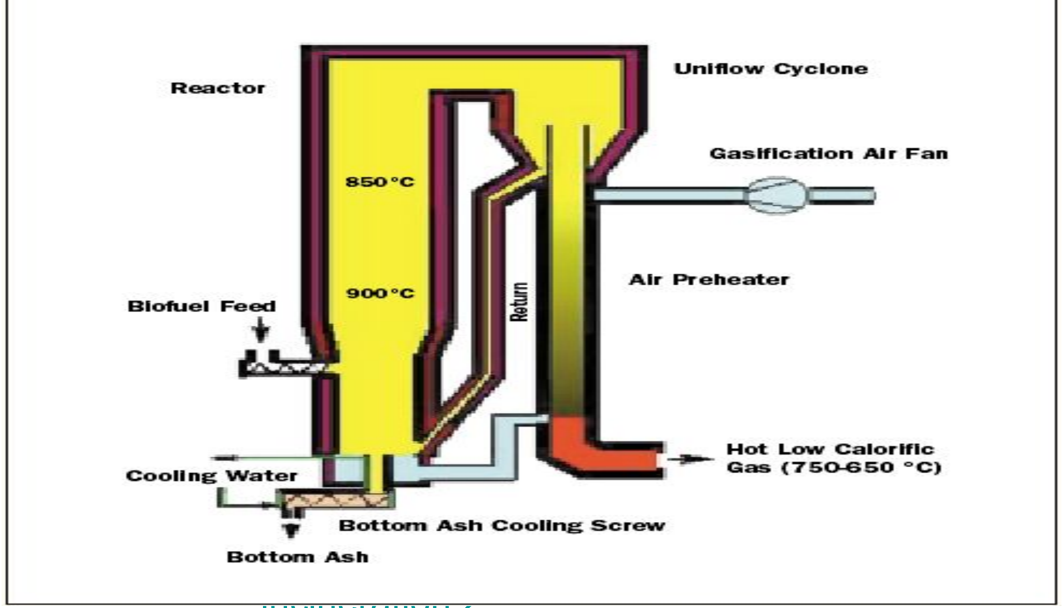


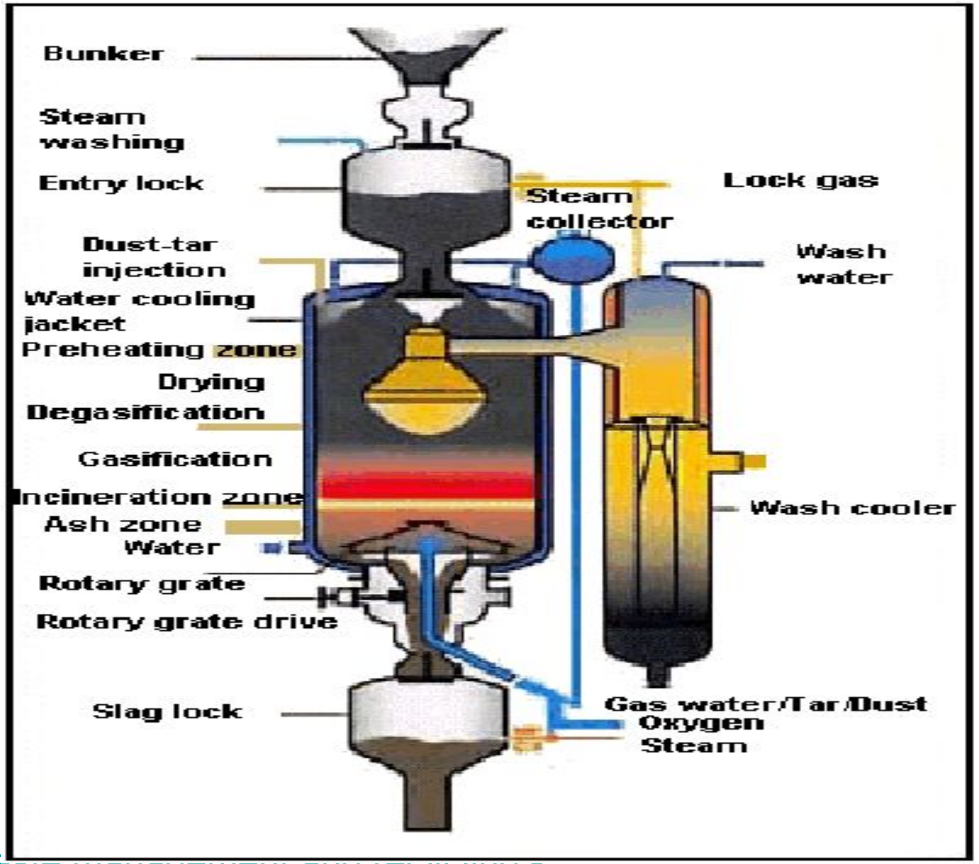
FIGURE 1
Foster Wheeler Atmospheric Gasifier Train

Gasification (cont

Pressurised gasification (BREF, 2003)

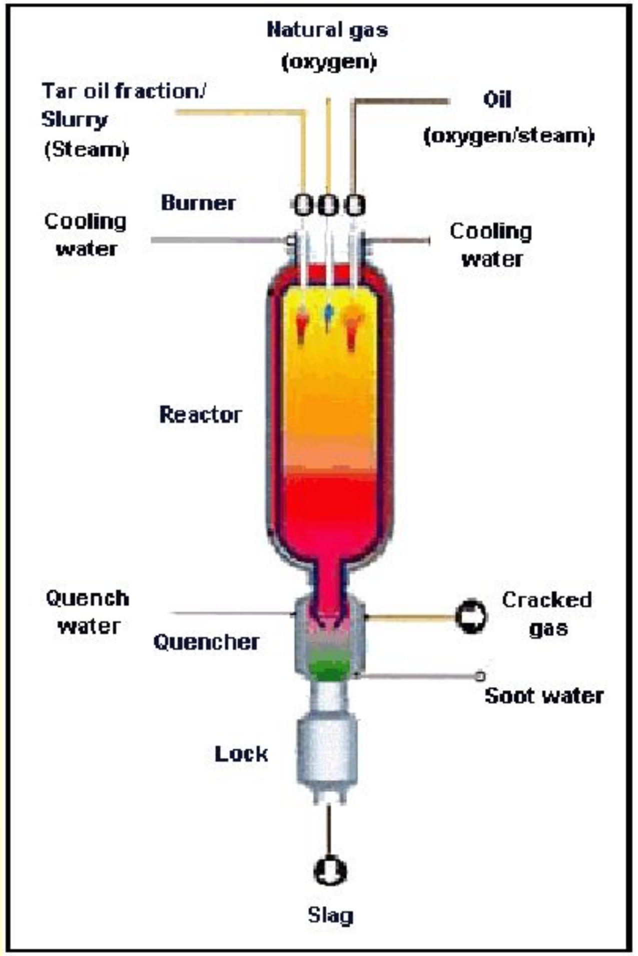
Coal-waste mixture (even 80% waste)

- waste mainly: plastics, dried sludge, polluted soil
- 800 – 1300 ^{o}C; 25 bar
- gasification agent = water vapour and oxygen

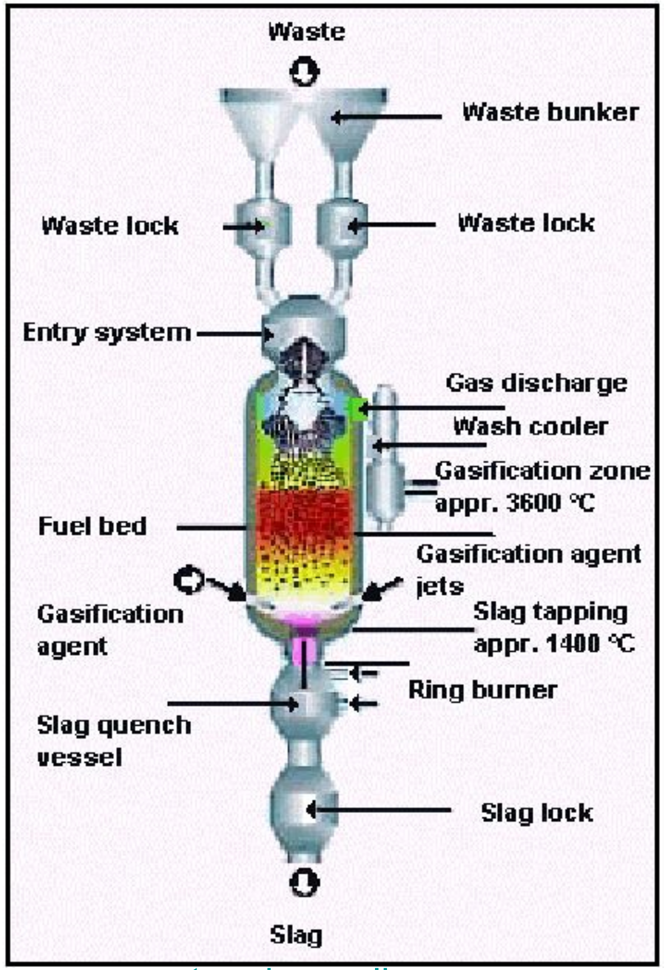


Gasification Figures (cont)

Concurrent gasifier (BREF, 2003)



German concurrent gasifier for gasifying liquid hazardous wastes; 1995- (BREF, 2003)



Gasification (cont)

Benefits

- gasification enables also low quality, wet fuel use in energy production
- synthesis gas recovery as material and energy
- less waste water from flue gas cleaning
- less waste than in incineration
    - solid wastes slag
- higher recovery rate of materials
- can be combined with more efficient energy recovery methods (gas turbines, IGCC, fuel cells…)
- smaller volumes of gas and equipment (pressurised gasification)
- incineration plant can be small
    - smaller flue gas ducts (chimneys)
- image: ”green”, clean energy
- for part of plants: cheaper electricity and heat
- ”green tariff” due to Kioto and emission trade

Gasification (cont)

Negative features

- new processes uncertainty in use??

Assumptions on waste incineration in general

- dioxin and heavy metal emissions are high
- **evaluated in Sweden**
  - Dioxins in 1988 90 g – nowadays 3 g, out of which 5-6% from waste incineration
  - Metal emissions reduced to fraction and waste incineration increased by 35%

Lecture 8:
Hazardous waste

Is the list definite?

- If a material is listed in the list of hazardous wastes
  - It can be classified as non-hazardous if it has none of the listed dangerous properties
- If a material is not listed in the list of hazardous wastes
  - It can be classified as hazardous if it has even one of the listed dangerous properties

http://ec.europa.eu/environment/waste/index.htm (general waste info)

http://www.environment-agency.gov.uk/business/topics/waste/32180.aspx (classification)

- In companies, records have to be kept and stored for any operations dealing with hazardous waste (collection, transport)
  - quantity, nature and origin of hazardous waste
  - transport and treatment method foreseen
- Directive 2008/98/EC provides additional obligations for labeling, record keeping, monitoring and control from the "cradle to the grave", i.e., from the waste producer to the final disposal or recovery.

Types of hazardous waste

- Solid wastes
- Liquid wastes
- Chemicals

- Industrial wastes
  - Well known; in environmental permits
  - Mainly taken to and treated by hazardous waste companies
  - Some can be treated in industrial plants
- Examples of typical industrial hazardous wastes
  - metal refineries waste
  - chemical industry waste
  - waste oils (not edible oils!)
  - waste from thermal processes
  - solvents

Treatment, main aspects

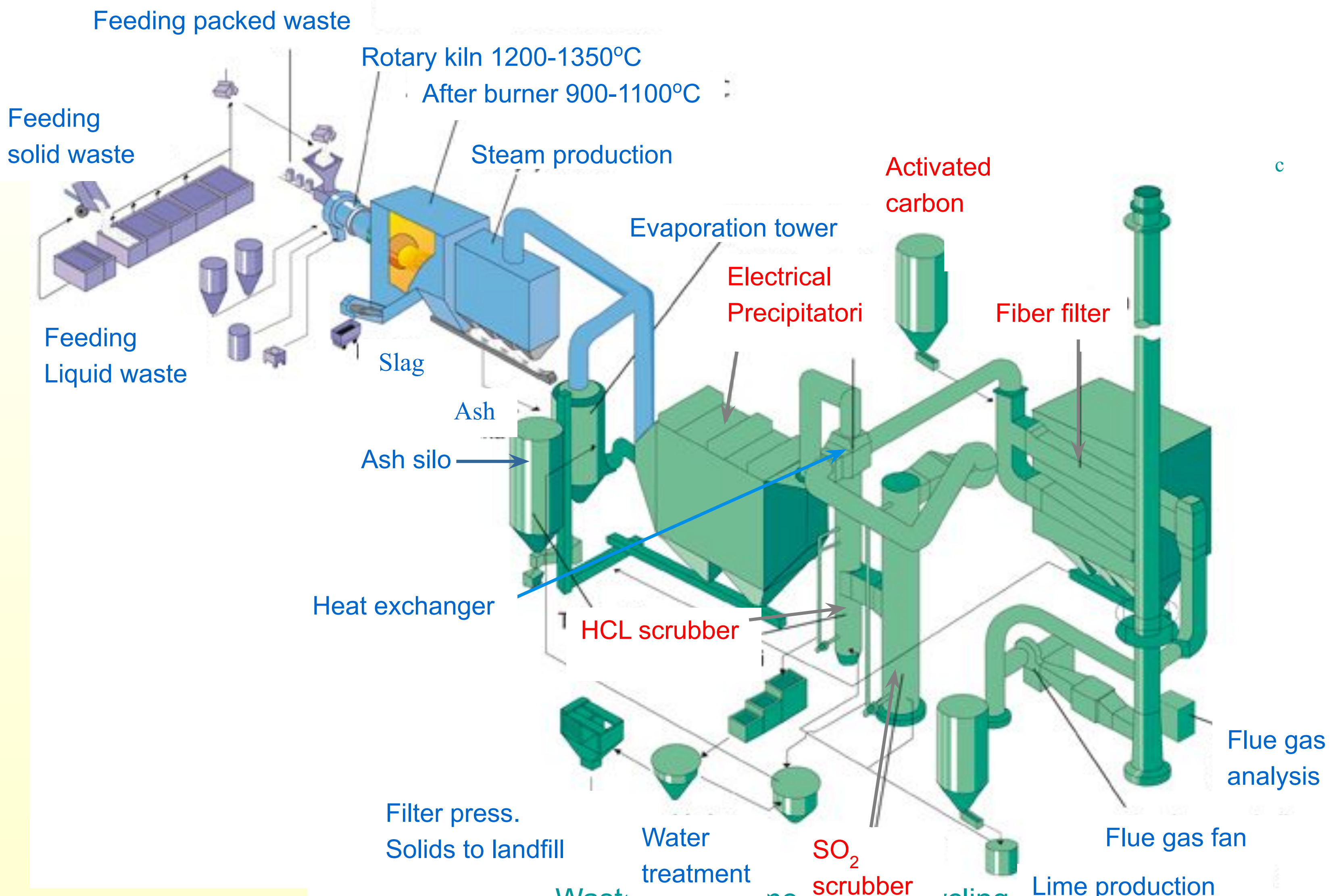
- Sorted and labelled waste
- Waste to energy
- Thermal treatment
- Physico-chemical treatment
- Biological treatment
- Material recovery
- Special treatments
- Final disposal

1 High temperature incineration

Process units at Ekokem

- The core unit is a 12-metre rotary kiln
  - 1 300°C (Directive 2000/76/EU For Hazardous waste >1100 °C for 2 s)
  - Long delay time in kiln and after-burn complete decomposition and burning
  - Energy is recovered electricity and district heat
  - The slag can be used e.g. in soil construction
  - Flue gases are cleaned
    - Cooling
    - Acid gases washing by lime
    - Particle removal by electrostatic precipitator
    - Gaseous emissions: further scrubbing
    - Dioxine and mercury removal by activated charcoal
- At Riihimäki, the energy produced comparable to 43 milj. m^3 natural gas.

High temperature incineration of hazardous waste

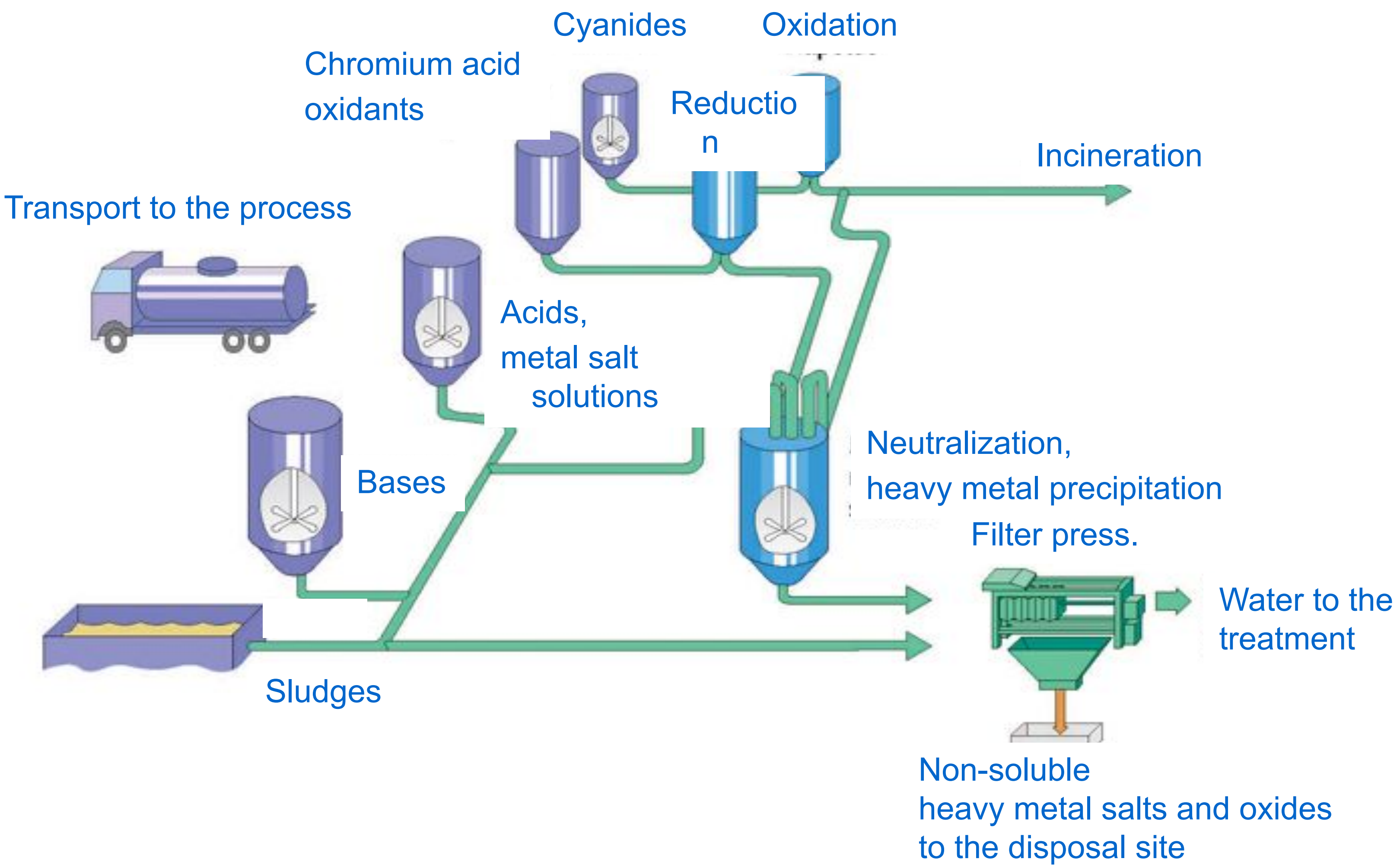


4 Physico- chemical processes

- Inorganic wastes, such as acids, bases and heavy metal containing liquids are made chemically safe
- Main methods
  - Neutralization of acid and bases
  - Precipitation of heavy metals
    - The remaining water is purified for use in processes
  - Oxidation and reduction reactions

- Notice: one type of waste can be used for processing another type of waste
  - Acid + base
  - Precipitating media

Physico-chemical processes



Lecture 9:
Life cycle assessment

10 Life Cycle Assessment = LCA

- Various names
  - *Life cycle analysis, LCA*
  - *Life cycle inventory, LCI*
  - *Also: material flow analysis, eco-balancing, cradle to grave analysis, LCIA: life cycle impact assessment (ecological dimensions), SLCC: Social life cycle costs….*
- A study of a product's, service's or particular action's environmental effects deriving from the whole life cycle of the product
- Includes
  - the indirect effects and emissions, for e.g. a car
    - manufacturing process of a car, extraction of raw materials, final disposal
  - operational stage (which would in a car's case include fuel consumption, tyres, lubrication, repair parts etc.)
- LCA does not take economical or social aspects into consideration??
  - The economists use similar LCC (life cycle costs); SLCC

Life Cycle Assessment = LCA

- Main idea – think of *a product*
  - *Materials needed to produce the product*
  - *Energy needed to produce the product*
  - *Transportation to end users*
  - *Use of the product*
    - *Need of energy during the use*
    - *Need of maintenance (e.g. paint)*
  - *Discarding the product*
- *Calculate for all stages above*
  - *all materials, energy and emissions*
  - *environmental impacts (global warming, air pollution, water pollution, environmental health consequences…)*
- *Have this all in numbers to be able to compare two products*

LCA, what is it for?

Companies

- Cleaner processes with good cost efficiency
- Benchmarking of processes
- Comparison of products
- Product declarations
- Marketing, spreading fact based information
- Focusing research and development actions
- Strategic management
- Defining the life cycle costs

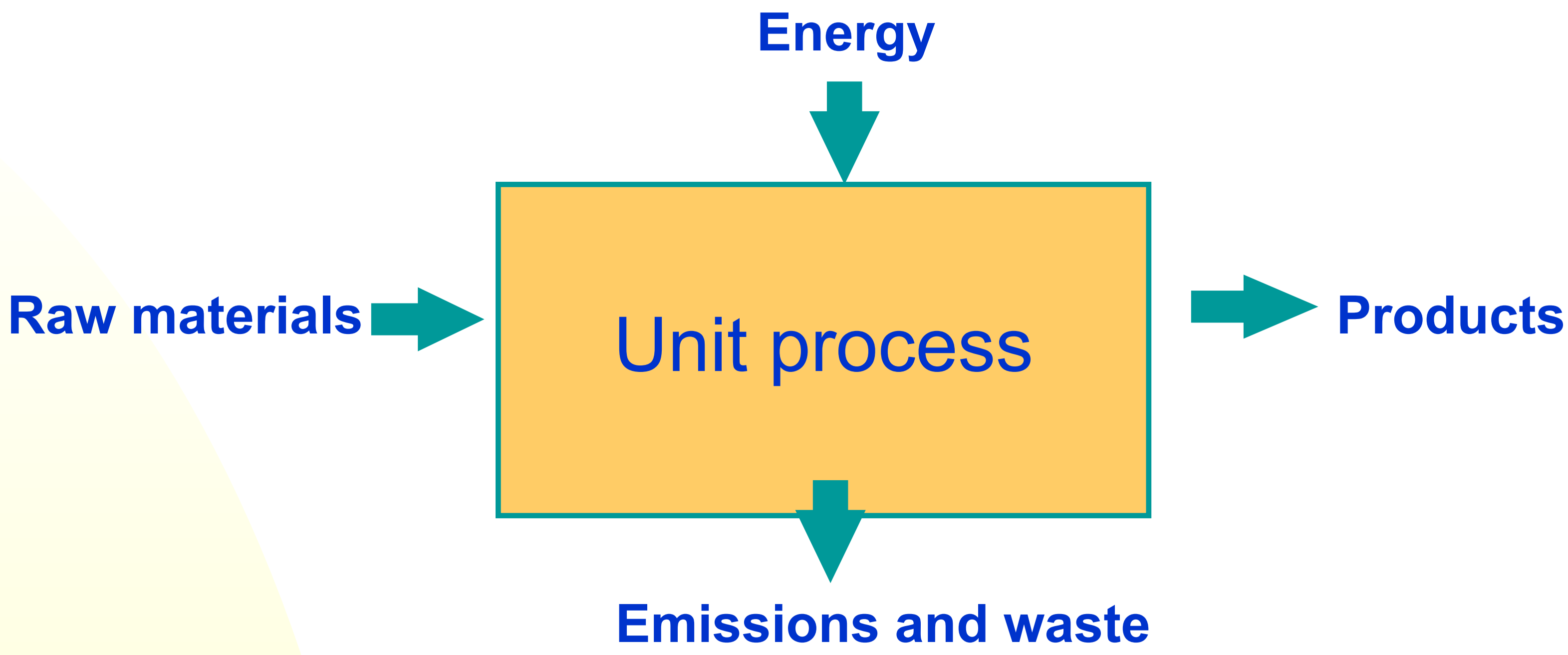
  (LCC=life cycle costs)

Politics/decision makers

- Sanctions and support mechanisms based on environmental performance
- Product policies
- Waste management policies
- BAT = best available technology
- Criteria for environmental labeling…
- Focusing rresources to the right places
- Etc. Etc.

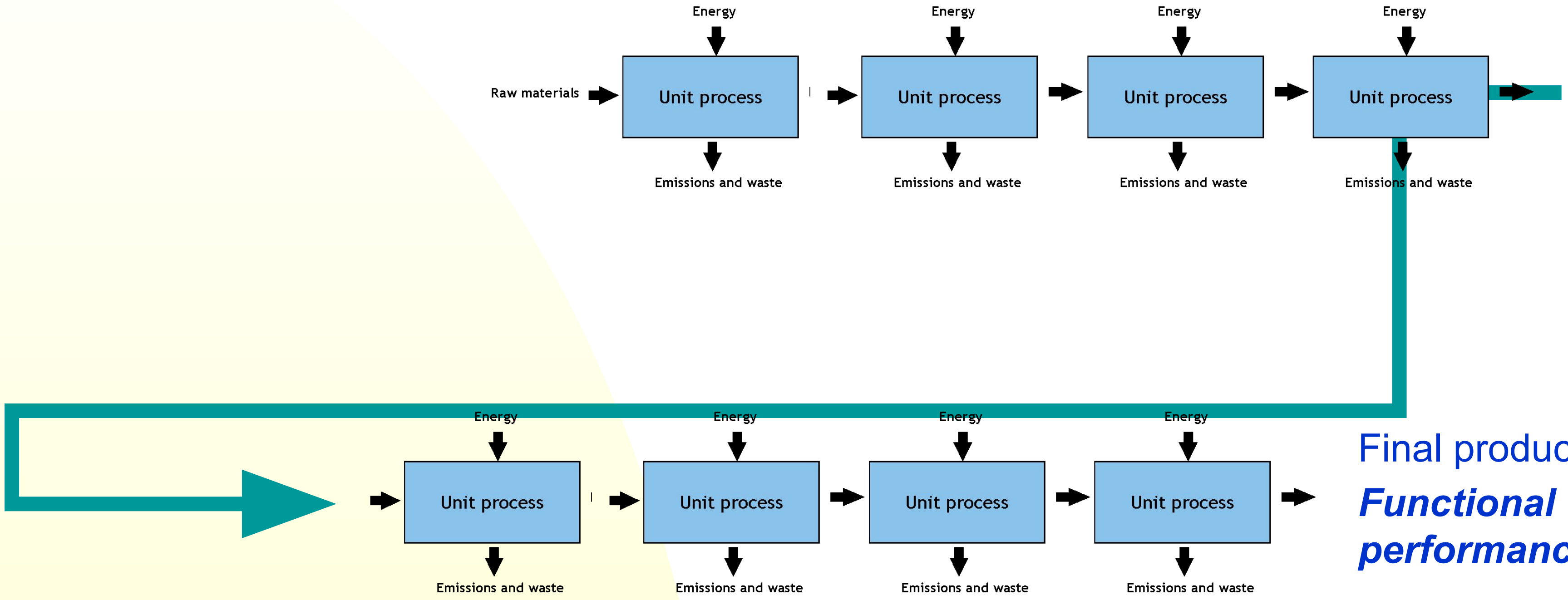
- ***Public?***
  - Carbon footprints
  - Car's CO_2 emissions
  - Etc.

Unit process



A unit process can be e.g.:
- raising a temperature of a room of 9m³ from 19°C to 20°C
- transporting waste in a waste truck with average speed of 50 km/h on a regional paved road, 1 kg * 1 km

A system is made up of several unit processes and leads to a desired outcome, which is called a functional unit.



Final product is

Functional unit= the quantitative performance of a system

A functional unit can be e.g.:

- Keeping the temperature of a room of 9m³ in a steady 20°C temperature for 30 years in Mikkeli
- The waste management of a 4 person family for one year

Emissions are often calculated per functional unit such as

- 1 kg of packaging material / 1 kg of fuel consumed
- 1 km of transport with a vehicle

Different emissions cause different things in our environment

Impact assessment deals with this topic, examples:

Categorizing the outputs in relation to the possible effects that they cause

Environmental effect, taking into account the magnitude of impacts (characterisation factors)

Total assessment,
-getting one score for all
-different methods
-requires evaluation of what effects are seen as important

SO_2, HCl, NO_x → Climate change

NO_x, P, NH_3 → Eutrophication

CO_2, CH_4, N_2O → Acidification

Etc.etc.

→ Index/result

NOTE:
Often the studies present the results separately for each impact category (or only one category such as Climate change potential)

Impact assessment methods - Midpoint

- Methods are either Midpoint or Endpoint methods.
- Midpoint is the preferred way according to ISO standard
- Midpoint methods include:
  - Resource use (raw materials, land, energy)
  - Health effects
  - Ecological effects

- The environmental effect indicators should present the results with
  - only a reasonable amount of uncertainty
  - in a form that is usable for the interest groups
- Middlepoint methods leads to the fact that the results may be given in many different units
- This can make it difficult to analyse which effect is the most important in the total system.

Impact assessment methods - Midpoint cont.

Midpoint-oriented methods place indicators relatively close to the interventions

Example:

- Global Warming Potential (GWP) is not expressed in temperature change in the atmosphere (this would be ”quite” difficult), but it is expressed in e.g. CO_2-equivalents
    - Different emissions are valued to the same global warming potential scale with CO_2 by characterisation factors (eg methane’s factor is 21 or 25 depending on the method)
    - Characterisation of emissions by their actual effects is difficult, especially for human health effects or ecotoxicity
    - http://www.waterfootprint.org/?page=files/home

Impact assessment methods – Endpoint or damage oriented

- **Endpoint or damage oriented methods** take a step further than midpoint methods
- Endpoint methods present results in the following categories:
  - Resource extraction
  - Human health
  - Ecosystem quality

- Endpoint= the negative phenomena in the environment, human health or natural resources that can be linked to a ceartain emission that causes it

- E.g. climate warming will cause problems for human health

  Human heath is the endpoint

  Emissions that cause the damage to human health are middlepoints.
- In real world, the characterisation factors for certain emissions vary according to the surrounding environment. Global effects are however different: Climate change and ozone layer depletion are truly global problems, it does not matter where you produce the emissions