SOLID WASTE MANAGEMENT

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INTRODUCTION, NOTIONS

Definitions from Article 3 of DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on waste

- 1. 'Waste': any substance or object that the holder:
  - discards;
  - intends to discard;
  - must discard.

- 9. 'Waste Management': the collection, transport, recovery and disposal of waste, including the supervision of such operations and the aftercare of disposal sites. It is an important area of "Sustainable Development (SD)"

- SUSTAINABLE DEVELOPMENT (by Brundtland Commission, report ("Our common future") published in 1987)

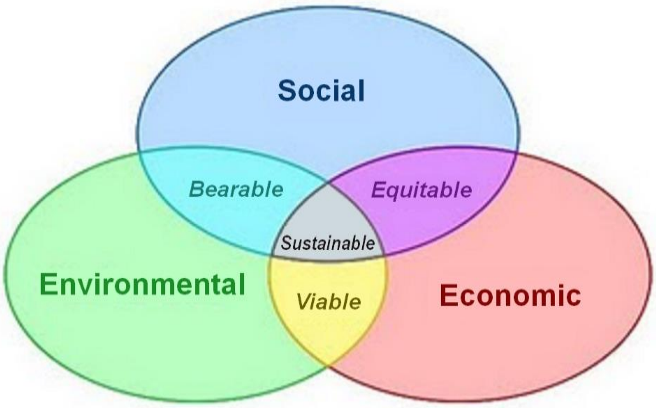
  "Development that meets the needs of present without compromising the ability of future generations to meet their own needs".

- *Parts of sustainable development*

  - Environmental sustainability
  - Economic
  - Social
  - (Cultural Diversity).

  Unsustainable situation*:* the natural capital is used faster than it can be replenished."

  Natural capital: sum of all natural resources.



UN SD Goal 12: *Responsible consumption and production*

"Ensure sustainable consumption and production patterns."

The targets of Goal 12 include using eco-friendly production methods and reducing the amount of waste. By 2030, national recycling rates should increase, as measured in tons of material recycled.

Further definitions:

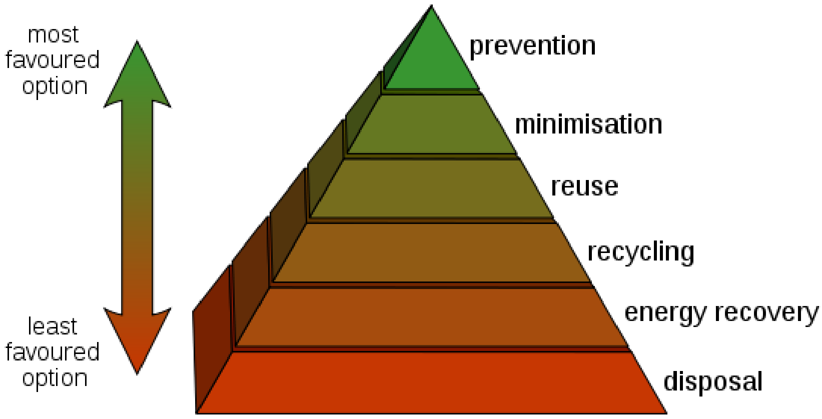
12. 'Prevention': measures taken *before* a substance, material or product has become waste, that reduce:
    (a) the *quantity of waste*, including through the re-use of products or the extension of the life span of products;
    (b) the *adverse impacts* of the generated waste *on the environment and human health*; or
    (c) the *content of harmful substances* in materials and products;
13. 'Re-use': any operation by which products or components that are not waste are used again *for the same purpose* for which they were conceived;
14. 'Treatment': *recovery or disposal* operations, including *preparation* prior to recovery or disposal;
15. 'Recovery': any operation the principal result of which is *waste serving a useful purpose by replacing other materials* which would otherwise have been used to fulfil a particular function, or *waste being prepared* to fulfil that function...
16. 'Preparing for re-use': *checking, cleaning or repairing* recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing;
17. 'Recycling'*: any recovery operation* by which waste materials are reprocessed into products, materials or substances whether *for the original or other purposes*. It includes the reprocessing of organic material but *does **not** include energy recovery*

and the reprocessing into materials that are to be used as *fuels* or for *backfilling* operations;

19. 'Disposal': *any operation which is not recovery* even where the operation has as a secondary consequence the reclamation of substances or energy. List of disposal operations in Annex I;

Waste Management Hierarchy

Classical diagram:



New hierarchy in the EU:

Prevention: minimisation of waste generation, hazard reduction, reuse

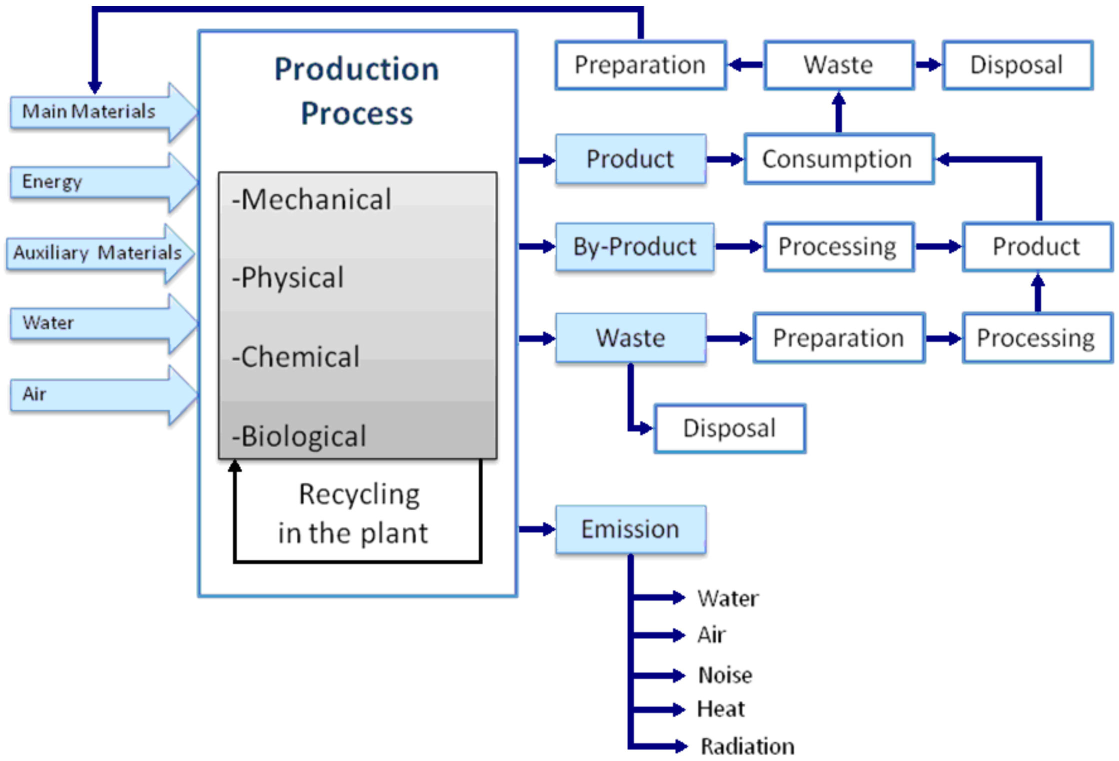
Preparing for reuse: repair, cleaning, disassemble

Recycling: material recovery, raw material production

Other recovery: energy recovery, fuel

Disposal: incineration, landfill

Material Cycle Producing Waste:



Municipal Solid Waste

Urban Solid Waste

- It includes predominantly household waste (domestic waste).
- With sometimes the addition of commercial waste.
- Collected by a municipality within a given area.
- Either solid or semisolid (sludgy, pasty) form.

Residual Waste

Waste left from household sources containing materials that cannot be separated out or sent for reprocessing.

Categories of Municipal Solid Waste

1) Biodegradable Waste: food and kitchen waste, green waste, paper (paper can also be recycled).
2) Recyclable Material: paper, glass, bottles, cans, metals, certain plastics.
3) Inert Wastes: construction and demolition wastes, dirt, rocks.

4) Composite Waste: waste clothing, tetra packs, waste plastics (toys).
5) Domestic hazardous & toxic wastes: batteries, electric and electronic waste, paints, chemicals, spray cans, fertilizer, and pesticide containers.

Composition of the Municipal Solid Waste stream at USA (%)

TYPE	1986	2000
Paper	37.5	38.1
Yard waste	17.9	14.8
Plastics	8.3	11.2
Metals	8.3	7.7
Food waste	6.7	5.9
Glass	6.7	6.1
Wood	6.3	7.2
Other	8.3	9.0

The quantity and quality of MSW depends strongly on the living standard.

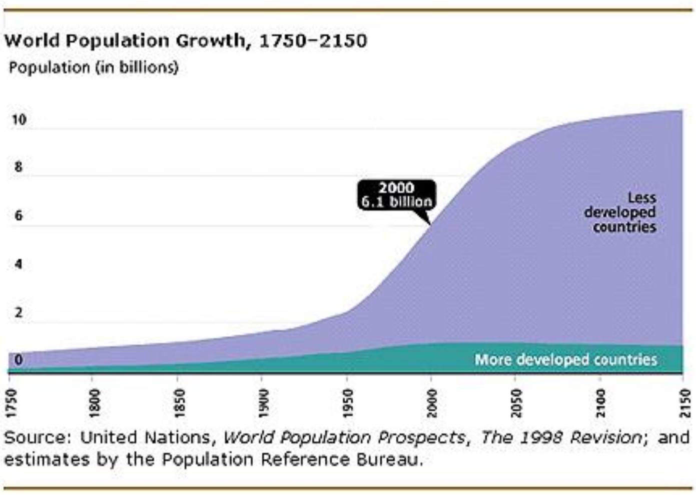
kg/capita/day (1988)	NYC	Budapest	Nigeria (Small Town)
	1.8	1.1	0.46

The greatest landfill for MSW in the world was the Fresh Kill Landfill in NYC (Staten Island, closed in 1986, temporarily open after Sept. 11 attacks):

-3706 acres, 15,000 tons/day, 150 methane wells, 10^6 gallon/day leachate treated

World Population Growth

Billion	Year
1	1800
2	1930
3	1960
4	1975
5	1987
6	2000



Trends in Municipal Solid Waste Management

Generation

The world generates 2.01 billion tonnes of municipal solid waste (MSW) annually.

At least 33 percent of that is not managed in an environmentally safe manner.

Worldwide, daily average: 0.74 kg/person

Generation ranges from 0.11 to 4.54 kg/person/day. High-income countries generate about 34 percent of the world's waste though they only account for 16 percent of the world's population,

Forecast, trends

Global waste is expected to grow to 3.40 billion tonnes by 2050, *more than double population growth* over the same period.

Daily per capita waste generation in

-high-income countries is projected to increase by 19 percent by 2050,

-low- and middle-income countries an increase of 40% or more is expected.

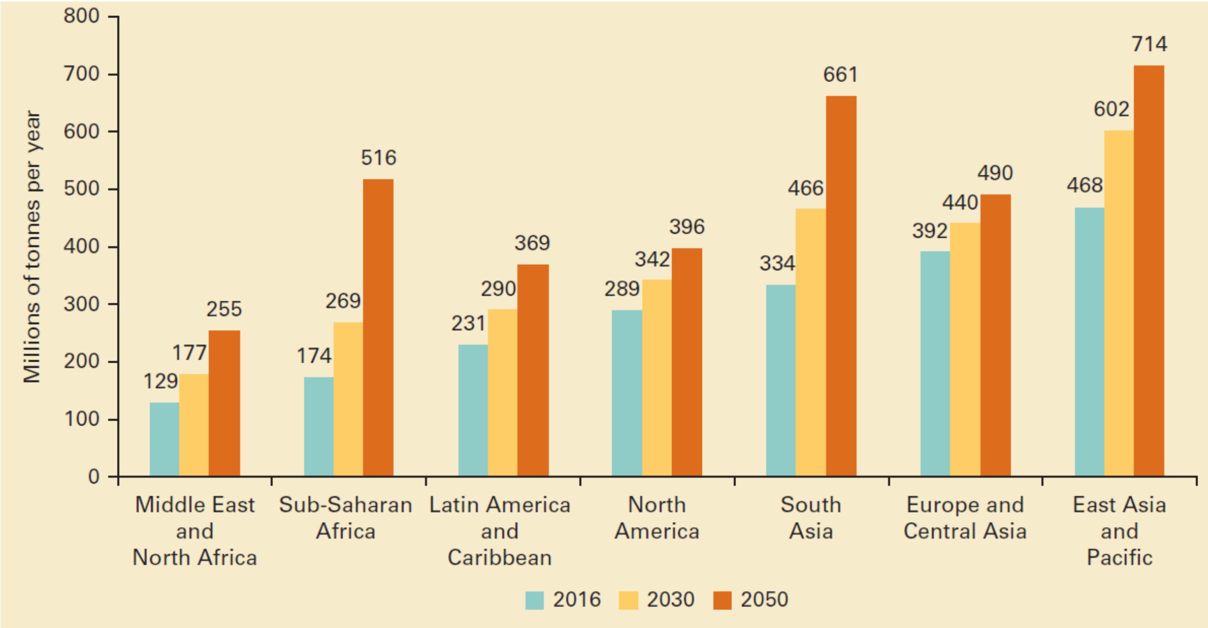
The *total quantity* of waste generated in low-income countries is expected to increase by more than three times by 2050.

Generation by regions

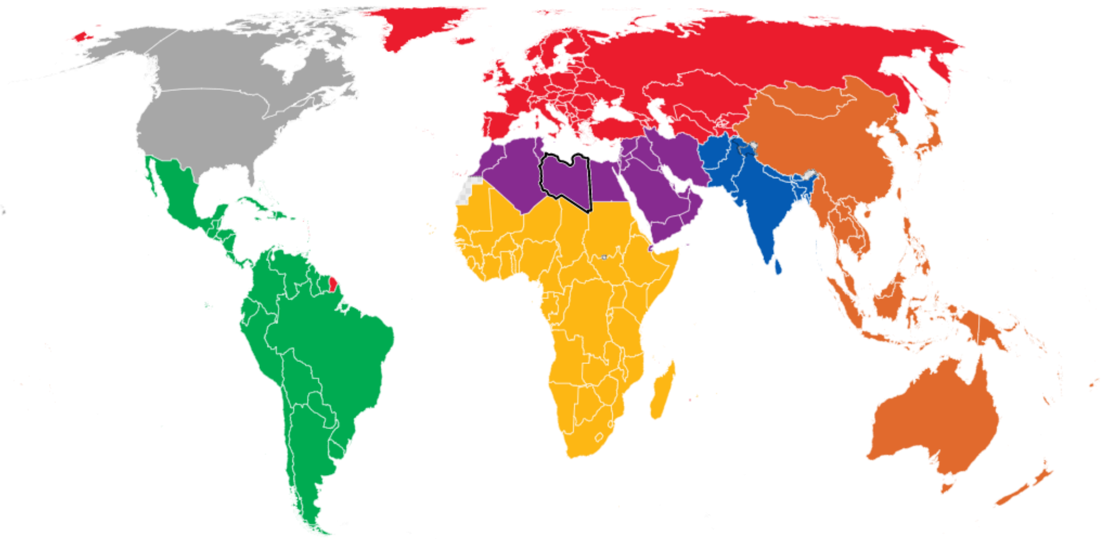
The East Asia and Pacific regions are generating *most of the world's waste*, at 23 percent, and the Middle East and North Africa region is producing the least in absolute terms, at 6 percent.

However, the *fastest growing regions* are Sub-Saharan Africa, South Asia, and the Middle East and North Africa, where, by 2050, total waste generation is expected to more than triple, double, and double respectively. In these regions, *more than half of waste is currently openly dumped*, and the waste growth will have vast implications for the environment, health, and prosperity.

Projected waste generation, by region (millions of tonnes/year)



https://datatopics.worldbank.org/world-development-indicators/the-world-by-income-and-region.html



The world by regions

Waste collection

Waste collection is a critical step in managing waste.

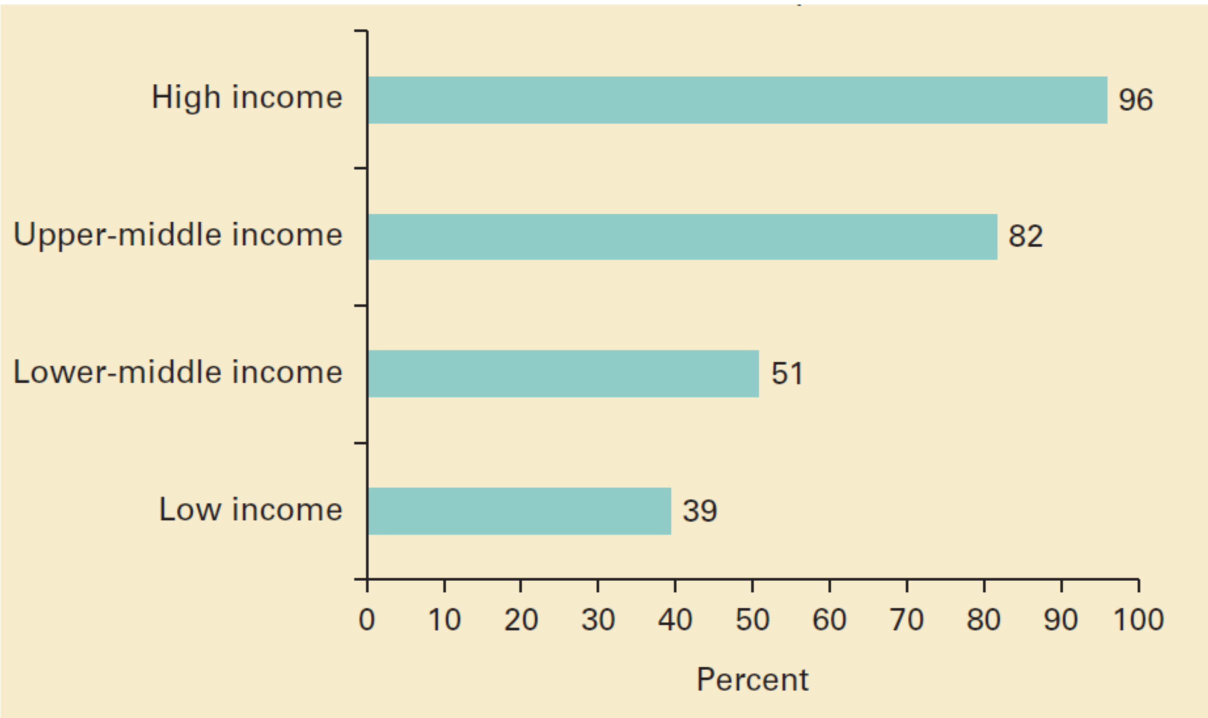
Rates vary largely by income levels.

Upper-middle- and high-income countries provide nearly universal waste collection.

Low-income countries collect about 48 percent of waste in cities, but this proportion drops drastically to 26 percent outside of urban areas.

Across regions, Sub-Saharan Africa collects about 44 percent of waste while Europe and Central Asia and North America collect at least 90 percent of waste.

Waste collection rates, by income level (percent)

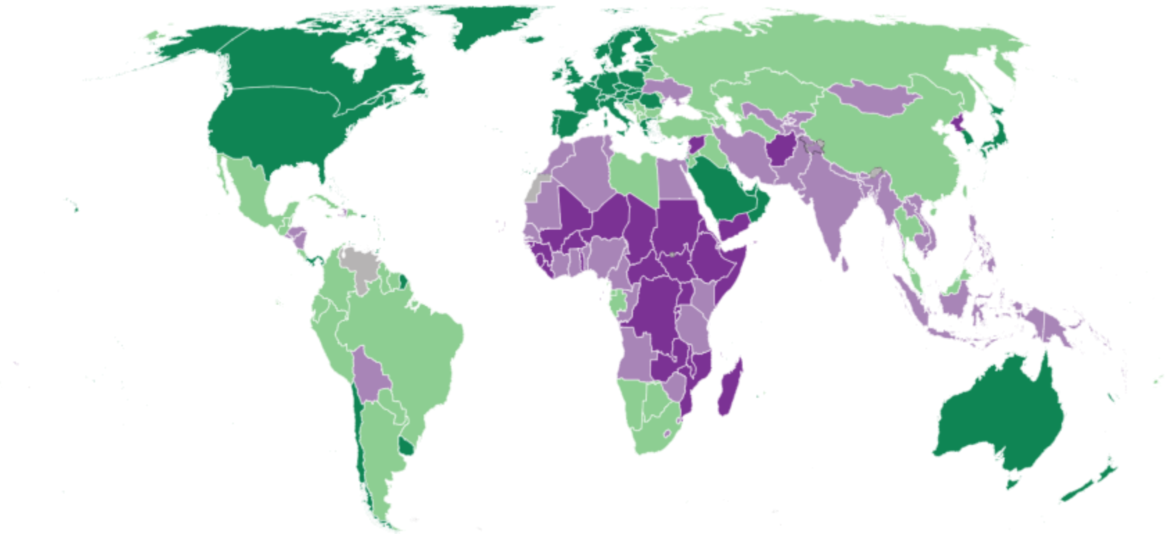


Groups by genaral national income (GNI) levels (USD/year/capita)

Group	July 1, 2021 (new)	July 1, 2020 (old)
Low income	<1,045	<1,035
Lower-middle income	1,046 – 4,095	1,035 – 4,045
Upper-middle income	4,096 -12,695	4,046 -12,535
High income	> 12,695	> 12,535

Factors influencing the GNI per capita of the countries:

economic growth, inflation, exchange rates and population growth.



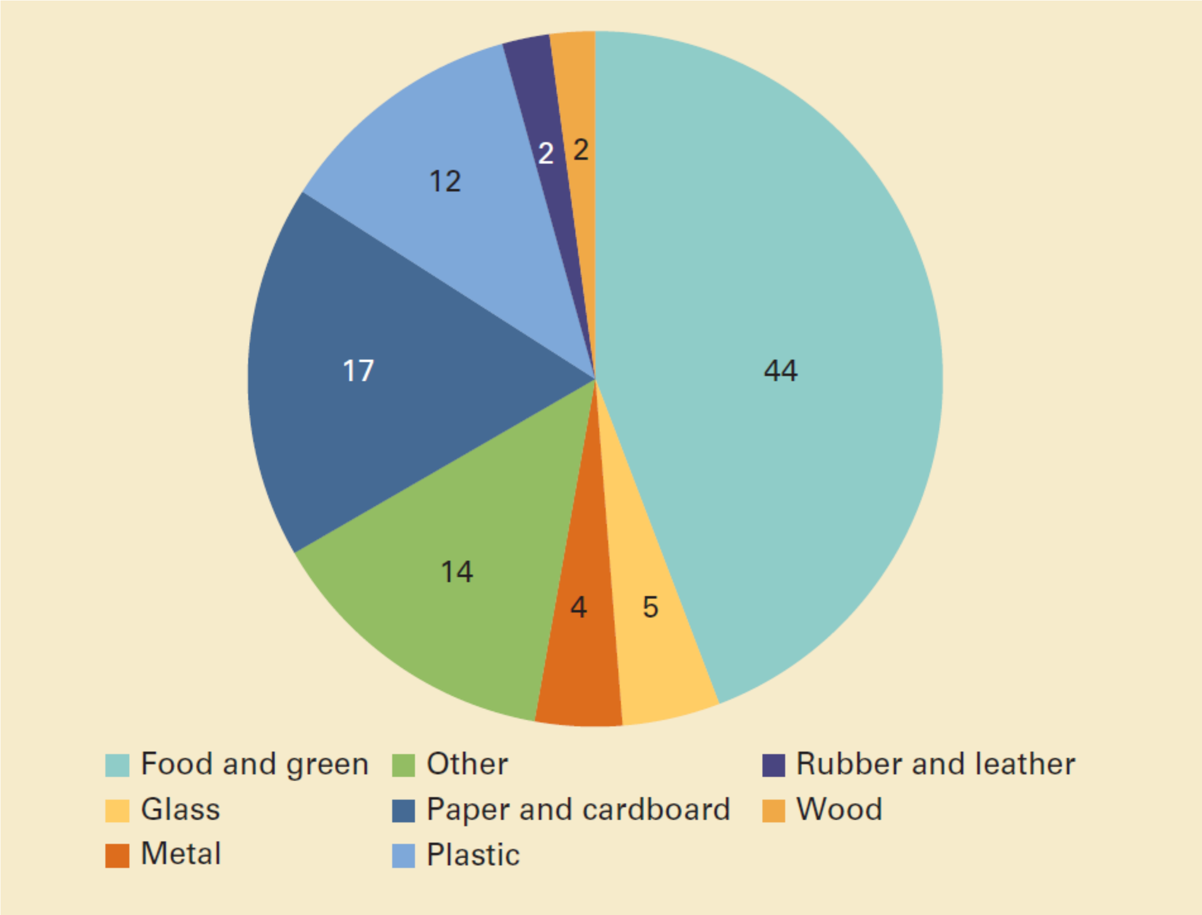
The world by income (2021)

Hungary: 1987: 3700 2020: 16 500 („high income”)

The world by property level (in USD)

Waste composition

Global waste composition (percent)



Waste composition *differs across income levels*, reflecting varied patterns of consumption.

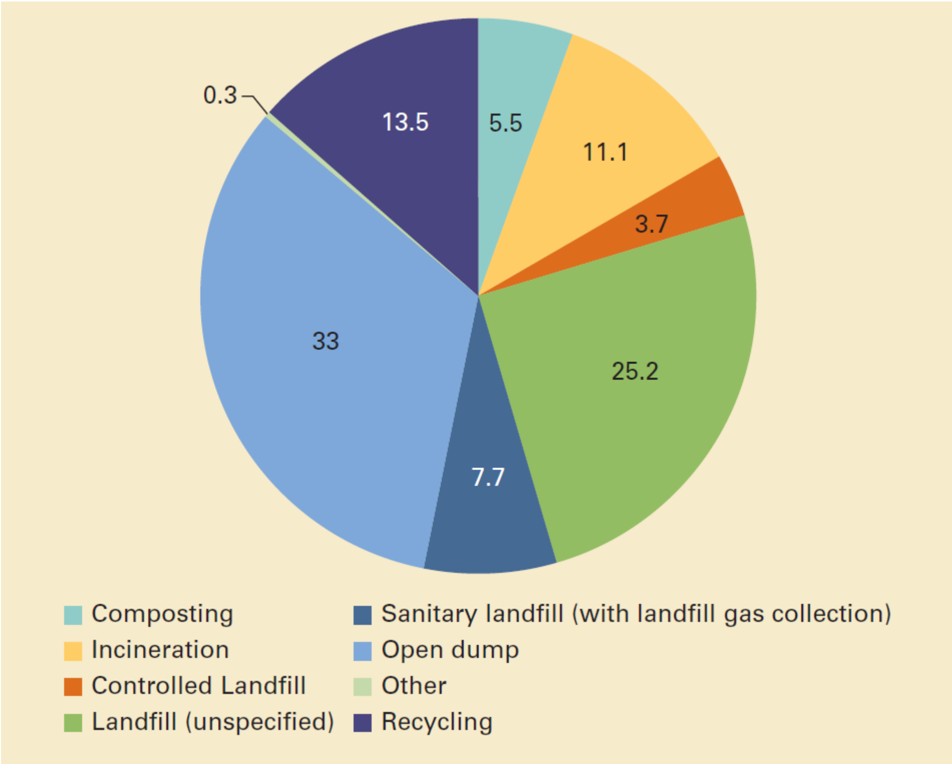
High-income countries generate relatively less food and green waste, at 32 percent of total waste, and generate more *dry waste* that could be recycled, including plastic, paper, cardboard, metal, and glass, which account for 51 percent of waste.

Middle- and low-income countries generate 53 percent and 57 percent food and green waste, respectively, with the fraction of organic waste increasing as economic development levels decrease. In low-income countries, materials that could be recycled account for only 20 percent of the waste stream.

Across regions, there is not much variety within waste streams beyond those aligned with income. All regions generate about 50 percent or more organic waste, on average, except for Europe and Central Asia and North America, which generate higher portions of dry waste.

Treatment and disposal

Global treatment and disposal of waste (percent)



Globally, most waste is currently dumped or disposed of in some form of a *landfill*. Some 37 percent of waste is disposed of in some form of a landfill, 8 percent of which is disposed of in sanitary landfills with landfill gas collection systems.

Open dumping accounts for about 33 percent of waste, 19 percent is recovered through recycling and composting, and 11 percent is incinerated for final disposal.

Adequate waste disposal or treatment, such as controlled landfills or more stringently operated facilities, is almost exclusively the domain of high- and upper-middle-income countries.

Lower-income countries generally rely on *open dumping*; 93 percent of waste is dumped in low-income countries and only 2 percent in high-income countries. Three regions openly dump more than half of their waste—the Middle East and North Africa, Sub-Saharan Africa, and South Asia.

Upper-middle-income countries have the highest percentage of waste in *landfills*, at 54 percent. This rate decreases in *high-income countries* to 39 percent, with diversion of 36 percent of waste to recycling and composting and 22 percent to incineration. Incineration is used primarily in high-capacity, high-income, and land-constrained countries.

CO2 emission

It is estimated that 1.6 billion tonnes of carbon dioxide (CO_2) equivalent greenhouse gas emissions were generated *from solid waste treatment and disposal* in 2016, or *5 percent of global emissions*. This is driven primarily by disposing of waste in open dumps and landfills without landfill gas collection systems. Food waste accounts for nearly 50% of emissions.

Solid waste–related emissions are anticipated to increase to 2.38 billion tonnes of CO_2-equivalent per year by 2050 if no improvements are made in the sector.

Responsibilities

In most countries, solid waste management operations are typically a local responsibility, and nearly 70 percent of countries have established institutions with responsibility for policy development and regulatory oversight in the waste sector. At least half of services, from primary waste collection through treatment and disposal, are operated by public entities and about one-third involve a public-private partnership.

Costs, financing

In high-income countries, operating costs for integrated waste management, including collection, transport, treatment, and disposal, generally exceed $100 per tonne.

Lower-income countries spend less on waste operations in absolute terms, with costs of about $35 per tonne and sometimes higher, but these countries experience much more difficulty in recovering costs.

Waste management is labour intensive, and costs of transportation alone are in the range of $20–$50 per tonne.

Cost recovery for waste services differs drastically across income levels. *User fees* range from an average of $35 per year in low-income countries to $170 per year in high-income countries, with full or nearly full cost recovery being largely limited to high-income countries. *User fee models* may be fixed, or variable based on the type of user being billed. Typically, local governments cover about 50 percent of *investment costs* for waste systems, and the remainder comes mainly from national government subsidies and the private sector.

Hazardous Wastes

Council Directive of 12 December 1991 on hazardous waste (91 / 689 /EEC), Annex III

PROPERTIES OF WASTES WHICH RENDER THEM HAZARDOUS

H1 'Explosive': substances and preparations which may *explode* under the effect of flame, or which are more sensitive to shocks or friction than *dinitrobenzene*.

H2 'Oxidizing': substances and preparations which exhibit *highly exothermic reactions* when in contact with other substances, particularly flammable substances.

H3-A 'Highly flammable':

- *liquid* substances and preparations having a *flash point below 21°C* (including extremely flammable liquids), or
- substances and preparations which may become hot and finally *catch fire* in contact with air at ambient temperature without any application of energy, or
- *solid* substances and preparations which may readily catch fire after brief contact with a source of ignition and which continue to burn or to be consumed after removal of the source of ignition, or
- *gaseous* substances and preparations which are flammable in air at normal pressure, or
- substances and preparations which, in contact with water or damp air, evolve highly flammable gases in dangerous quantities.

H3-B 'Flammable': liquid substances and preparations having a *flash point* equal to or *greater than 21°C and less than or equal to 55°C.*

H4 'Irritant': non-corrosive substances and preparations which, through immediate, prolonged, or repeated contact with the skin or mucous membrane, can *cause inflammation*.

H5 'Harmful': substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may involve *limited health risks*.

H6 'Toxic': substances and preparations (including very toxic substances and preparations) which, if they are inhaled or ingested or if they penetrate the skin, may *involve serious, acute, or chronic health risks and even death*.

H7 'Carcinogenic': substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may *induce cancer*, or increase its incidence.

H8 'Corrosive': substances and preparations which may *destroy living tissue* on contacts.

H9 'Infectious': substances containing viable micro-organisms or their toxins which are known or reliably believed to *cause disease in man or other living organisms*.

H10 'Teratogenic': substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may *induce non-hereditary congenital malformations*, or increase their incidence.

H11 'Mutagenic': substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may *induce hereditary genetic defects*, or increase their incidence.

H12 Substances and preparations which *release toxic or very toxic gases* in contact with water, air, or an acid.

H13 Substances and preparations capable by any means, *after disposal*, of yielding another substance, e.g., a *leachate*, which possesses any of the characteristics listed above.

H14 'Ecotoxic': substances and preparations which present or may present immediate or delayed *risks for one or more sectors of the environment*.

They require special treatment. (German name: Sonderabfall)

Basel Convention

The Basel Convention is an international treaty that was designed to reduce the transboundary movements of hazardous waste between nations, and specifically to prevent transfer of hazardous waste from developed to less developed countries.

The Convention was opened for signature on 22 March 1989 and entered into force on 5 May 1992.

Processing and Resource Recovery

1. Thermal Processes

A. Incineration (combustion)	B. Thermal decomposition
- Exothermic process - Organic components → flue gases: gases & water steam - Incombustible inorganic material → slag (bottom ash) and fly ash.	- Endothermic process - Chemical decomposition in oxygen – free (pyrolysis) medium or in medium which is poor in O_2 (gasification).

Incineration (Combustion) of Wastes

Main characteristics of incineration:

- We burn wastes of heterogeneous composition.
- Conditions required:
  - Air in excess: usually by 50 – 150 % more than necessary,
    EU: in the flue gas min. 6 vol% O_2
  - Convenient temperature (T): T_{MIN} = 800-850°C; T_{MAX}=1050 – 1100°C
    - T_{MIN}: each combustible substance has a min. ignition T where in the presence of O_2 the combustion is sustained. Above this T the heat is generated at higher rate than it loses to the surroundings.
    - T_{MAX} is determined by the softening and melting T of the slag if it is not melted.
      (In technologies where the slag is melted T_{MAX} = 1200 - 1700°C).
  - Residence time (at high T)
    - Usually 0.5 – 1h for solid wastes, for gases 2 sec (in the post-combustion chamber)
  - Convenient turbulence (the air must meet the waste)

- Quantity of solid residue
    - Solid Waste: 20 – 40%

      In melted slag technology: 15 – 20%
    - Liquid or sludgy waste: 2 -10%
    - Medical wastes: 8 – 10%

- Characteristics of the waste to be burned:
    - State (of matter): solid/sludgy/liquid
    - Composition by:
        - Proximate analysis (fixed carbon, volatile combustible matter, moisture, ash content)
        - Ultimate analysis (content of C, H, O, N, S)
    - Heating value
    - Density
    - Softening/melting point and characteristics of the ash
    - Particle size, its distribution, maximal size of pieces.
    - Viscosity (in the case of liq. wastes)
    - Ignition temperature
    - Content of halogens, heavy and other metals.
    - Content of toxic materials.
    - Infectivity

Proximate analysis

Determination of fixed carbon, volatile combustible matter, moisture, and ash content of the waste to estimate its capability as a fuel.

-The fixed carbon, volatile combustible matter can be burnt while moisture and ash not. The vaporisation of the moisture consumes heat.

Method of analysis (tests):

1. *Moisture*: Determination from the loss of weight by heating at 105 °C for one hour.
2. *Volatile combustible matter*: the additional loss of weight after ignition at 950 °C in a covered crucible (O_2 is excluded).
3. *Fixed carbon*: combustible residue after the volatile combustible matter is removed; ignition at 600 to 900 °C.
4. *Ash*: the weight of residue after combustion in an open crucible.

% Fixed carbon=100 % - % moisture - % ash- % volatile matter

It does not provide any information of possible pollutants emitted during combustion. These data are determined by ultimate analysis.

Ultimate analysis

Total elemental analysis (percentage of each individual element (C, H, O, N, S) present

It is used

-mainly to characterise the organic fraction of the waste and

-for assessing the suitability of waste as fuel,

-for predicting emissions from combustion,

-for ensuring suitable nutrient ratios (e.g. C/N) for composting.

A chemical formula can be given for the waste, e.g., $C_{655}H_{1029}O_{408}N_{10.1}S$

Heating value

Two heating values: high and low. The high heat of combustion includes the latent heat of vaporisation of water molecules generated during the combustion process.

Ash reduces the heating value (J/kg waste) and retains heat when removed from the furnace (loss of heat).

Even a dry sample of MSW generates moisture (free water) which must be evaporated. The energy demanded can be considerable and may result in an inefficient combustion process.

Density:

Important information for predicting storage volume (in collection truck, in a landfill cell)

It is increased by compaction whose extent can be characterised by the

compaction ratio: $r=V_c/V_0$ and degree of volume reduction $F= (V_0 - V_c)/V_0$

The density of the

- raw uncompacted solid waste: 115-180 kg/m^3 (in USA)
- compacted SW in landfill after compaction: 300-900 kg/m^3

ρ=f(composition, moisture content, physical shape, degree of compaction)

Glass, ceramic, ash, and metals increase it.

Moisture replaces the air occurring in voids and increases □.

Increase of □□

-decreases the cost of collection and hauling (transport),

-by shredding, baling and other size reduction technics (by decrease of irregularity, as well).

Bale: large mass of paper, straw, goods pressed together and tied with rope/wire, ready to be moved.

From MSW balers produce bales of corrugated cardboard, newspaper, high grade and mixed paper, aluminium cans, plastic containers.

Operation of balers can be fully automated or needs significant amount of work of an operator. Most balers are of low force, after the baled product is released, it rebounds to its original form, and it must be tied. Some high-power balers apply sufficient force such that the bale maintains its shape after the force is removed. Bales of aluminium and metal cans hold their form better than those of HDPE containers or old newspapers.

- **Steps of combustion technology**
  - Reception, storage
  - Preparation (e.g., chopping)
  - Feeding
  - Combustion
  - Cooling of flue gases and heat recovery
  - Purification of flue gases
  - Treatment of slag and fly ash

Equipment of Combustion

Classification can be done:

- By the type of combustor: with grate or without grate
- By the aim of the equipment: incinerator or industrial equipment operating at high T (e.g. cement kiln).

- Circumstances of burning
  - Introduction of air in 2 parts
    - Primary (underfire) air supply (ca. 80%):
      through the grates from below for
      - feeding burning of the bulk of waste.
      - cooling the grates
    - Secondary (overfire) air supply (ca. 20%):
      - to burn out perfectly the waste: to burn the particulates, to eliminate CO.
- Criteria for wall (lining) of combustion chambers
  - Mechanical strength
  - Resistance to fire (fire-proof/heat resistant)
  - Resistance to abrasive effects
  - Resistance to chemical effects
  - Materials: fireclay, alundum (artificial corundum)
- Auxiliary burners
  - Fuelled by oil or gas.
  - Aim: stabilization or increase of power
- By the direction of flow of waste and flue gases the equipment can be:
  - Co-current: waste and gases move in the same direction.
    - Disadvantage: Difficult drying and ignition of waste. (Air must be preheated.)
  - Counter-current: waste and flue gases move in the opposite direction.
    - Disadvantage: danger of imperfect burning: one part of the flue gases does not go through the hottest zone.
  - Cross-current (mixed current)

Incinerators with Grate

-For combustion of solid or sludgy wastes

-Moving (or fixed) grate

-Role of the grate:

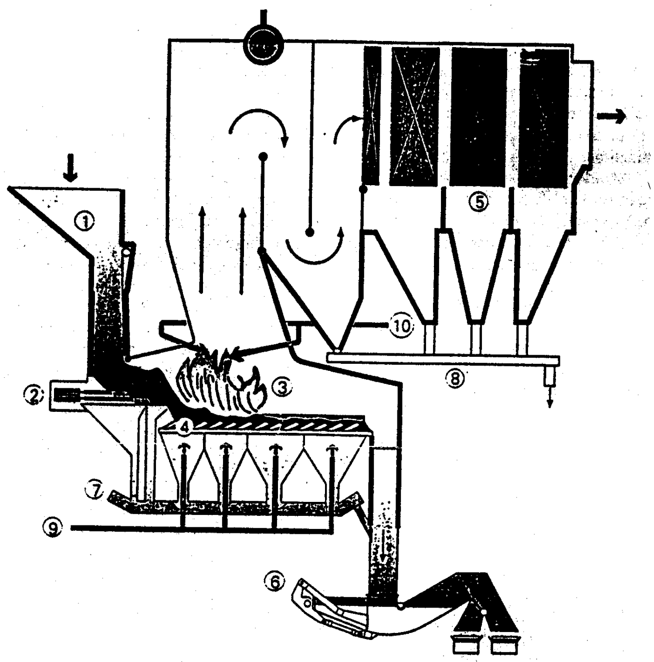
- It holds the waste.
- Ventilation (aeration) of the combustion chamber
- It moves, blends the waste.

-Each grate is turned separately by a separate electromotor

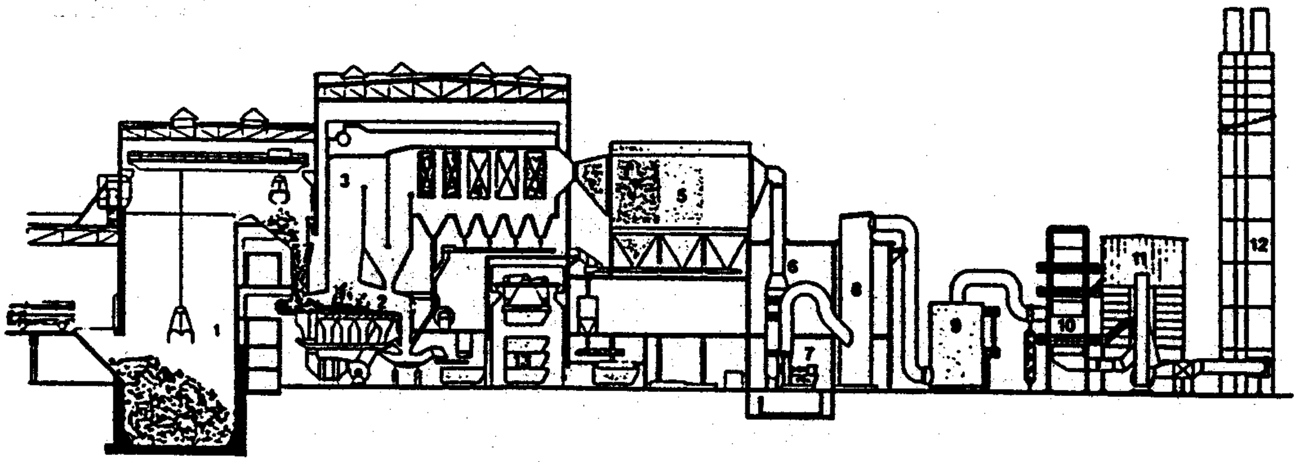
-Max. thermal charge of the grate: 2000 – 4000 MJ/m^2h (to prevent melting of the grate)

-Many moving grates are also cooled with water internally for keeping their mechanical strength.

Simplified scheme of a grate incinerator for combustion of MSW



1. feed hopper (funnel) and refuse shaft 2. feeder 3. combustion chamber 4. combustion grate 5. heat recovery steam generator 6. deslag equipment 7. grate residue removal 8. fly ash transporting system 9. primary air supply 10. secondary air supply



Completed scheme of a traditional MSW incinerator

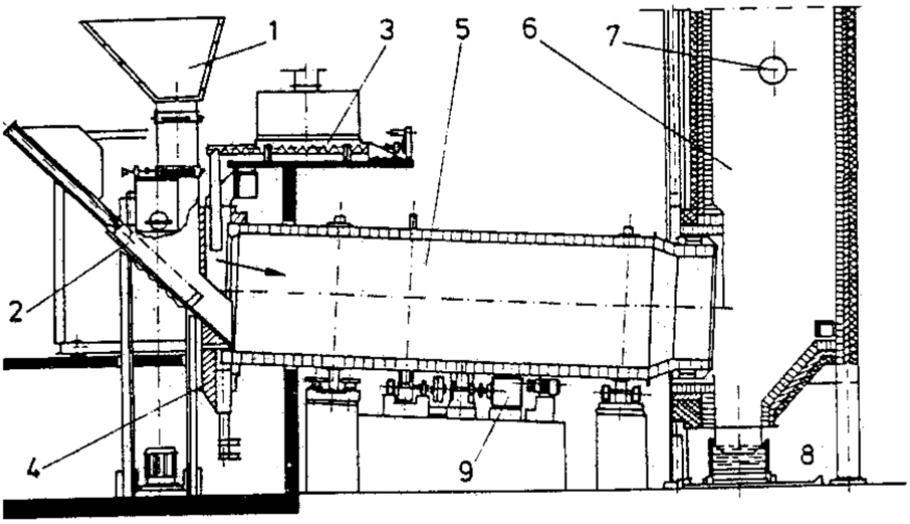
1. refuse barn 2. combustion grate 3. post- combustion chamber 4. steam generator (boiler) 5. electrofilter 6. feed water preheater 7. suction fan 8. flue gas scrubber 9. wet dust separator 10. NO_x reducer 11. dioxin separator 12. stack 13. deslag equipment

Incinerators without Grate

Usually cylindrical form:

The intensity of heat radiation is almost doubled → lower heat loss

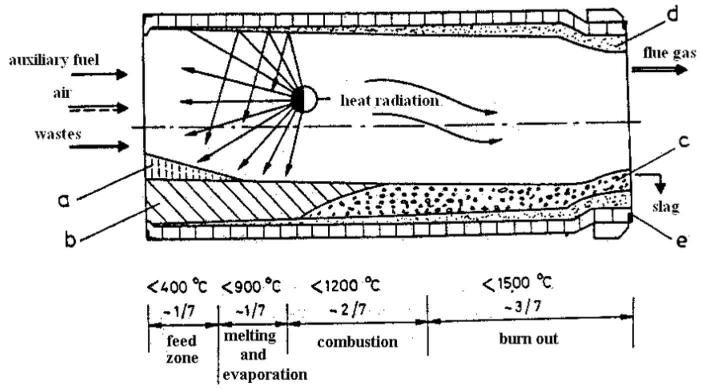
- **Rotary Kiln**



Scheme of a rotary kiln

1. feed hopper 2. hydraulic feeder 3. screw conveyor for sluges 4. head of kiln 5. rotative combustion drum 6. post- combustion chamber 7. burning of liquid wastes 8. deslag equipment (wet system) 9. drive

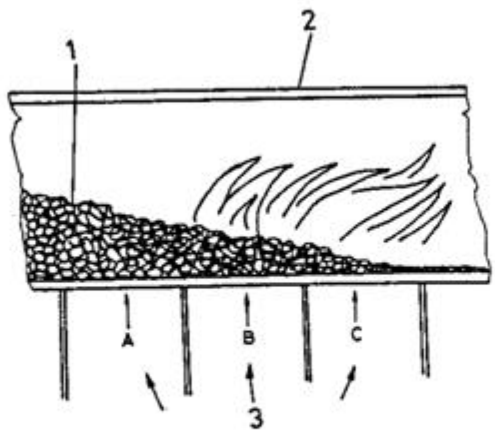
  - For solid, sludgy, and liquid wastes
  - Co-current (Fig.) or counter-current
  - Refractory lined cylindrical combustion field.
  - It inclines slightly, is turning slowly.
  - The angle of inclination and the speed of rotation can be varied.
  - Two-way motion of waste
    - It turns with the mantle of the kiln; this motion increases the residence time of the waste.
    - It moves forward (due to the slope (and continuous feeding))
  - At the end of the kiln the gases accumulate (intensive turbulence)
  - Post-combustion chamber (after-burner):
    stationary, oil or gas burners, T=900-1000°C
  - The slag flows out by gravitation (in slagging mode)
  - Air excess coefficient. λ = 2 -2.5
  - L = 8 – 13 m
  - D = 3 – 4 m
  - $V_{WASTE} = 0.2\ V_{KILN}$

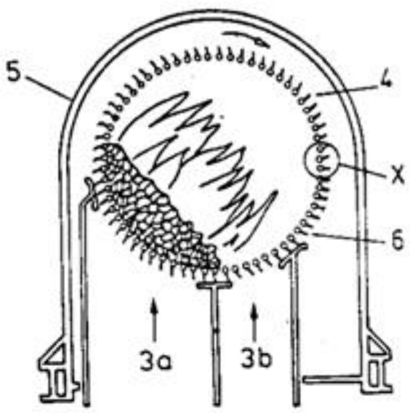


Temperature zones of a rotary kiln

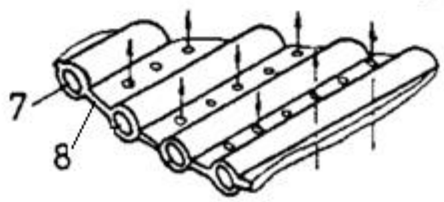
a. water steam b. combustible material c. slag d. melt of slag e. masonry (wall)

- **Westinghouse – O'Connor Rotary Kiln (Fig.)**
    - It is not walled up with bricks.
    - Membrane-wall cooled by water.
    - Air inlet:
      -through the holes between the tubes of the membrane-wall → good distribution of air,
      -air can be introduced directly above the combustion field, as well.





X part



Scheme of a Westinghouse-O'Connor rotary kiln

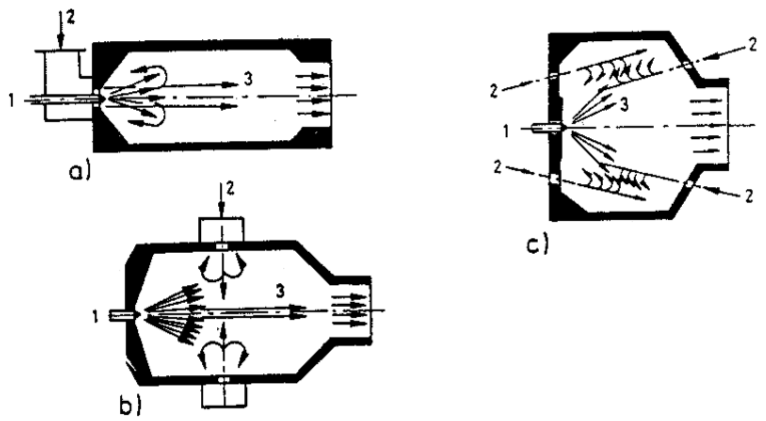
1. waste 2. rotative kiln 3. air supply a. lower blast (primary) b. upper blast (secondary) 4. cooling ribs 5. casing 6. water tubes 7. water flow 8. air flow.

- **Combustion chambers**
    - For liquids, gases, and sludgy wastes.
    - Fixed drum, walled up (lined with bricks)
    - Mixing of waste and air is provided by nozzles and atomizers.

a. Co-Current Flow:
   - Waste and gases move in the same direction.
   - Mixing of waste and air is slower → its efficiency is lower than that of cross and counter-current flow chambers.
   - Only for gaseous and liquid wastes which can be atomized easily.

b. Cross-Current Flow:
   - Air inlet through radial holes
   - Better mixing of waste and air → shorter equipment → lower investment cost.

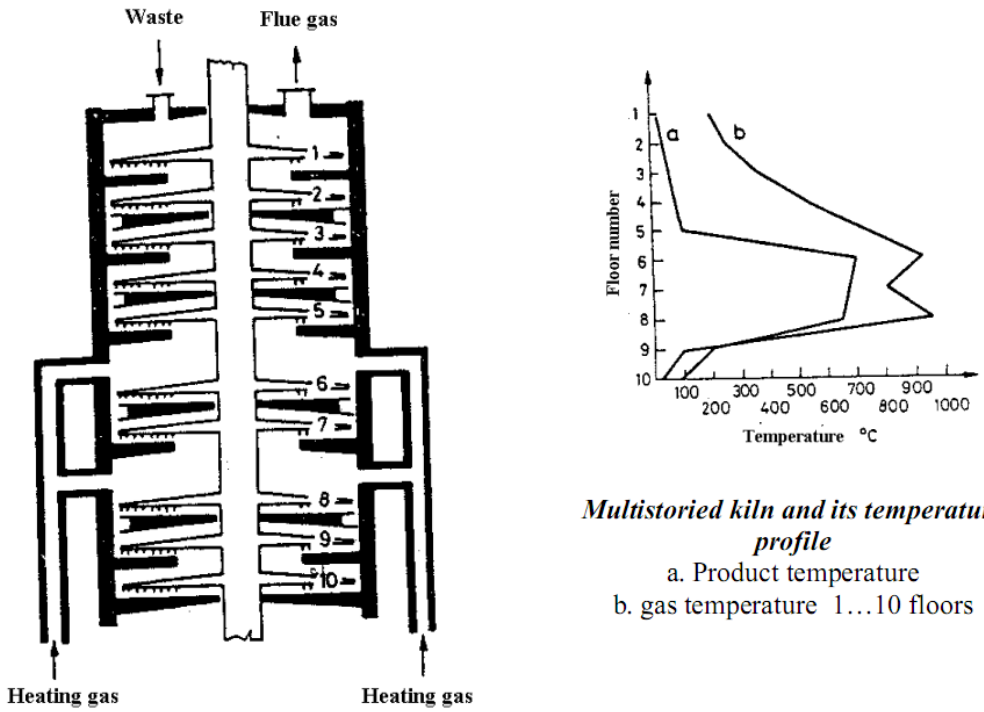
c. Counter-Current Flow:
   - Air is blown in several free jets.
   - Intensive mixing and combustion
   - Exclusively for liquid wastes



Basic types of combustion chambers

a. Cocurrent (parallel) flow b. Crossflow c. Countercurrent flow
1. Fuel feeding 2. Air inlet 3. Combustion chamber

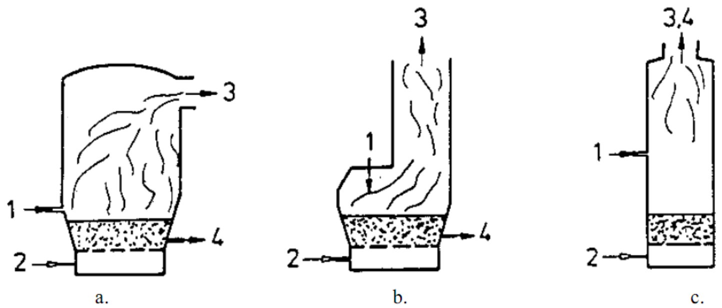
- **Multistoried kiln**
    - For sludgy wastes
    - Counter-current
    - Operating zones
        - Floors 1-5: drying
        - Floors 6-7: combustion (zone of highest T)
        - Floors 8-10: cooling of slag
    - On the chilled axis there are scrapers moving the solid waste toward the centre.
    - Flue gases are saturated with water vapour and stinking (smelly) → they need purification.



Multistoried kiln and its temperature profile
a. Product temperature
b. gas temperature 1…10 floors

- **Fluidization kiln**
  a. Process of fluidization: solid granular material is kept in pulsed motion with a gas (or liquid) flowing upwards from below. At fluidization
     -the solid material fluidized behaves as a fluid and
     -the heat and mass transfers are very efficient.

  b. Incineration in a fluidization kiln:
     - For shredded solid, sludgy, and liquid wastes.
     - Eddy bed: layer consisting of fine granular material moving above the grill (quartz, corundum, basalt).
     - T = 750 – 850°C.
     - Feeding of waste above the eddy bed by dropping in or by pulverization.
     - Ash can leave either with the material of the eddy bed (a, b) or with the flue gases (c).
     - Simple construction
     - No moving components
     - λ = 1.1 -1.3 (much lower than for the other types of combustors)
     - Residence time is also low.
     - Heat recovery
       - Cooling tubes in the eddy bed (better)
       - Boiler after the kiln: problem: high content of dust and fly ash of flue gas decreases the efficiency and lifetime of the boiler.



Different constructions for combustion in fluidized bed
1. waste 2. air 3. flue gas 4. discharge of ash

- **Combined fluidization and multi-storied kiln**
  - In multi-storied part: drying of waste.
  - In fluidization part: combustion (with less air).

Heat Recovery, Cooling of Flue Gases

The flue gases leaving the combustion field have a temperature between 850 and 1300 °C.
Goals:

- to recover heat,
- to protect the purification equipment,
- to decrease corrosion.

The flue gases must be cooled down: usually to ca. 250 °C:

Danger of corrosion: $T_{min:}$ above the dew point of acidic gases: 140-180 °C,

T_{max}<450 °C because of halogens

Cooling media: water (or air)
Direct or
indirect cooling: boilers (producing steam) or heat-exchangers (hot water)

Heat Recovery Facilities:

1. *Production of low-pressure steam*: for district heating (seasonal consumption!) and heating of industrial equipment (heating plant)
2. *Production of high-pressure steam*
    a. Generation of electrical energy (in turbines) and production of heating steam (heating power plant)
    Typical net energy from MSW: 0.67 MWh (=2412 MJ) electricity, 2 MJ for district heating

    Heating power plant with turbine of condensation with withdrawal:

    The production of steam can be fitted to the needs of heat consumers.

    b. Generation of electrical energy, only (power plant of condensation):
    Maximal electrical energy, but high investment costs, low efficiency of the heat recovery.

Emergency condensers: combustion of waste need not be stopped when the heat recovery system is not operating (e.g., during maintenance); designed for 50 % of the maximal steam production.

Another possibility: if incinerator is close to a waste-water treatment plant.

Facilities for thermal treatment of waste-water sludges:

a. Direct feeding of *hot flues gases* into the sludge dryer unit (the gases (humid, smelly) are led back to the incinerator)

b. The *steam* produced in the incinerator is used for the thermal treatment, drying of the sludge.

Solid Products of Combustion:

1. Slag: cooling down, separation of ferrous materials in magnetic separators, transportation to MSW landfill (or recycling: road construction, after preparation (breaking into small pieces, classification by size))
2. Fly ash:
   It leaves the combustion field with the flue gases, separation from them with electro-filter or bag-house filter (preliminary separation can be done in cyclones), disposal with other hazardous wastes (high content of halogen, soluble salts, toxic metals etc.)

Flue gas purification

The *air pollution* caused by flue gases is the most serious environmental problem of waste incineration.
The composition of flue gases is variable, it depends on

- characteristics (composition) of the waste,
- type of the incinerator,
- operational parameters of the incinerator.

Emissions:

SO_2, NO_x, HCl, HF, CO, dust, metals (including toxic ones: Pb (lead), Hg, Cd), organic compounds: dioxins, furans, other polycyclic aromatic compounds

Emission standards (EU directive 2000/76)):

	mg/Nm^3	
SO2	50	
NO_x	200 or 400 depending on the capacity of incinerator (>6 t/h) (<6 t/h)	
Total dust	10	
TOC	10	(Total organic carbon)

Dioxin/furan: 0.1 ng TE/Nm^3 TE: toxicity equivalent

Philosophy of combustion:

- earlier: pollutants must remain in the slag.
- nowadays: pollutants must leave with the flue gases and then they must be separated from them during the flue gas purification.

Distribution of different metals between the products (%)

	Pb	Hg
Slag	60-70	0
Fly ash	30-35	20-25
Flue gas	4-5	70-80

Flue gas contains metals and other pollutants in the form of *aerosol*.

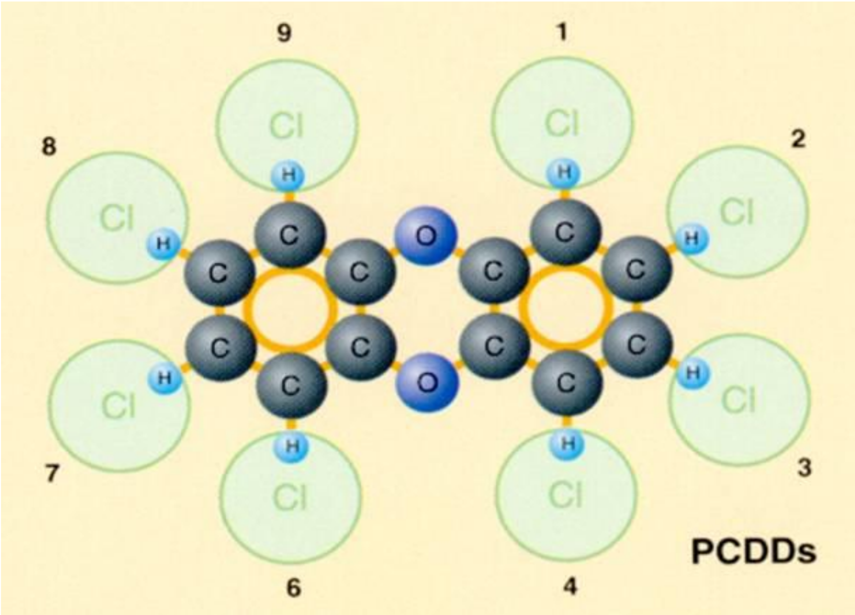
Aerosol: gas + small size (10^{-7} - 10^{-3} cm) particles distributed in it
Particles can be solid (dust/smoke) or liquid (fog/mist)

Dioxins, furans:

These harmful compounds (causing cancer) are generated during the combustion.

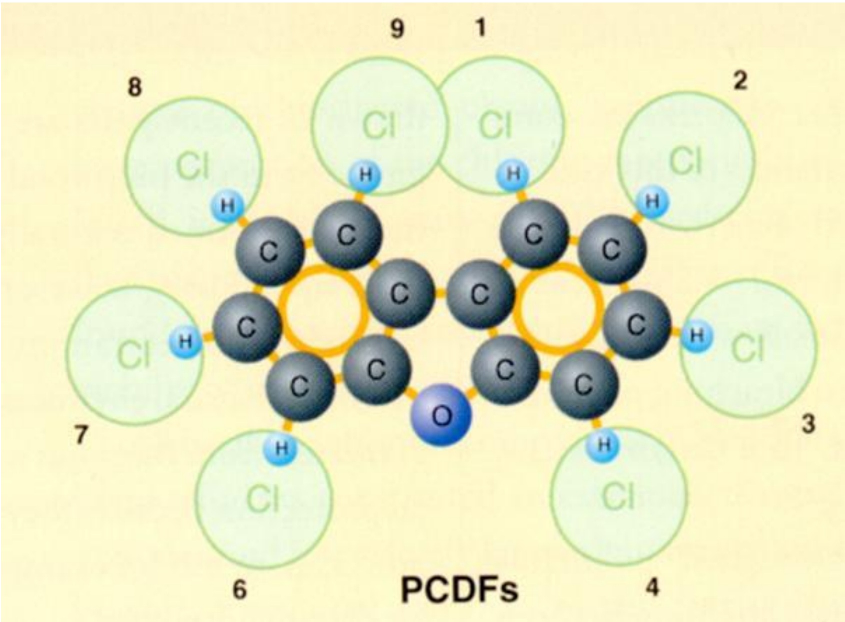
- of chlorinated organic compounds or
- in presence of NaCl (sodium chloride).

a. Dioxins: polychlorinated dibenzo dioxins (PCDD)



The most toxical one is 2,3,7,8 tetrachloro- dibenzo dioxin (TE=1.0, reference compound) (Instead of hydrogen chlorine atoms in positions 2, 3, 7 and 8)

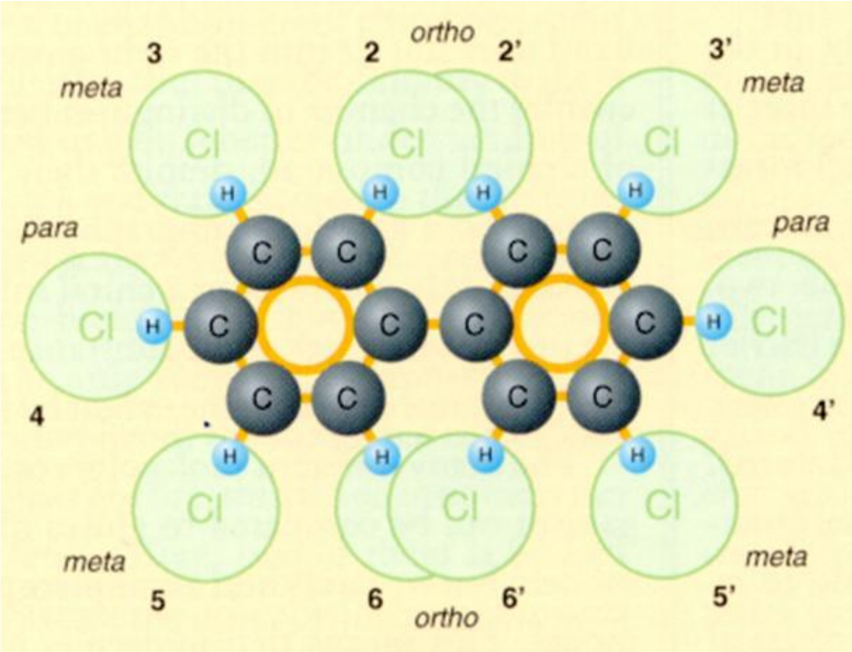
b. Furans: polychlorinated dibenzo furans (PCDF)



The most toxical one is 2,3,4,7,8 pentachloro- dibenzo furan (TE=0.5)

c. Other toxic organic compounds:

- polychlorinated biphenyls (PCB)



- polybrominated diphenyl ether: flame retardant used in electric circuit boards and monitors

Removal of pollutants from flue gases

1. Separation of solid particles (dust removal):

with (dry or wet) electro-filters or bag-house filters

removal efficiency: $\eta = (c_{in} - c_{out})/c_{in}$

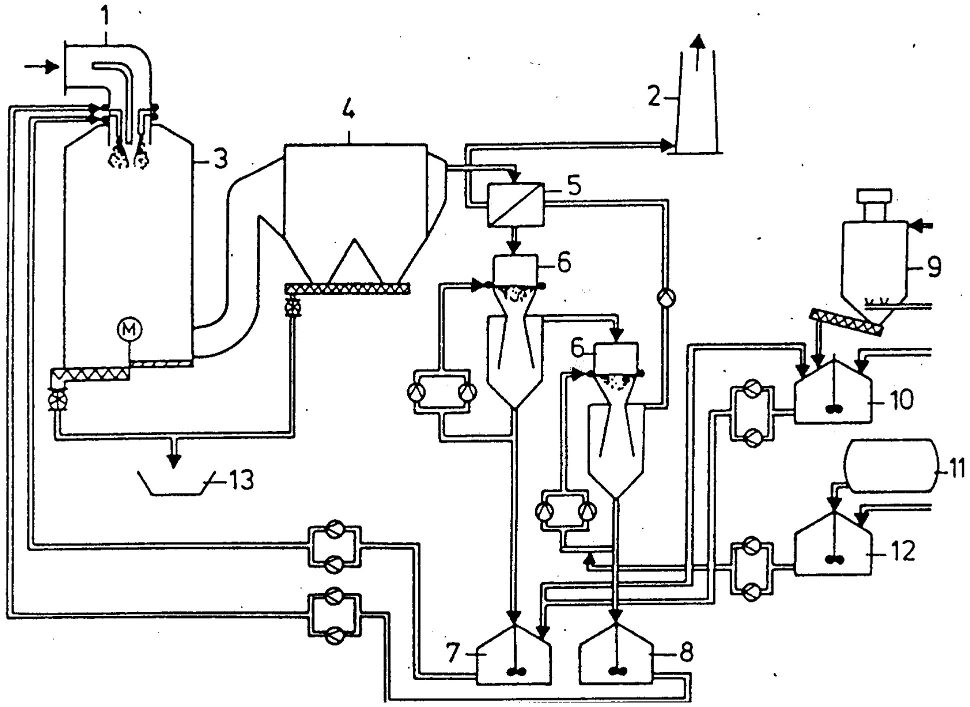
$\eta > 0.99$

for preliminary removal ($\eta < 0.9$) cyclone can be applied

2. Separation of gaseous pollutants

a. wet (absorption, scrubbing, Fig.):
Two stages of absorption:

1. In acidic or neutral medium
2. In caustic (alkali) solution (PH>7, mainly for the removal of SO_2)



Two stage scrubbing (in Venturi scrubbers) with evaporation of wastewater

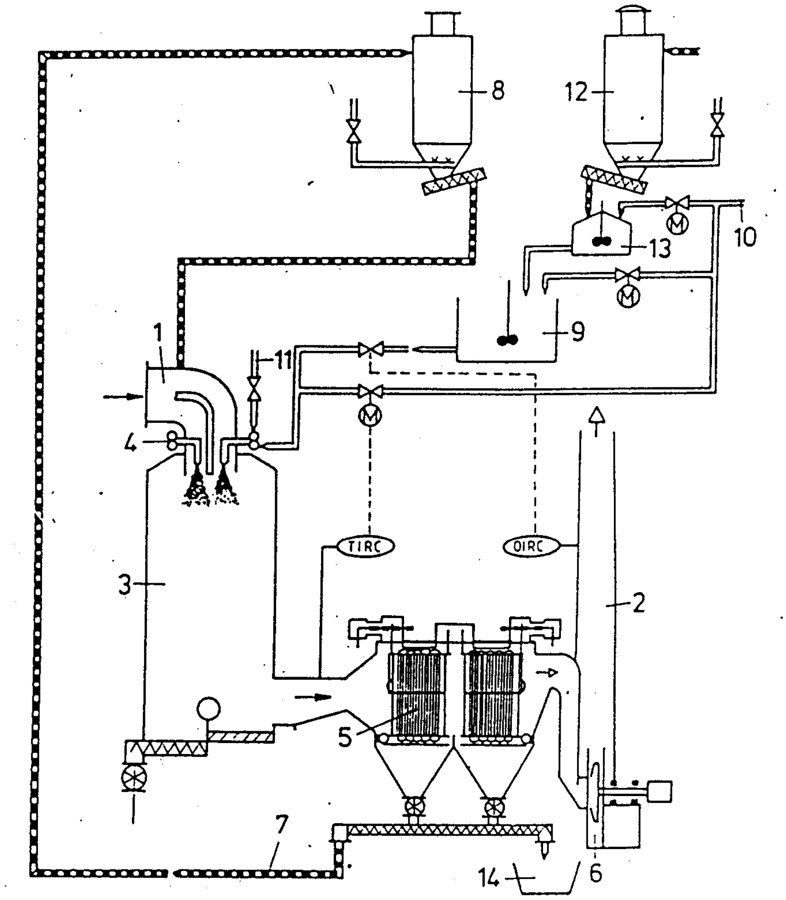
(Deutsche Babcock AG)

1. unpurified (raw) flue gas 2. purified flue gas 3. spray dryer vaporiser 4. filter separator 5. glass tube heat exchanger 6. Venturi scrubber 7. neutraliser tank 8. sludge collector 9. lime silo 10. preparation of lime milk 11. alkali storage 12. preparation of alkali solution 13. dry final product

Problem: Hg can be accumulated in the system. The Hg content can be reduced with TMT forming complex with Hg from 2.5 to 0.05 mg/l.

b. semi-dry method (Fig.):

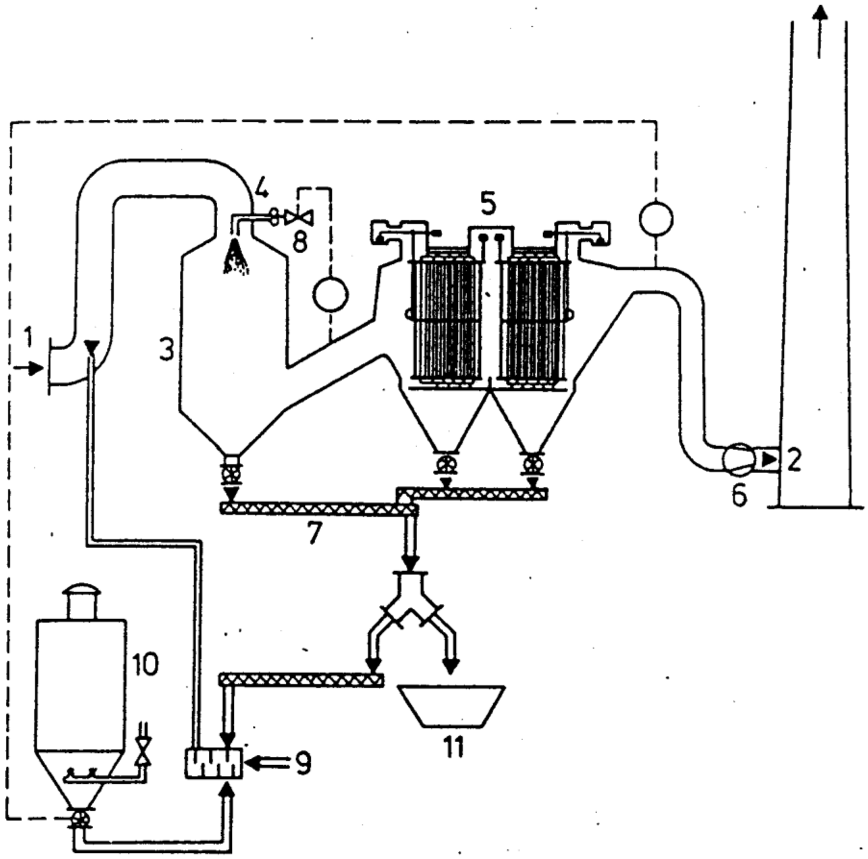
The sorbent is suspension or solution (e.g., lime milk)



Scheme of the semidry flue gas purification (Deutsche Babcock AG)

1. un-purified (raw) flue gas 2. purified flue gas 3. spray dryer 4. atomisers 5. electro-filters 6. fan 7. dust transporting system 8. silo for recycled material 9. lime milk tank 10. water 11. compressed air 12. lime silo 13. lime dissolver 14. dry final product

c. dry method (Fig.):
The sorbent is solid, and it is applied in excess. The flue gas is humidified. Feeding of the sorbent by pneumatic transport.

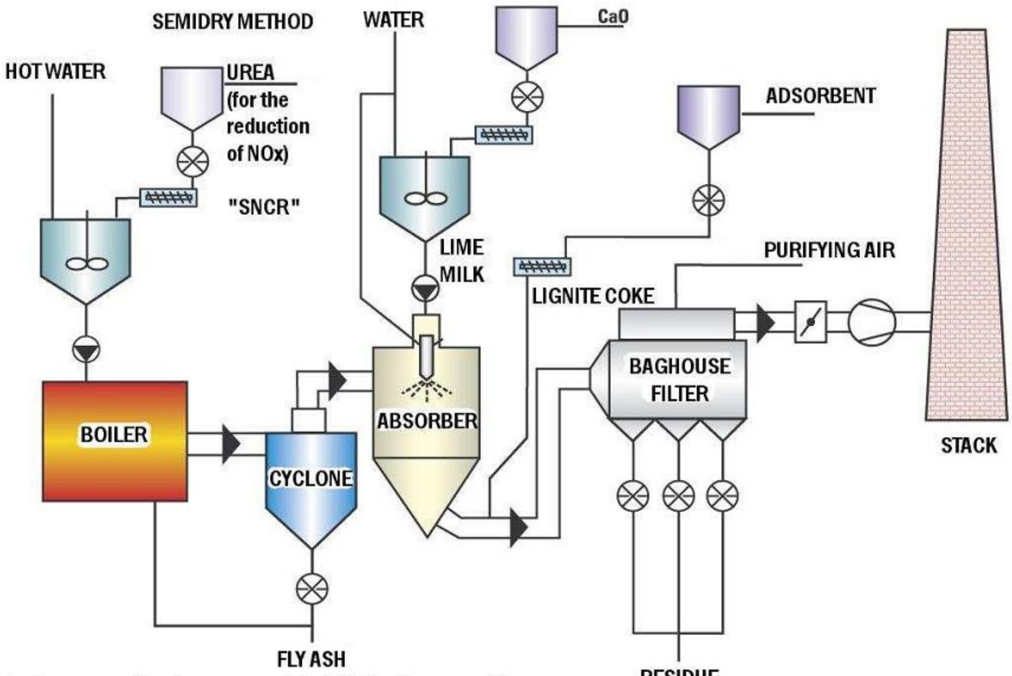


Scheme of the dry flue gas purification (Deutsche Babcock AG)

1. un-purified (raw) flue gas 2. purified flue gas 3. reactor 4. atomisers 5. electro-filters 6. fan 7. dust collection system 8. water 9. compressed air 10. lime silo 11. dry final product

Flue gas purification in MSW incinerator of Budapest

2/3 of the MSW is combusted here.
Purification of flue gases by semi-dry method without producing wastewater.



The flue gas purification system of the MSW incinerator of Bp.

The main parts of the flue gas purification system (Fig.):

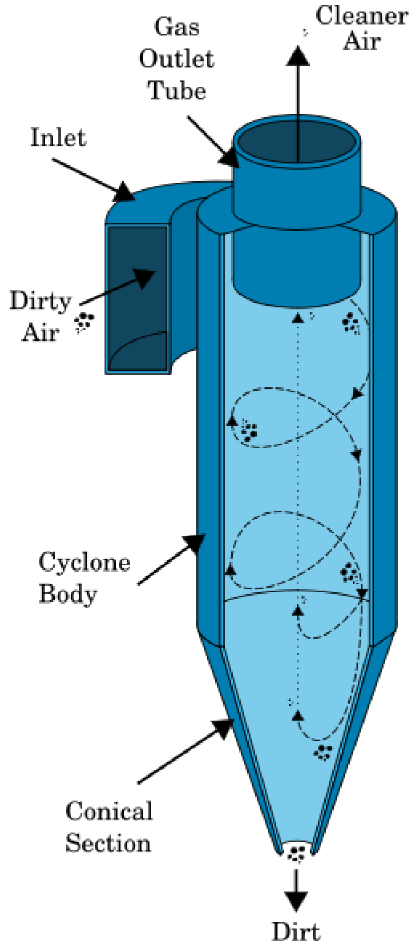
- Injection of urea for the selective non-catalytic reduction (SNCR) of NOx into the furnace.
- Cyclone for the preliminary removal of flying ash (particulates).
- Absorber where acidic gases are neutralised with lime milk.
- Feeding of lignite coke for the adsorption of dioxins, furans, and Hg vapour.
- Bag-house-filter (type: reverse pulsejet) for the removal of fly ash residue, reaction salts, used adsorbent, excess of absorbent and adsorbent.
- Ventilator for transporting flue gas into the stack and ensuring the draft of the furnace.

Cyclone

Cyclone is an equipment for removing

- solid particulates from a gas, or liquid stream,
- fine droplets of liquid from a gaseous stream.

without the use of filters.



A *high speed rotating (air)flow* is established within a cylindrical or conical container. In the cyclone *air flows* in a *helical pattern*, beginning at the top (wide end) of the cyclone and ending at the bottom (narrow) end before exiting the cyclone in a straight stream through the center of the cyclone and out the top (chimney).

Larger (denser) particles in the rotating stream have too much inertia to follow the tight curve of the stream, and *strike the outside wall*, then *falling to the bottom* of the cyclone where they can be removed.

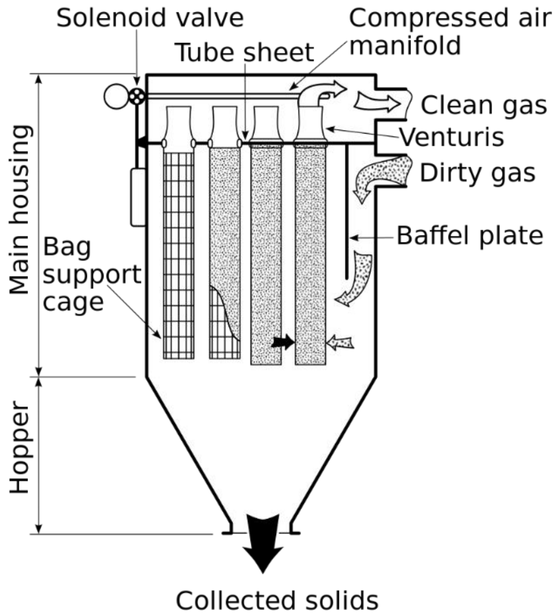
In a *conical system*, as the rotating flow moves towards the narrow end of the cyclone, the rotational radius of the stream is reduced, thus separating smaller and smaller particles.

Cut point of the cyclone: the size of particle that will be removed with a 50% efficiency. Particles larger than the cut point will be removed with a greater efficiency, and smaller particles with a lower efficiency.

Baghouse filter

A baghouse filter is an *air pollution control device* and dust collector that *removes particulates from gas streams*. Unlike electrostatic precipitators, where performance may vary significantly depending on process and electrical conditions, baghouses have a *particulate collection efficiency of 99% or better*, even when particle size is very small.

Most baghouses use *long, cylindrical bags* (or tubes) made of woven or felted fabric as a *filter medium*. Dust-laden gas enters the baghouse through hoppers and is directed into the baghouse compartment. The *gas is drawn through the bags*, either on the inside or the outside depending on cleaning method, and a *layer of dust accumulates on the filter media surface* until air can no longer move through it. When a sufficient pressure drop (ΔP) occurs, the *cleaning* process begins.



Schematic of a reverse pulse-jet baghouse filter

In ***reverse pulse-jet baghouses***, individual bags are supported by a metal cage (filter cage), which is fastened onto a cell plate at the top of the baghouse. *Dirty gas* enters from the bottom of the baghouse and *flows from outside to inside the bags*. The metal cage prevents collapse of the bag.

Bags are cleaned by a short burst of compressed air injected through a common manifold over a row of bags. A digital sequential timer turns on the solenoid valve at set intervals to inject air into the blow pipe and clean the filters. The compressed air is accelerated by a Venturi nozzle. The duration of the compressed-air burst is short (about 0.1 seconds), it acts as a rapidly moving air bubble, traveling through the entire length of the bag and causing the bag surfaces to flex. This *flexing of the bags breaks the dust cake*. The dislodged dust falls into a storage hopper below.

Reverse pulse-jet dust collectors can be operated continuously and cleaned without interruption of flow.

I. Waste incineration | **II. Flue gas cleaning** | **III. Energy**

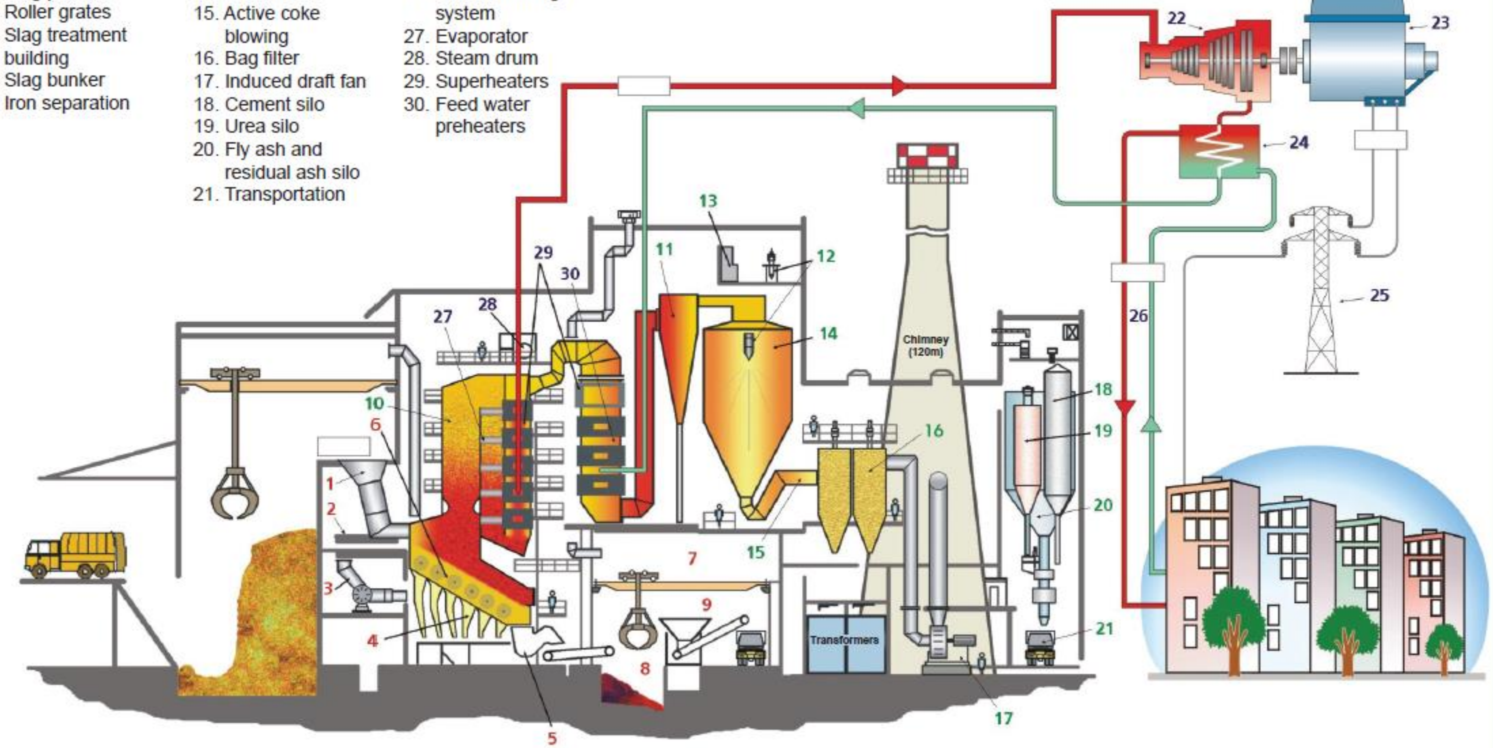
1. Feed chute
2. Waste feeder
3. Primary air fan
4. Air distribution chambers
5. Slag pusher
6. Roller grates
7. Slag treatment building
8. Slag bunker
9. Iron separation

10. Urea injection
11. Cyclones
12. Lime milk atomizer
13. Hydraulic unit
14. Absorber
15. Active coke blowing
16. Bag filter
17. Induced draft fan
18. Cement silo
19. Urea silo
20. Fly ash and residual ash silo
21. Transportation

22. Turbine
23. Generator
24. Heat exchanger
25. Electric power transmission line
26. District heating system
27. Evaporator
28. Steam drum
29. Superheaters
30. Feed water preheaters

TECHNOLOGICAL SYSTEM I-II-III.

Budapest Waste-to-Energy Plant Operational Flow-Chart



The flow chart of Budapest Waste-to-Energy Plant depicts the three pillars of the waste-to-energy technology: waste incineration, flue gas cleaning and power generation.

Combustion of wastes in high temperature industrial technologies

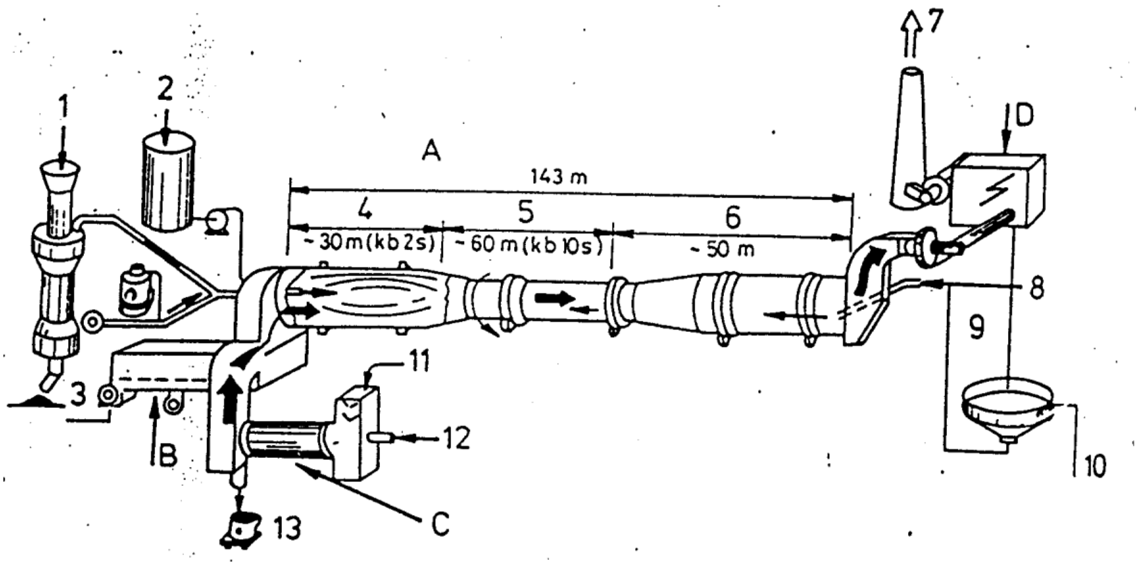
The modification of an existing industrial equipment for accepting waste as fuel is cheaper than the installation of a new waste incinerator (lower investment cost)
The incineration can be made in steam boilers, cement kilns, blast furnaces etc.

a. Steam boiler:

-The minimum power is 3 MW.
-Mainly for liquid wastes exempt of halogens.
-The amount of waste burnt is max. 20 % of that of the normal fuel (in the case of waste exempt of halogen and of high heating value max. 50 %).
- Dust removal is necessary (from the flue gases).

b. Cement kiln:

grinding
Raw sludge---->clinker---->cement powder
Liquid waste is combusted, while solid and pasty wastes are thermally decomposed by pyrolysis in a rotary kiln.
The PH of both raw sludge and clinker is alkaline, therefore wastes with high halogen content can be treated.
There is no emission of HCl and HF. Max. 4-5 kg halogen/t clinker.



Scheme of a cement kiln with pyrolysis kiln suitable for incineration of wastes

A. Clinker kiln B. Clinker cooler C. Pyrolysis kiln D. Electrofilter

1. coal (primary fuel) 2. liquid waste (secondary fuel) 3. clinker outlet 4. sintering (shrinking) zone 5. calcination zone 6. drying zone 7. flue gases (ca. 150 °C) 8. raw sludge 9. separated dust tank 10. water 11. solid waste 12. tarry, viscous (pasty) waste 13. slag removal

c. Blast furnace (where iron ore is melted with blasts of hot air)
d. Other high temperature industrial technologies e.g., glassmaking

Equipment used in waste pre-treatment

I. Shredders

Shredding: unit operation for size reduction. Shredders were originally developed for crushing of stone and ores but now they are applied to scrap metal, plastic, aluminium, wood, paper products and for breaking down concrete, steel, and other building materials.

Goals of shredding:

- Increase of (specific) surface for further processing (e.g., magnetic separation)
- Decrease of size (e.g., of oversized wastes)

Types of action in the shredding process:

- crushing: reduction of particles by pounding (like a hammer),
- shearing: forcing two parts of an item in different directions (like scissors), and
- grinding: friction applied to the surface of an object (like a coffee grinder).

All shredding units employ two or more of these actions simultaneously.

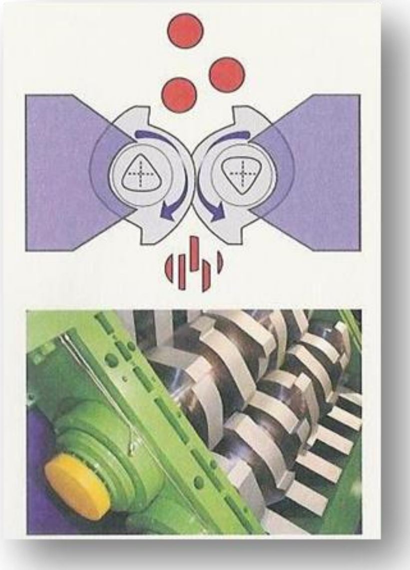
Benefits of shredding (MSW):

-reduction of waste volume,
-easier separation after shredding,
-more homogeneous waste,
-increased surface area of the fuel particles.

Shredders are available in a variety of shapes and sizes (from portable paper shredders to huge units for shredding flattened automobiles (at the rate 1/min)).

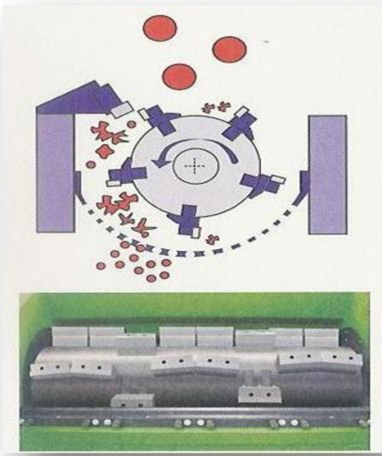
The most common types: rotary shear, granulator, hammermill, chain crusher.

1. Rotary shear



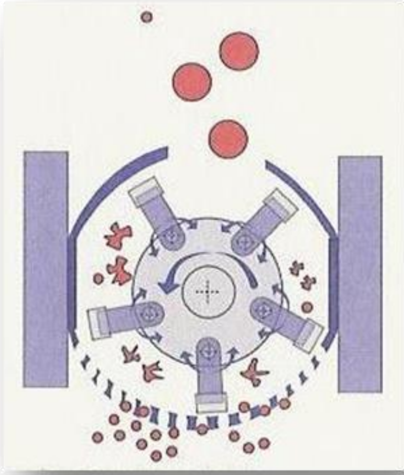
Two parallel, counter-rotating shafts with a series of discs mounted perpendicularly and acting as cutters, working in scissor-like fashion. Compared with hammermills they are low speed devices (60 to 190 rpm).
The waste is directed to centre of the rotating shaft. The size is reduced by the shearing and tearing action of the cutting discs. The final particle size (2.5 to 25 cm) is controlled by
-spacing between the discs on the shafts,
-orientation of the shafts and
-spacing between the shafts.
The shredded materials fall through and are pulled through the discs.
Most are driven by hydraulic motors that can be reversed automatically in the case of obstruction.
Lower speeds imply lower energy costs and less maintenance of moving parts.
Large steel and other durable objects must be removed prior to entering the shredder.

2. Granulator



Only one rotating shaft with a series of discs. One *other series of discs are fixed* mounted perpendicularly to the wall. The particles are moving on a forced trajectory within the equipment until their size decreases below the bore diameter of the sieve located at the bottom of the equipment, then they fall out through the holes. By exchanging the sieve different particle sizes can be set.

3. Hammermill



It is large cylindrical (or tapered) unit equipped with *a central rotor with a series of attached rapidly rotating hammers*. Hammers are either *fixed or swing* on the rotating shaft.

The rotor and hammers are enclosed within in a heavy-duty housing whose interior may be lined with *stationary breaker plates or mounted cutter bars*.

Shredding relies on heavy force breakage of particles by the hammers. Further size reduction: the particles are struck against breaker plates or cutting bars fixed around the inner wall.

Rotational speed: 700-3000 r/min   Power: 500-700 kW

High speed shredders are very noisy.

Input is always from the top and materials flow through the machine by gravity.

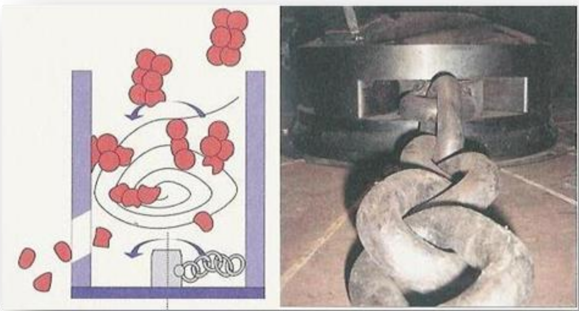
The shaft can be oriented in the horizontal or the vertical direction.

- Horizontal:

Most have a grate placed across the outlet under the hammers whose opening size may be changed depending on desired size of the final product. The hammers pound the material until it is small enough to pass through the grate openings.

- Vertical

4. Chain crusher



Breakage of particles by a chain on a rotating shaft.

II. Separation of wastes by size (screening)

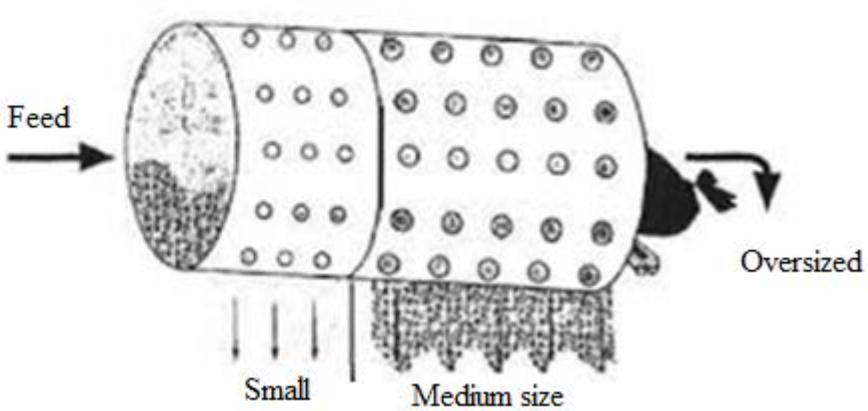
Separation/classification by size.
It can be carried out either dry (common) or wet.
The primary applications of screening during MSW processing:
- removal of oversized materials
- removal of undersized materials
- recovery of paper and plastics for recycling or as refuse derived fuel (RDF)
- separation of soil, glass, and grit from combustible materials

Major types of screening equipment:
1. Trommel screen
2. Disc screen
3. Vibrating shaker screen

1. Trommel Screens

The trommel is a *rotating, perforated cylinder* with a diameter 0.6-3 m.
The screening surface consists of perforated plate or wire mesh.
The drum is *inclined in a slight angle*.
The rotational speed of the drum: 10-15 r/min.
The waste is introduced at the upper end via a conveyor belt.
The waste falling through the openings are collected by a conveyor or a hopper.
The *sizes of the trommel* influences the efficiency of separation to a great extent:
-The longer the drum the higher is the residence time of the waste.
-The greater the diameter, the more effective is the breaking up of the large objects.
-Sizes of trommels: a. large: up to 15 m long, diameter: 2.5-3 m b. small: L=0.6-1.2 m, D=0.3-0.6 m

In two-stage trommels in the first section with small openings (with diameter of 2-3 cm) soil, broken glass falls through and from the second section with larger apertures (with diameter of 12-15 cm) glass, aluminium and plastic containers are removed.

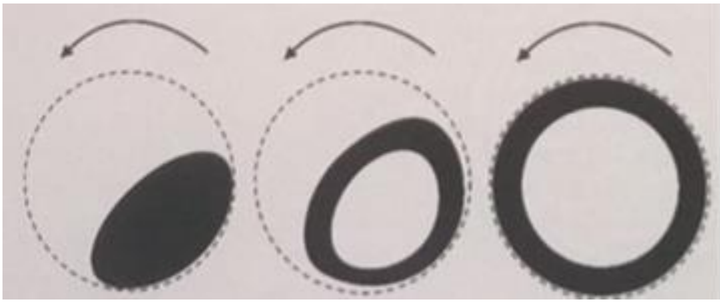


Schematic of two-stage trommel screen

Depending on the *rotation speed (n)* waste behaves in different ways within the trommel:
a. cascading: at low n it travels only slightly up the sides and immediately slides back.
b. cataracting: at higher n, it rises further, then tumbles and slides back (substantial turbulence of waste).
c. centrifuge: at even higher n it adheres to the inside of the trommel it tends to centrifuge. Critical rotational speed:

$$n_c = (g/4\pi^2 r)^{1/2}$$

where g acceleration of gravity [m/s^2]
r radius of trommel [m]
The optimal rotation speed is just below n_c.



a. Cascading b. Cataracting c. Centrifuging

Ways of behaviour of the waste in the trommel depending on the rotation speed

Photo of a compound trommel screen

Municipal waste within a trommel screen

Factors influencing the separation efficiency of a trommel screen:
- characteristics of the material fed (dense or loose, fragile, or not, wet, or dry),
- feed rate,
- size ranges of the drum (length, diameter),
- number and size of openings,
- incline angle of the cylinder,
- rotation speed.

The retention time of the waste within the trommel for
- raw waste before shredding: 25-60 s,
- shredded, air classified light wastes: 10 sec.

2. Disc Screens

It contains a series of parallel and interlocked discs mounted on shafts, which *rotate in one direction* carrying the waste along similarly to a conveyor belt.
Undersized materials fall between the spaces in the discs and then they are collected in a hopper.
The *larger pieces* are carried along the top and then they are deposited in a second hopper.
The size of separation is determined by the spacing.
- between the outer diameter of the shafts and
- of the discs on the shaft.

By varying the spacing of the discs on the drive shaft the desired particle size ranges can be changed.
In the case of blockage an electronic sensor signals for the shaft to rotate in the opposite direction.

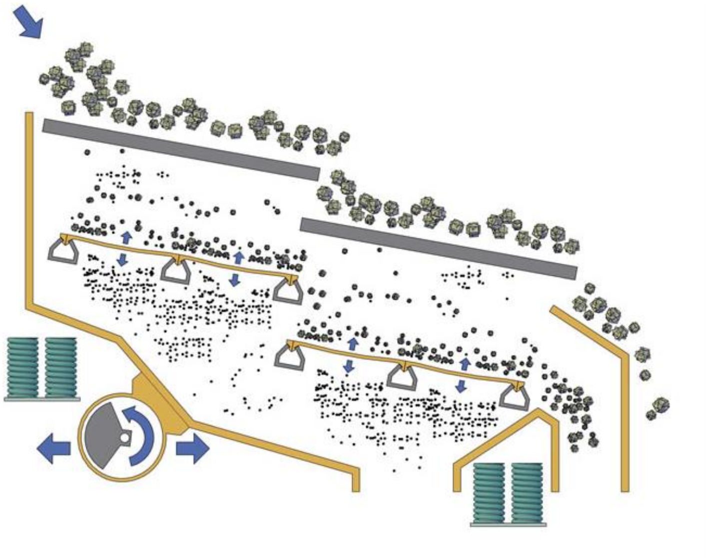
3. Vibrating Screens

It consists of a mounted flat screen and undergoes a reciprocating or gyrating motion.

They are mainly used for

- purifying more concentrated fractions of waste (metals, glass, and wood chips), which have been already processed into a relatively fine particle size and
- removing impurities (such as broken ceramics, glass, and stones) from compost feedstock.

The *vibration improves the effectiveness* of separation. *The product shakes and the particles jump* without sliding on the screening surface. Each jump is an attempt of the particle to pass through a hole and the probability of this happening is much greater if the machine vibrates.



Schematic of a vibrating screen

Three level vibrating screen

For large classifications low frequencies and large vibration amplitudes are preferable and for fine classifications high frequencies and small amplitudes. In other words, if the particle is large, a slow and wide movement is better in which the particle makes few jumps but large and if it is small, it is better than many jumps but smaller.

Literature

Pichtel J., Waste management practices, Taylor & Francis, London, 2005

III. Separation equipment

1. Air classifier

An air classifier is a machine, which separates materials by a combination of
-density,
-size and
-shape.

The material stream to be sorted is injected into a chamber, which contains a column of rising air. Inside the separation chamber, *air drag* on the objects supplies an *upward force* which
-counteracts the *force of gravity* and
-lifts the material to be sorted up into the air.
Due to the dependence of air drag on object size and shape, *the objects* in the moving air column *are sorted vertically* and can be separated in this manner.

Air classifiers are commonly employed in industrial processes where a large volume of mixed materials with differing physical characteristics need to be separated quickly and efficiently. Air classifier is helpful for
-cement,
-air pollution control,
-food processing,
-pigments,
-pharmaceutical,
-cosmetics or
-chemical industries.

One such example is in *recycling centres*, where various types of metal, paper, and plastics arrive mixed together and need to be sorted before further processing can take place.

*Air separation of Municipal Solid Waste (*Pichtel, 2005)

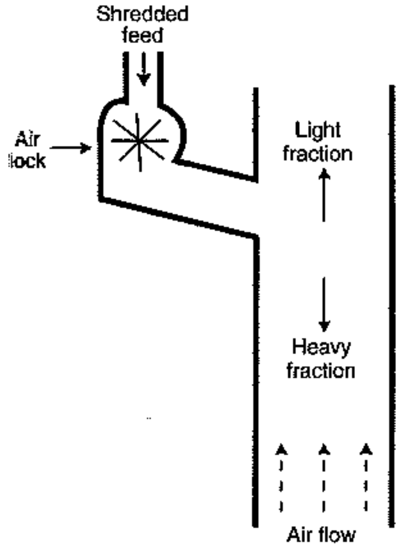
Unit operation for the *separation light waste components* (paper, plastic, wood) *from heavier materials* (metal, glass, stones) based on their different behaviours when subjected to a stream of air. The MSW stream is separated in a Material Recovery Facility (MRF) into a *light fraction* (60 to 75 % of the total) *concentrating the combustibles* as a fuel product. Metals and glass can be separated from the heavy fraction and sold, as well. Often the air classifier is located after the magnetic separator before a secondary shredder.

Separation is optimised through the proper
-design of separation chamber,
-airflow rate, and
-material feed rate.

There are several designs with varying capacity and efficiency of separation:

a. Vertical, straight

This is the most common configuration. Shredded MSW is dropped downward into the chute. An upward *air stream fed by blowers lifts light materials upwards* for subsequent capture in a cyclone. Airflow has uniform direction, and its rate is held constant. Along the length *baffles* may be installed causing turbulence within the housing and separation of aggregated particles.



Schematic of a typical air classifier

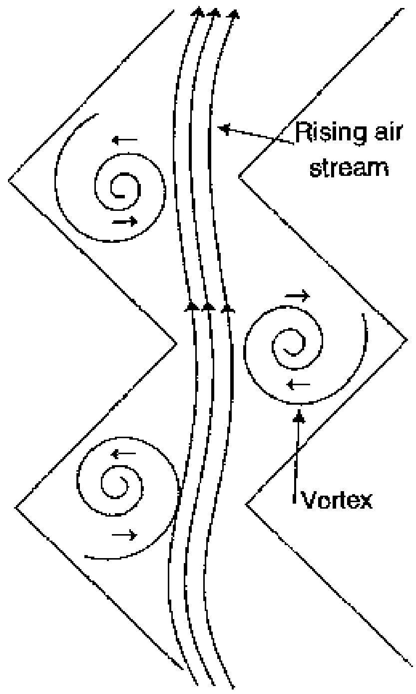
b. Vertical, zig-zag

A rapid stream of air is drawn up at a constant rate through the vertical column having a *zig-zag internal configuration*.

Shredded waste is introduced at either the top or the middle of the column through a *rotary air lock mechanism*. Air is introduced at the base.

This equipment uses gravitational force and the impact upon the sides of the housing to break up aggregates and minimise entrapped light particles.

Its shape creates a vortex effect causing the waste to fall and thus enhances separation of clumps. However, the zig-zag shape enhances blockage of input wastes.



Vortex effect in a zig-zag air classifier

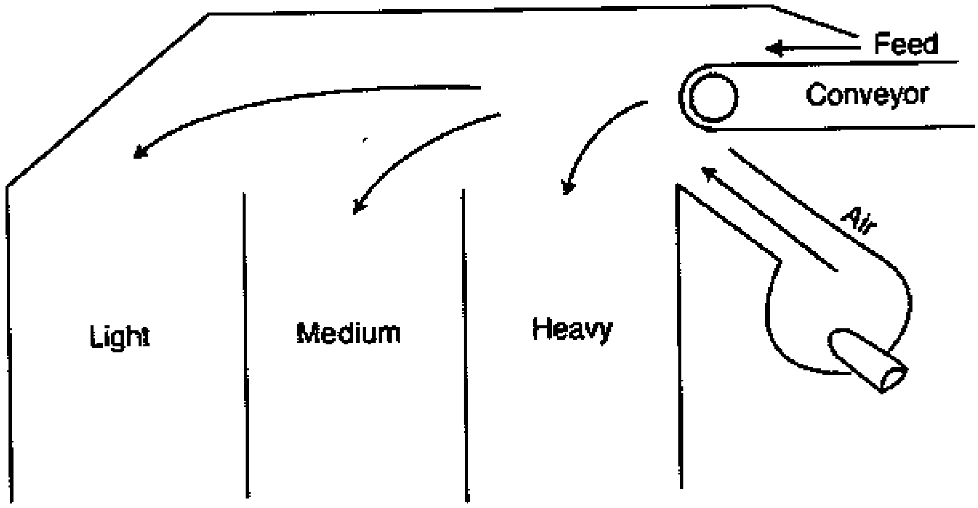
c. Pulsed air classifier

The *airflow velocity is varied* by a louver valve. It provides a better discrimination between materials. Velocity of the falling objects is a function of time until its terminal velocity has been attained.

By varying the velocity of the air stream, the falling particles can be kept in a velocity range such that *the particles with the close terminal velocity can be better separated*.

d. Horizontal air classifier

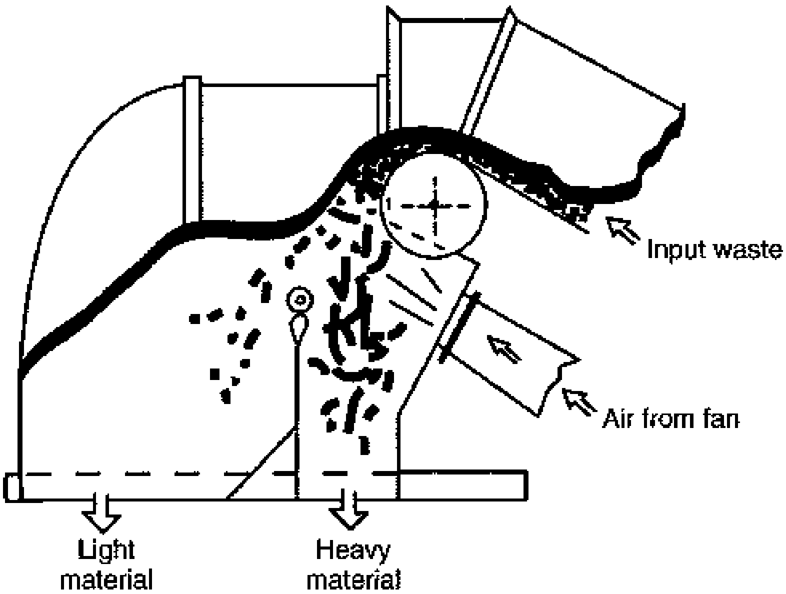
Both *the light and heavy waste components are entrained* with the air stream *in the same direction*.
The waste and air enter at one end of the shaft and are forced toward the other end.
Heavy components leave the shaft and drop off first into an opening, then the *medium-weight* ones and finally the *light* fraction.



Horizontal air classifier

e. Air knife

It can be compared with throwing leaves and twigs upward into an autumn breeze.
The air flow is forced horizontally through a vertically dropping input.
Lighter particles are carried with the air stream while the *heavier ones* quickly drop.
Air knife is used to prevent light contamination from carrying over during magnetic separation. Air is blown opposite the direction of travel of the metal under the magnet.



Air knife

Two types of *air transport system*:

a. Positive pressure system:

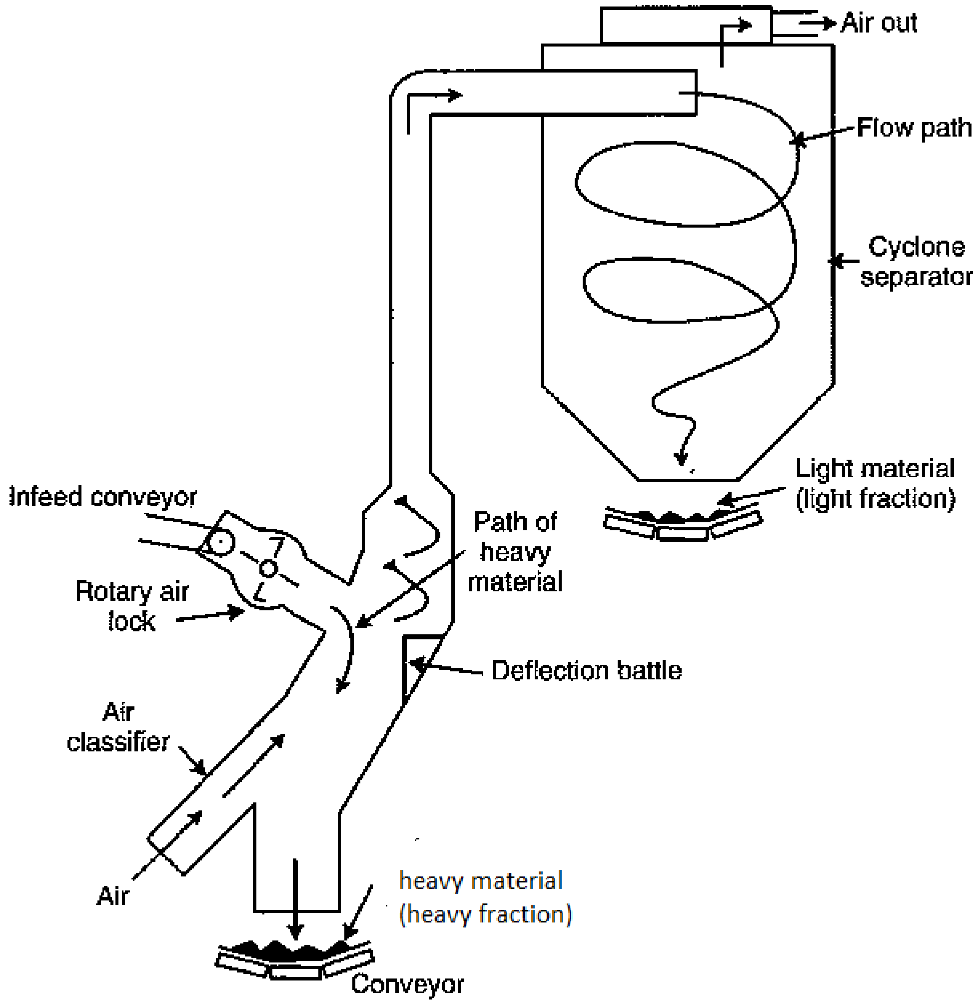
The *waste feed is pushed* through the system *by a blower* attached to the housing of the classifier creating a higher pressure within the system relative to the environment.

b. Negative pressure system:

The *waste feed is pulled* through the system by an exhaust placed at the end of the system creating a lower pressure within the system relative to the environment.

The *light fraction* entrained by the air must be removed from the air stream. For this purpose, a *cyclone* is often used after the air classifier. Before being discharged to the outer atmosphere the air is passed through a dust collection system, typically a *baghouse filter*. Alternatively, the discharge air can be recycled back to the air classifier.

The light fraction is stored in bins or conveyed to another shredder for further size reduction before storage or utilisation as a fuel or compost feedstock.



3

Complete air classification system

Efficiency of Separation in an Air Classifier

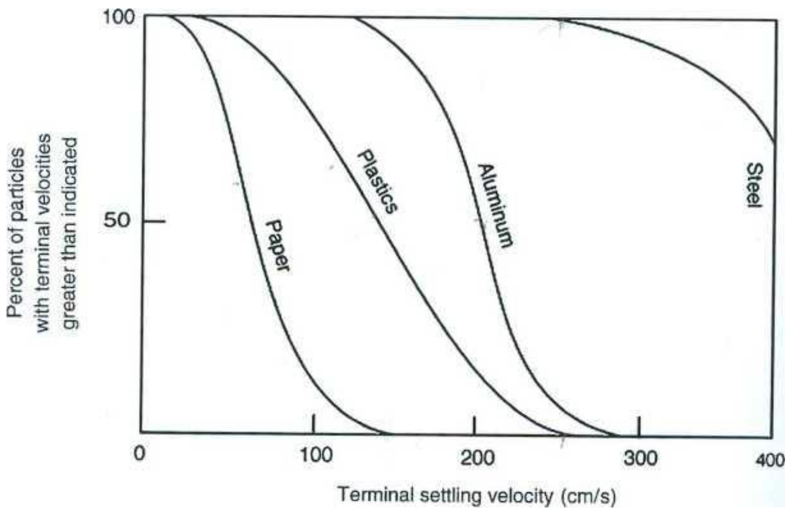
In an air classifier *complete separation* of one material from all others *is not possible*.

The *recovery of organics* (usually in light fraction) is complicated by two factors:

- Not all organics are aerodynamically light, and many inorganics (e.g., aluminium foil) are not aerodynamically heavy.

- Perfect separation of heavy and light materials is difficult, because of the stochastic nature of material movement within the classifier.

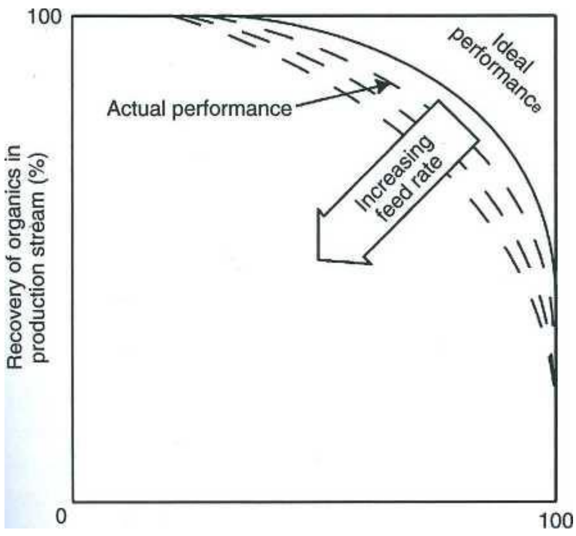
The effectiveness of air classification can be estimated by the next figure where the fraction of particles not entrained with the air stream of various materials is plotted against air velocity at which the particles just begin to rise with the air stream (that is, their terminal settling velocity).



Terminal settling velocities of different MSW components.

As the air velocity in an air classifier is increased from zero, the first material to float upwards and collect in the extract is *paper*. At an air velocity of about 150 cm/sec, all the paper occurs in the extract. However, at this velocity about 60% of the *plastic* is also entrained. *Aluminium* will start to become entrained with the extract at the air velocity about 120 cm/sec. At an airflow of ca. 260 cm/sec, all the paper and plastic will be collected in the extract; however, this will be contaminated by 90 % of the aluminium. The *steel* component would not become entrained until the air velocity exceeded 250 cm/sec. There is a velocity (much higher than 400 cm/s) at which, all the input feed may become entrained.

The next figure shows the efficiency of separation between organic and inorganic fractions as a function of the feed rate to the air classifier.



Recovery of inorganics in the reject stream (%)

With a greater loading of solids, the efficiency of separation decreases, and an increasing proportion of light particles falls into the underflow stream rather than be separated as originally planned.

EXAMPLE

Shredded MSW containing equal amounts of paper, plastics, aluminium, and steel is fed into an air classifier operating with an air velocity of 200 cm/sec.

Calculate the recovery of the organic product and the purity of the product.

Solution

The ratio entrained the different materials:

Material	Paper	Plastics	Aluminium	Steel
% entrained	100	80	50	0

The total organics (paper + plastic) in the product is

$$100\ (1/4) + (80)\ (1/4) = 45\ \%\ \text{of feed}$$

The total inorganics (aluminium + steel) in the product is

$$(50)\ (1/4) + (0)\ (1/4) = 12{,}5\ \%\ \text{of the feed}$$

The recovery of organics is calculated as

$$R_{org} = 45/(25 + 25)\ \text{X}\ 100 = 90\ \%$$

and the purity of the product is

$$P_{product} = 45/(45 + 12.5)\ \text{X}\ 100 = 78.3\ \%$$

Reference

Pichtel J., Waste Management Practices, Taylor and Francis, New York, 2005

2. Magnetic separator

Recovery of magnetic material, primarily *ferrous metals*, from the waste.

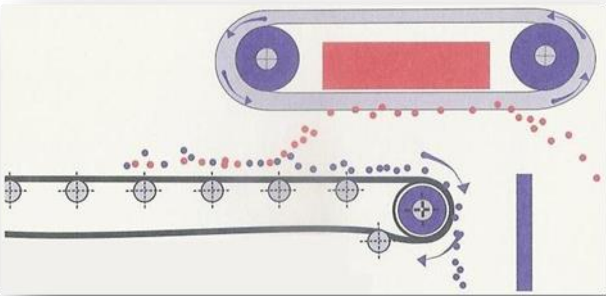
Either permanent or electromagnets are applied.

Configurations:

a. Magnetic belt pulley
b. Drum magnet
c. Magnetic head pulley

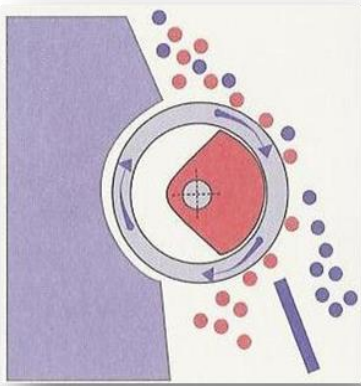
a. Magnetic belt pulley

The simplest form: a single magnet is mounted between two pulleys. The ferrous materials rise upwards. The gap between the belt and magnet permits an interval where entrained non-ferrous materials can fall back onto the feed belt.



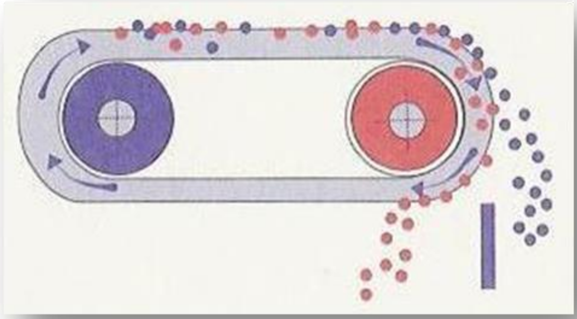
b. Drum magnet

A stationary magnet is located inside a revolving drum which is positioned. The ferrous metal is attracted against the force of gravity and is conveyed around the drum circumference until it exits the magnetic field and is discharged.



c. Magnetic head pulley

The material to be sorted is passed over the pulley. The nonferrous material falls along a different trajectory than the ferrous material. A splitter is positioned over the discharge end of the feed belt.



Entrainment of nonferrous particles with the desired ferrous product is a common problem.

The *efficiency of magnetic separation* depends on:

-height of the magnet above the conveyor belt,

-magnetic force applied,

-speed of conveyor,

-thickness of the layer of waste on the conveyor,

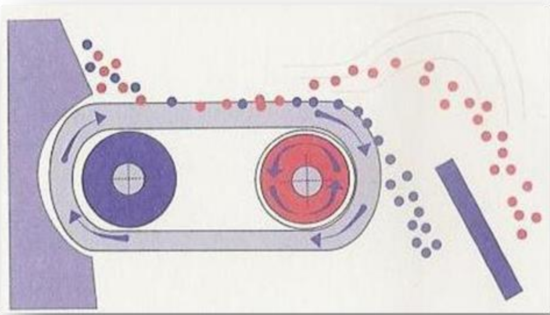
-material density: dense wastes sink below other wastes on the conveyor.

3. Eddy current separator

Separation of (electric conducting) *metals from* (non-conducting) *non-metals* based on *difference of conductivity.*

Permanent or electromagnetic field is employed to generate an electrical current (eddy), which causes the metallic particles to be ejected.

A magnetic rotor with alternating polarity is spinning rapidly inside a non-metallic drum driven by a conveyor belt. As nonferrous *metals* pass over the drum, the alternating magnetic field creates eddy currents in the particles, repelling the (conducting) material away from the conveyor and propelling it forward over a splitter. The *other materials* drop off at the end of the conveyor.

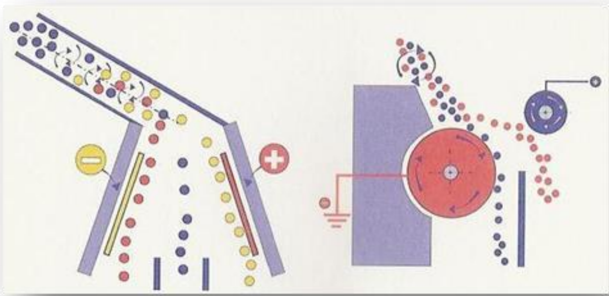


4. Electrostatic separator

Separation of *insulating (non-conducting) materials* (e.g., different plastics).

This process uses *electrostatic charges* to separate usually crushed particles of material.

The trajectory of electrically insulating particles can be influenced, as well. *In the feeding system* of these separators the surface of non-conducting particles becomes electrostatically charged due to the arising *strong friction*. Then the *mixed fraction passes through a strong electrostatic field*, which deflect the charged particulates depending on their charge and separates them from the other materials.



Final disposal (landfilling)

The waste is made harmless

- without changing its chemical composition
- by isolating it of its environment.

The aim: prevention of mass transfer between the waste and its environment.

Protection means:

Natural protection means:

They form a passive protection system exploiting favourable

- geological,
- hydrological,
- soil,
- geo-morphological,
- meteorological conditions.

The migration (diffusion) of the water must be slow. The soil/rock is suitable for natural protection if

- its permeability is very low: $k<10^{-6}$ cm/s,
- it forms uninterrupted (continuous) and undisturbed (permanent) layer.

Suitable materials: clay (if not sandy), granite (if not cracked (ruptured))

Technical protection system:

Artificial completion of the natural protection to the necessary extent.

Its elements:

- isolation of the landfill with protective and closing layers,
- keeping off the rain and underground water from the waste,
- collection and treatment of leachates,
- to ensure favourable discharge (draining) conditions in the landfill,
- construction and operation of monitoring system,
- collection and treatment of biogas,
- covering, closing of the dump, restoring of the landscape (recultivation).

Landfilling of MSW

Before dumping the organic and recyclable parts (paper, plastics, glass etc.) of the MSW are selected and separated. The organic wastes are composted.

Composting: aerobic decomposition of biodegradable organic matter, producing compost (substratum for plants). Main parts of the composting process:

addition of natural materials (to set the C/N ratio), digestion (aging), putrefaction.

The Directive 1999/31/EC on the landfill of waste is intended to prevent or reduce the adverse effects of the landfill of waste on the environment, in particular on surface water, groundwater, soil, air and human health.

It defines the different categories of waste (municipal waste, hazardous waste, non-hazardous waste, and inert waste) and applies to all landfills, defined as waste disposal sites for the deposit of waste onto or into land. Landfills are divided into three classes:

- landfills for hazardous waste;
- landfills for non-hazardous waste;
- landfills for inert waste.

A standard waste acceptance procedure is laid down to avoid any risks:

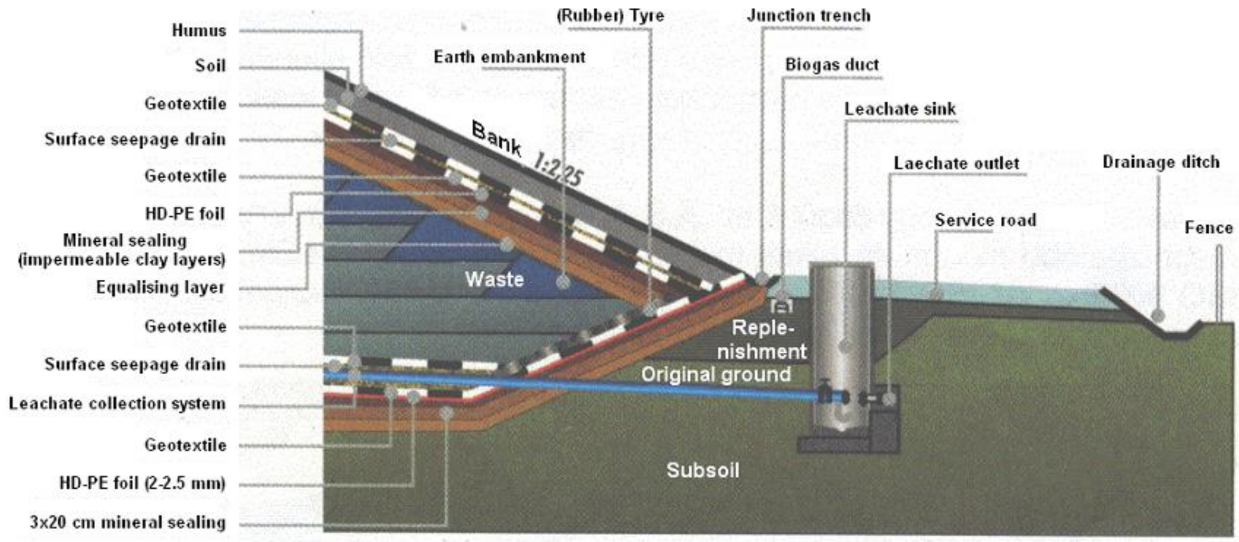
- waste must be treated before being landfilled;
- hazardous waste within the meaning of the Directive must be assigned to a hazardous waste landfill;
- landfills for non-hazardous waste must be used for municipal waste and for non-hazardous waste;
- landfill sites for inert waste must be used only for inert waste.

The following wastes may not be accepted in a landfill:

- liquid waste;
- flammable waste;
- explosive or oxidising waste;
- hospital and other clinical waste which is infectious;
- used tyres, with certain exceptions;
- any other type of waste which does not meet the acceptance criteria laid down (in Annex II.)

Requirements for landfilling:

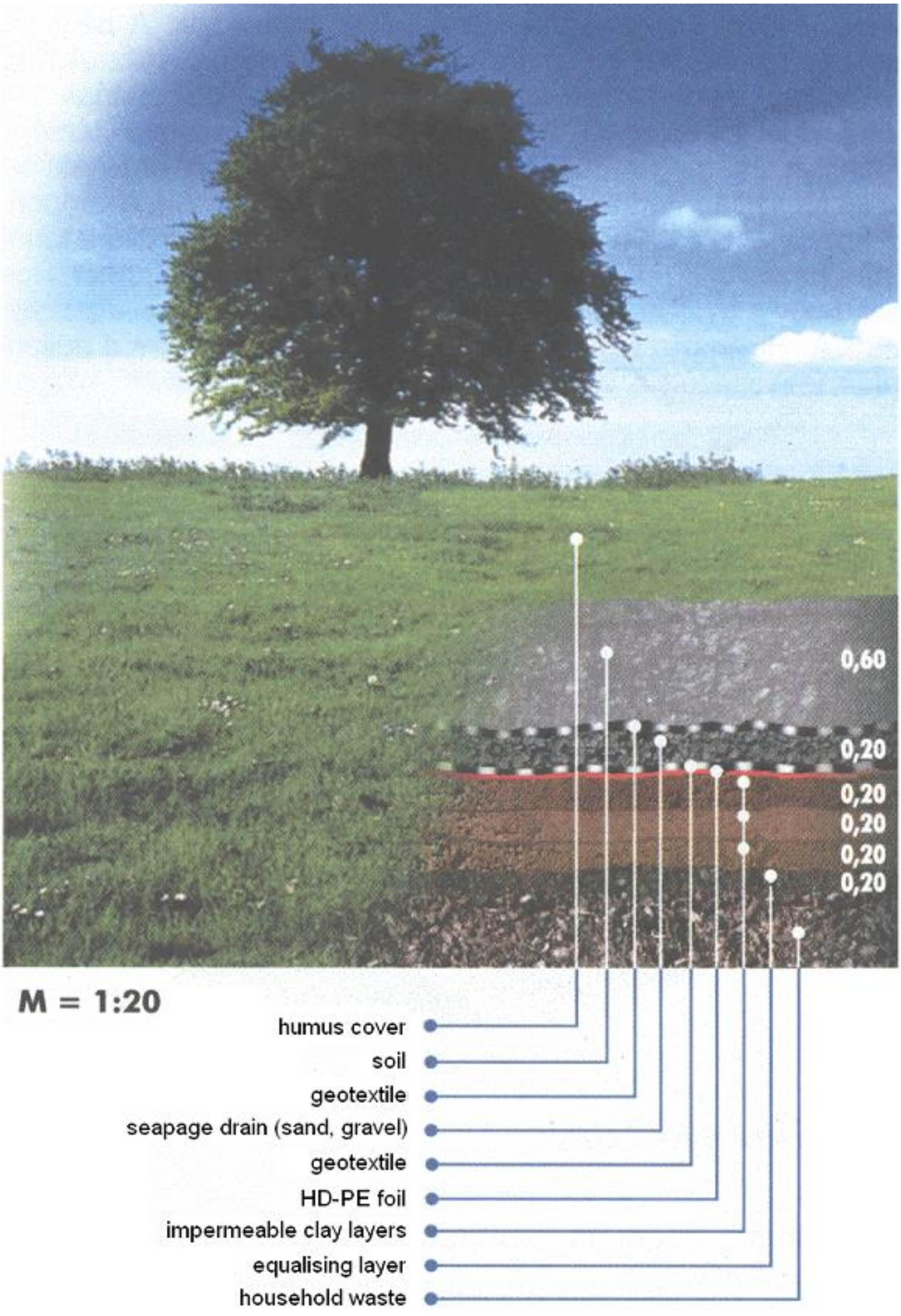
- to preclude the possibility of polluting soil and underground water,
- to control the quality (composition) of the waste transported in,
- to minimise the inevitable pollution (air pollution, dust, stink),
- continuous control of the operation of the landfill, monitoring,
- plan for preventing earthquake damages,
- collection and treatment of biogas,
- to restore the landscape (recultivation).



Scheme of a MSW landfill

Geotextiles

Synthetic polymers (mainly polypropylene or polyester) formed into fibres then into a woven or non-woven fabric. These fabrics are termed geotextiles when placed in the ground. They are porous to liquid flow across their planes and within their thickness, but to widely varying degrees. They have a lot of application area, but they have at least one of the following functions: separation, reinforcement, filtration, drainage, and containment. For the synthetic fibres the biodegradation is not a problem.



Final cover of a landfill