Physical and Chemical Properties of Solid Waste

CE 431: Solid Waste Management

Types of Waste

- ***Biodegradable*** materials are materials that are degraded easily by microorganisms (either aerobic or anaerobic), into their basic elements. Most organic solid wastes are biodegradable.
- ***Putrescible*** materials are those that decompose rapidly, particularly in warm weather, and unless carefully controlled, develop objectionable odours.
- ***Non-putrescible*** materials decompose very slowly. Plastic and polythene bags used for shopping are classed under this category.
- ***Refuse*** describes all putrescible or non-putrescible waste material that is discarded or rejected including, but not limited to, garbage, rubbish, incinerator residue, street cleaning, dead animals, and offal (Salvato, 1992).
- ***Leachate*** comprises liquids seeping from solid waste as it degrades and decomposes. It generally contains decomposed waste, water and microorganisms. In landfills, it percolates through soils, causing surface and groundwater pollution.

Categories of solid waste

Table 2.1

- Household
- Commercial
- Institutional
- Civic Amenity
- Treatment Plants
- Construction
- Sanitation
- Municipal
- Mineral
- Industrial
- Agricultural
- Healthcare
- **Hazardous**

Quantity of Solid Waste

Depends on:

- status of development of a country
- socio-economic conditions
- availability of resources
- geographic location
- attitude of waste generators and/or manufacturers
- availability and enforcement of laws to regulate waste, and promote
- recycling and resource recovery
- culture
- season of year
- level of technological advancement.

Rate of Generation

Table 2.3: Solid waste generation rate and income

Country	Rate of generation (tonne/cap/yr)	Average income (US$/cap/yr)
Low-income	0.2	350
Middle-income	0.3	1,950
Industrialised	0.6	17,500

Table 2.4: Rates of generation of solid waste in Asian countries (kg/capita/day)

Country	Large cities	Medium cities	Small towns
Bangladesh	0.5	0.4	0.4
Burma	-	0.36	-
Hong Kong	3.6	-	-
China	1.59	-	-
India	0.5	0.3-0.4	0.1
Indonesia	0.65-0.83	0.55-0.63	0.47-0.50
Japan	1.2	1.1	-
Korea	2.8	-	-
Nepal	0.4	0.2-0.3	-
Philippines	0.5	-	-
Taiwan	0.9	-	-
Thailand	0.8-0.9	0.7	0.6

Source: Aziz, 1996 in Jindal et al, 1998

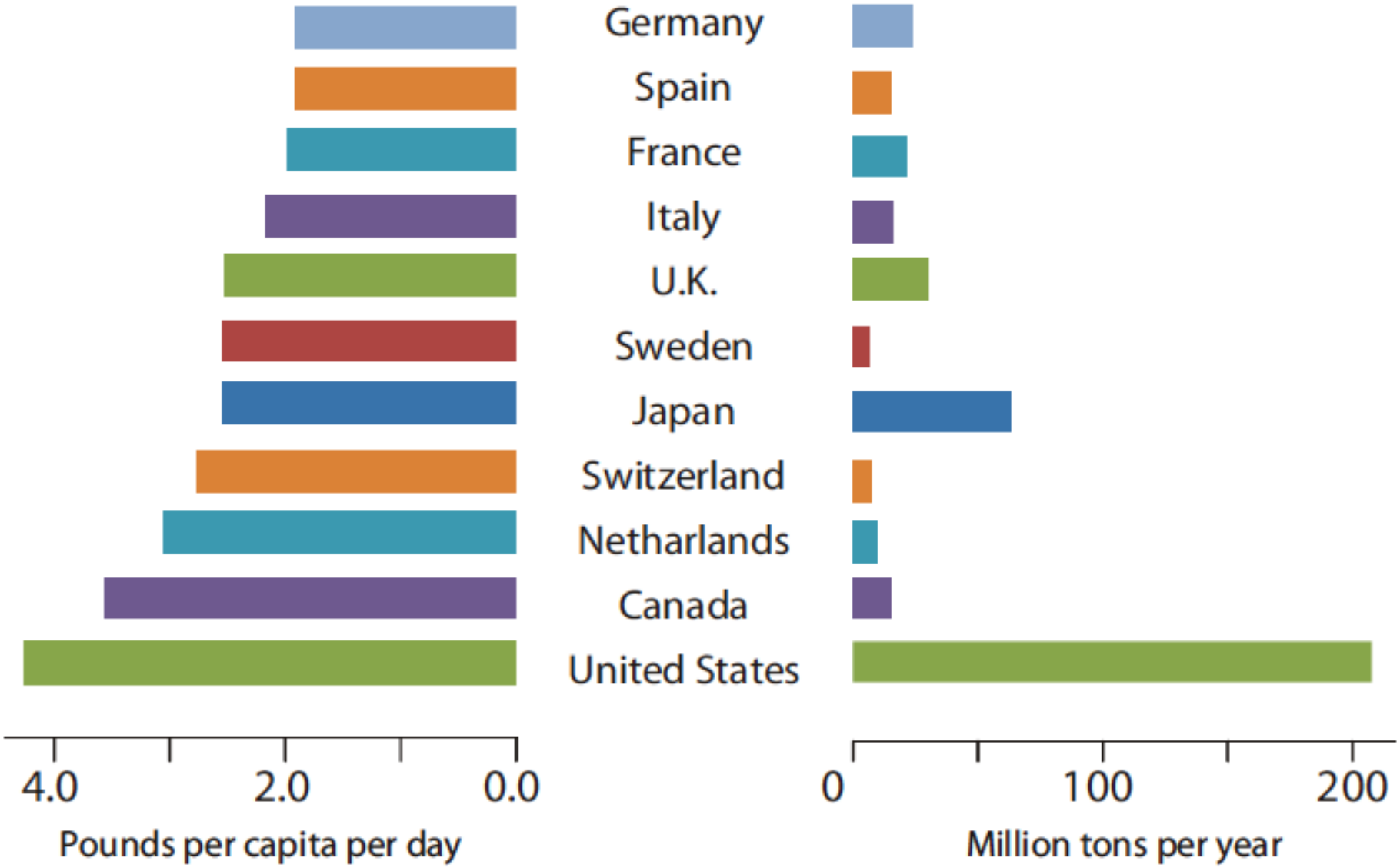


Figure 2.1: Per capita generation of municipal solid waste in selected industrialised countries

Table 2.5: Per capita municipal solid waste generation in USA (1960 to 1997)

Year	Generation (kg/c/d)
1960	2.68
1970	3.25
1980	3.66
1997	4.44

Source: Warmer, 1999

Table 2.6: Rates of generation of municipal solid waste

Source	Generation rate (kg/capita/day)
Residential	0.3-0.6
Commercial	0.1-0.2
Street sweeping	0.05-0.2
Institutional	0.05-0.2
Industrial	0.1-1.0

Source: Contreau-Levine, 1982

Composition of Solid Waste

Important to know to select –

- types of storage
- types of collection
- frequency of collection
- potential for resource recovery
- choice of method of disposal.

Table 2.7: Composition of solid waste in different cities of Bangladesh

Constituent	% by dry weight	
	Range	Typical
Food waste	65-88	78
Paper	1-7	3
Plastics, rubber	1-4	1.5
Textiles	1-7	2.5
Glass, metals, ceramic, grass, other construction materials	7-19	15

It is apparent from Table 1.3 and Table 2.7 that there are two major components of MSW organic (combustible) and inorganic (non-combustible) waste. The organic fraction of solid waste generally comprises putrescible and nonputrescible materials.

The putrescible material generally comprises food wastes (materials developed from the preparation and consumption of foods), papers, paperboard, yard trimmings and the like. These wastes decompose rapidly, particularly in warm weather, and unless carefully controlled, develop objectionable odors. This type of waste accounts for more than 53 per cent of the total MSW in industrialized countries, and up to 90 per cent of the total MSW in developing countries (Table 1.3). These organically decomposing wastes serve as breeding grounds for disease vectors, and are aesthetically unpleasant.

Non-putrescible materials decompose very slowly. The organic fraction of municipal solid waste generally comprises food waste, papers, plastics, rubbers, leathers, textiles, and similar matter. The inorganic fraction comprises inert materials, metals, bulky items, containers, etc.

Properties of Solid Waste

- Physical
- Chemical
- Biological

Physical Characteristics

- This includes the determination of percent contents of various ingredients of the solid waste.
- Bulk Density is generally calculated.
- Function of location, season, storage time, equipment used, processing (compaction, shredding, etc.)
- Used in volume calculations.

- Bulk density

- Collection, transportation, final disposal

Physical Characteristics

- Specific Weight (Density)
- Moisture Content
- Particle Size and Distribution
- Field Capacity
- Permeability of Compacted Waste

Specific Weight

- Specific weight is defined as the weight of a material per unit volume (e.g. kg/m3, lb/ft3)
- Usually it refers to uncompacted waste.
- It varies with geographic location, season of the year, and length of time in storage.

Table 2.8: Bulk densities of residential waste for various countries

Country	Bulk density, kg/ m^3
Industrialised country	
United Kingdom	150
USA	100
Middle-income country	
Singapore	175
Tunisia	175
Hong Kong	233
Egypt	330
Low-income country	
Bangladesh	600
Burma	400
China	476
India	300-560
Indonesia	250-400
Nepal	350-600
Pakistan	210-500
Sri Lanka	400
Thailand	290-390

Source: Jindal et al. (1998), Muttamara et al. (1994), Habitat

Typical Specific Weight Values

Components	Density (kg/m^3)	
	Range	Typical
Food wastes	130-480	290
Paper	40-130	89
Plastics	40-130	64
Yard Wastes	65-225	100
Glass	160-480	194
Tin cans	50-160	89
Aluminum	65-240	160

Typical Specific Weight Values

Condition	Density (kg/m^3)
Loose MSW, no processing or compaction	90-150
In compaction truck	355-530
Baled MSW	710-825
MSW in a compacted landfill (without cover)	440-740

Moisture Content

- The moisture in a sample is expressed as percentage of the wet weight of the MSW material

- The wet-weight method is most commonly used in the field of solid waste management.
- Wet- weight Moisture content is expressed as follows:

$$M = \left(\frac{w - d}{w} \right) x100$$

- Where, M= wet-weight moisture content, %
- w= initial mass of sample as delivered, kg (or lb)
- d= mass of sample after drying at 77°C, kg (or lb)

Typical Moisture Content Values

Type of Waste		Moisture Content, %	
		Range	Typical
Resindential	Food wastes (mixed)	50 - 80	70
	Paper	4 - 10	6
	Plastics	1 - 4	2
	Yard Wastes	30 - 80	60
	Glass	1 - 4	2
Commercial	Food wastes	50 - 80	70
	Rubbish (mixed)	10 - 25	15
Construction & Demolition	Mixed demolition combustibles	4 - 15	8
	Mixed construction combustibles	4 - 15	8
Industrial	Chemical sludge (wet)	75 - 99	80
	Sawdust	10 - 40	20
	Wood (mixed)	30 - 60	35
Agricultural	Mixed Agricultural waste	40 - 80	50
	Manure (wet)	75 - 96	94

Particle Size and Distribution

The size and distribution of the components of wastes are important for the recovery of materials, especially when mechanical means are used, such as trommel screens and magnetic separators.

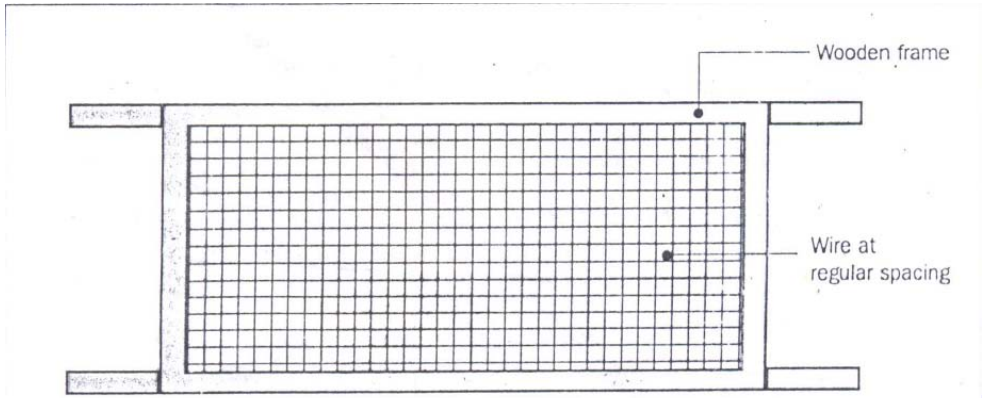


Figure 2.1. A typical screen for determining size distribution

Particle Size and Distribution

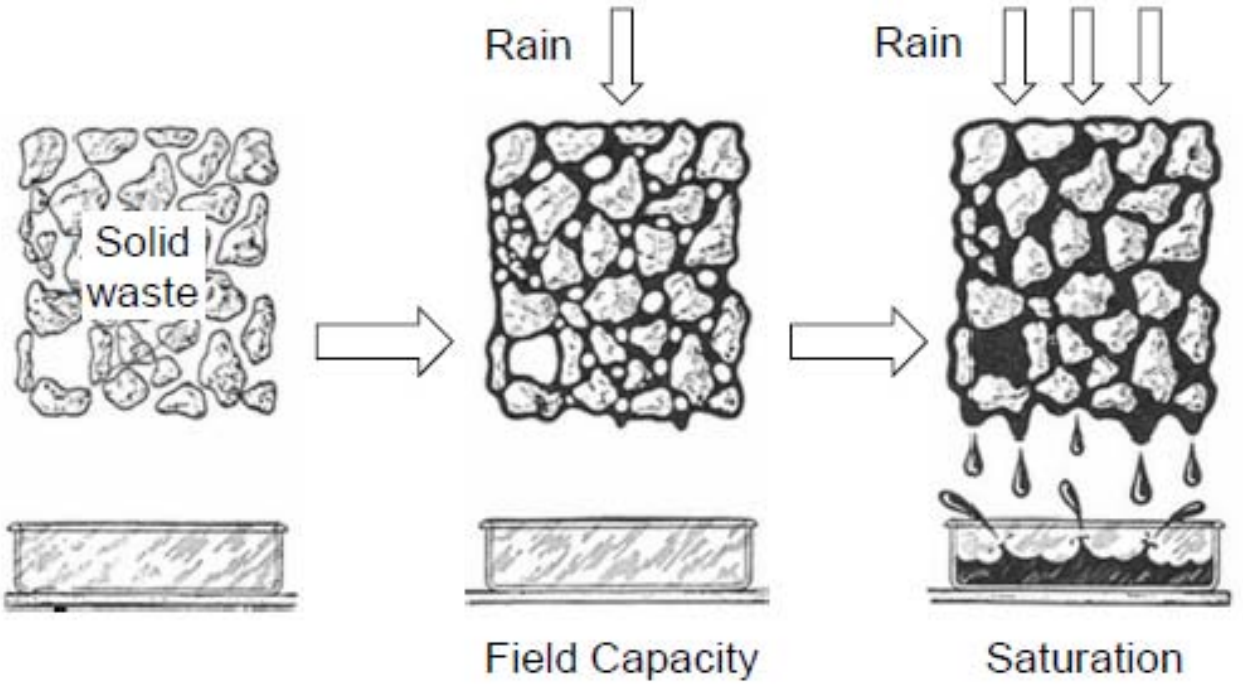
- The size of waste components can be determined using the following equations:

- $S_c = L$
- $S_c = (L+w)/2$
- $S_c = (L+w+h)/3$

- *S_c : size of component, mm*
- *L : length, mm*
- *W : width, mm*
- *h : height, mm*

Field Capacity

- The total amount of moisture that can be retained in a waste sample subject to the downward pull of gravity



Field Capacity

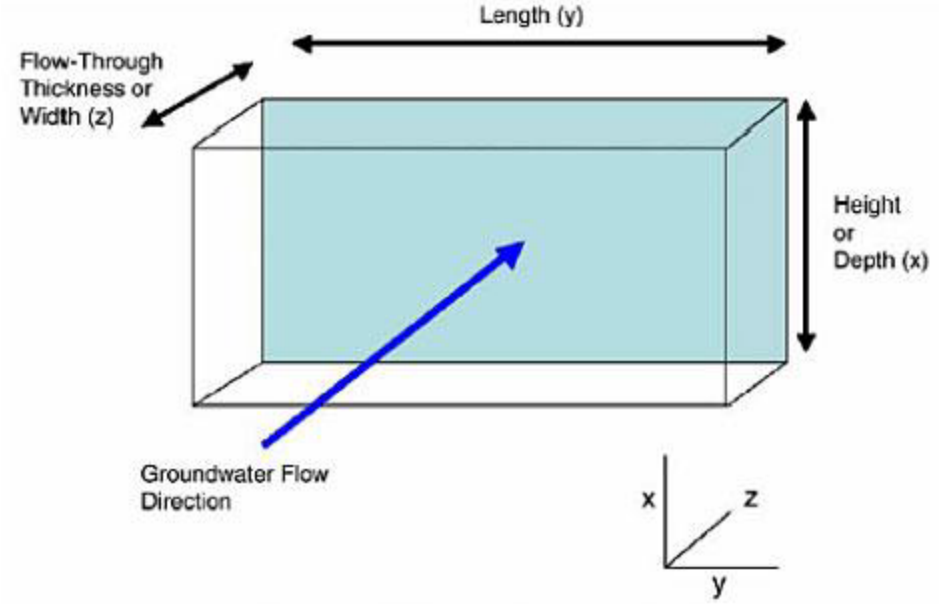
- Field capacity is critically important in determining the formation of leachate in landfills

- It varies with the degree of applied pressure and the state of decomposition of wastes, but typical values for uncompacted commingled wastes from residential and commercial sources are in the range of 50 - 60%.

Permeability of Compacted Waste

- The permeability (hydraulic conductivity) of compacted solid waste is an important physical property because it governs the movement of liquids & gases in a landfill.

- Permeability depends on:
  - Pore size distribution
  - Surface area
  - Porosity



Chemical Characteristics

- Chemical properties of MSW are very important in evaluating the alternative processing and recovery options.
- Used primarily for combustion and waste to energy (WTE) calculations but can also be used to estimate biological and chemical behaviours.
- Waste consists of combustible (i.e. paper) and non-combustible materials (i.e. glass).
- If solid wastes are to be used as fuel, the four most important properties to be known are:

Proximate Analysis

- Loss of moisture (temp held at 105 C)
- Volatile Combustible Matter (VCM) (temp increased to 950 C, closed crucible)
- Fixed Carbon (residue from VCM)
- Ash (temp = 950C, open crucible)

Fusing Point of Ash

- Clinker (agglomerations of carbon and metals) formation temperature, 2000 to 2200 F (1100-1200 C)

Ultimate Analysis

- Molecular composition (C, H, N, O, P, etc.)

Typical Proximate analysis values

Type of Waste	Moisture	Volatiles	Carbon	Ash
Mixed food	70.0	21.4	3.6	5.0
Mixed paper	10.2	75.9	8.4	5.4
Mixed plastics	0.2	95.8	2.0	2.0
Yard wastes	60.0	42.3	7.3	0.4
Glass	2.0	-	-	96-99
Residential MSW	21.0	52.0	7.0	20.0

Proximate Analysis

- Loss of moisture (temp held at 105 C)
- Volatile Combustible Matter (VCM) (temp increased to 950 C, closed crucible)
- Fixed Carbon (residue from VCM)
- Ash (temp = 950C, open crucible)

Fusing Point of Ash

- Clinker (agglomerations of carbon and metals) formation temperature, 2000 to 2200 F (1100-1200 C)

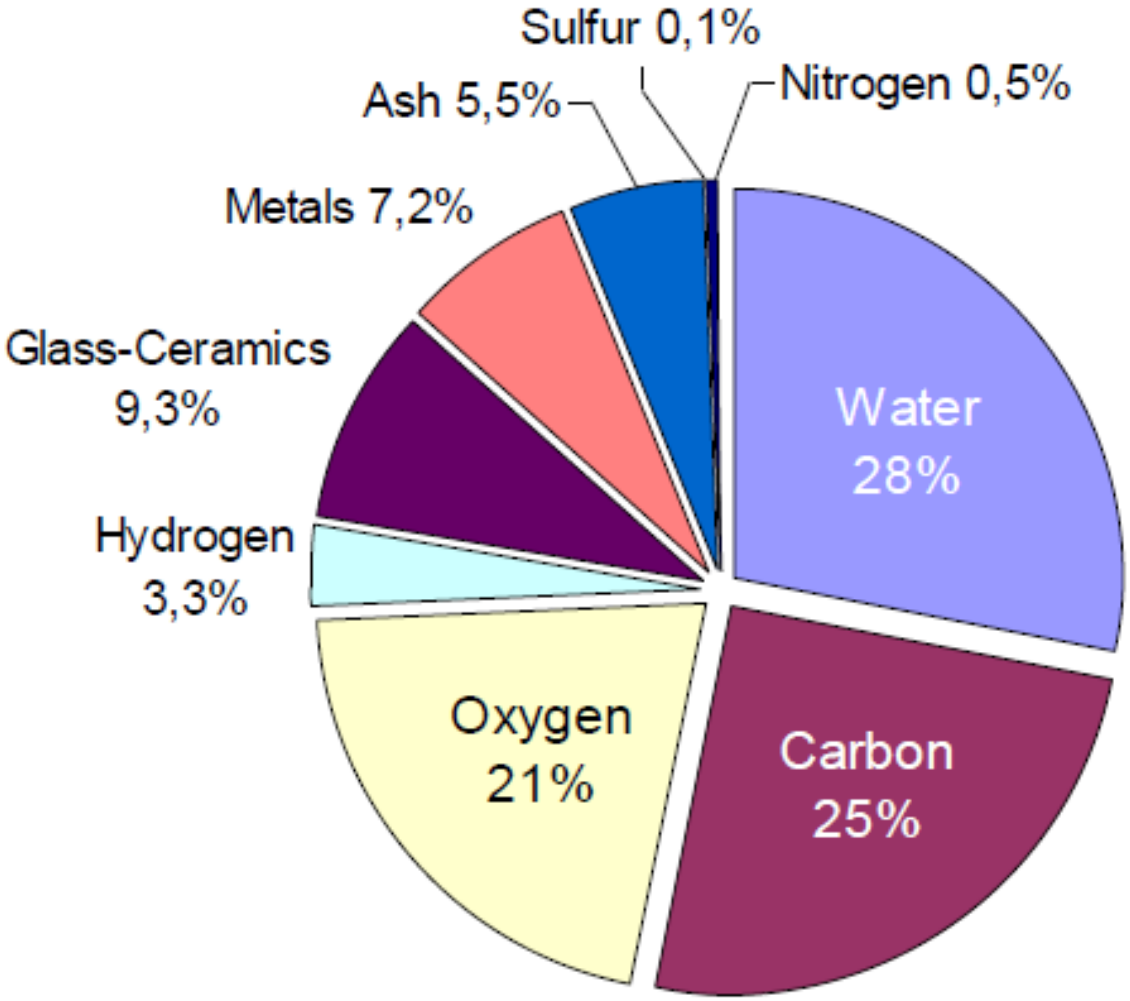
Ultimate Analysis

- Molecular composition (C, H, N, O, P, etc.)

Typical data on ultimate analysis of combustible materials found in SW

Type of waste	Percent by weight (dry basis)					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food and food products						
Fats	73.0	11.5	14.8	0.4	0.1	0.2
Food wastes (mixed)	48.0	6.4	37.6	2.6	0.4	5.0
Fruit wastes	48.5	6.2	39.5	1.4	0.2	4.2
Meat wastes	59.6	9.4	24.7	1.2	0.2	4.9
Paper products						
Cardboard	43.0	5.9	44.8	0.3	0.2	5.0
Magazines	32.9	5.0	38.6	0.1	0.1	23.3
Newsprint	49.1	6.1	43.0	<0.1	0.2	1.5
Paper (mixed)	43.4	5.8	44.3	0.3	0.2	6.0
Waxed cartons	59.2	9.3	30.1	0.1	0.1	1.2
Plastics						
Plastics (mixed)	60.0	7.2	22.8	—	—	10.0
Polyethylene	85.2	14.2	—	<0.1	<0.1	0.4
Polystyrene	87.1	8.4	4.0	0.2	—	0.3
Polyurethane[b]	63.3	6.3	17.6	6.0	<0.1	4.3
Polyvinyl chloride[b]	45.2	5.6	1.6	0.1	0.1	2.0
Textiles, rubber, leather						
Textiles	48.0	6.4	40.0	2.2	0.2	3.2
Rubber	69.7	8.7	—	—	1.6	20.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Wood, trees, etc.						
Yard wastes	46.0	6.0	38.0	3.4	0.3	6.3
Wood (green timber)	50.1	6.4	42.3	0.1	0.1	1.0
Hardwood	49.6	6.1	43.2	0.1	<0.1	0.9
Wood (mixed)	49.5	6.0	42.7	0.2	<0.1	1.5
Wood chips (mixed)	48.1	5.8	45.5	0.1	<0.1	0.4
Glass, metals, etc.						
Glass and mineral[c]	0.5	0.1	0.4	<0.1	—	98.9
Metals (mixed)[c]	4.5	0.6	4.3	<0.1	—	90.5
Miscellaneous						
Office sweepings	24.3	3.0	4.0	0.5	0.2	68.0
Oils, paints	66.9	9.6	5.2	2.0	—	16.3
Refuse-derived fuel (RDF)	44.7	6.2	38.4	0.7	<0.1	9.9

Chemical Composition of typical MSW



Typical data in elemental analysis % by weight

Type	C	H	O	N	S	Ash
Mixed food	73.0	11.5	14.8	0.4	0.1	0.2
Mixed paper	43.3	5.8	44.3	0.3	0.2	6.0
Mixed plastic	60.0	7.2	22.8	-	-	10.0
Yard waste	46.0	6.0	38.0	3.4	0.3	6.3
Refuse Derived Fuel (RDF)	44.7	6.2	38.4	0.7	<0.1	9.9

Proximate Analysis

- Loss of moisture (temp held at 105 C)
- Volatile Combustible Matter (VCM) (temp increased to 950 C, closed crucible)
- Fixed Carbon (residue from VCM)
- Ash (temp = 950C, open crucible)

Flusing Point of Ash

- Clinker (agglomerations of carbon and metals) formation temperature, 2000 to 2200 F (1100-1200 C)

Ultimate Analysis

- Molecular composition (C, H, N, O, P, etc.)

Energy Content

- Knowledge of the energy content of an organic fraction of solid waste is essential for evaluating its potential for use as a fuel in a combustion system.
- Depends on the constituents of a sample
- Can be estimated by modified Dulong formula

Energy Content (KJ/Kg) = 338.2C+1430 (H-O/8) + 95.4S

Inert Residue and energy content of typical MSW

Components	Inert Residue Percentage		Energy, kJ/kg	
	Range	Typical	Range	Typical
Organic				
Food wastes	2-8	5	3489-6978	4652
Paper	4-8	6	11630-18608	16747
Cardboard	3-6	5	13956-17445	16282
Plastics	6-20	10	27912-37216	32564
Textiles	2-4	2.5	15119-18608	17445
Rubber	8-20	10	20934-27912	23260
Leather	8-20	10	15119-19771	17445
Yard wastes	2-6	4.5	2326-18608	6513
Wood	0.6-2	1.5	17445-19771	18608
Misc. organics	-	-	-	-
Inorganic				
Glass	96-99 +	98	116-233	140
Tin cans	96-99 +	98	233-1163	698
Aluminum	90-99 +	96	-	-
Other metal	94-99 +	98	233-1163	698
Dirt,ashes,etc	60-80	70	2326-11630	6978
Municipal solid waste	-	-	9304-13956	11630

Biological Characteristics

- The organic fraction of MSW (excluding plastics,rubber and leather) can be classified as:

- Water-soluble constituents - sugars, starches, amino acids and various organic acids
- Hemicellulose - a product of 5 and 6-carbon sugars
- Cellulose - a product of 6-carbon sugar glucose
- Fats, oils and waxes - esters of alcohols and long-chain fatty acids
- Lignin - present in some paper products
- Lignocellulose - combination of lignin and cellulose
- Proteins - amino acid chains

Biological Characteristics

Biodegradability

- Organic fraction often equated with the volatile solids (VS) content of the waste
  - However, not all organic materials are easily degradable
- Biodegradable fraction -
- Degradation produces odours
  - Hydrogen sulfide, H_2S (rotten eggs)
  - Methyl mercaptans
  - Aminobutyric acid
  - Methane is odourless.
- Attracts flies, vermin, rodents (vectors)

Biological Characteristics

- The most important biological characteristic of the organic fraction of MSW is that almost all the organic components can be converted biologically to gases and relatively inert organic and inorganic solids.

- The production of odors and the generation of flies are also related to the putrescible nature of the organic materials. These will be discussed when talking about landfill processes.

Biological Characteristics

- Volatile solids (VS), determined by ignition at 550°C, is often used as a measure of the biodegradability of the organic fraction of MSW.

- Some of the organic constituents of MSW are highly volatile but low in biodegradability (e.g. Newsprint) due to lignin content.

- The rate at which the various components can be degraded varies markedly. For practical purposes, the principal organic waste components in MSW are often classified as rapidly and slowly decomposable.

Biodegredable fractions of typical MSW

Component	Percent of MSW	Percent of each component that is biodegredable
Paper and paperboard	37.6	0.50
Glass	5.5	0
Ferrous metals	5.7	0
Aluminum	1.3	0
Other nonferrous metals	0.6	0
Plastics	9.9	0
Rubber and leather	3.0	0
Textiles	3.8	0.5
Wood	5.3	0.7
Other materials	1.8	0.5
Food waste	10.1	0.82
Yard trimmings	12.8	0.72
Miscellaneous inorganic	1.5	0.8
Total	100	

Chemical formula of solid waste

- Step One: Derive ultimate analysis and moisture of solid waste components
- Step Two: Convert moisture content into hydrogen and oxygen
- Step Three: Revise Composition in Kg
- Step Four: Compute Molar Composition of Waste
- Step Five: Compute Normalized Mole ratio

Forecasting Future waste quantities

Factors to be considered :

- waste generation rate
- waste characteristics
- rate of population growth
- degree of commercial and industrial development
- per capita consumption
- future policy directives and their effect on waste management practices

Macroeconomic factors

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