Chapter 9&12

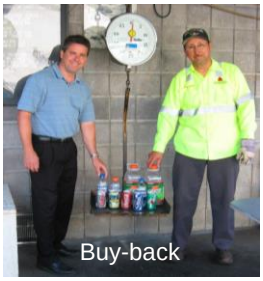
Separation and Processing of Solid Waste

Recovery of Materials in MSW

- The methods now used to recover source-separated waste materials include *curb side collection* and homeowner delivery of separated materials to *drop-off* and *buy-back centers*.
- The further separation and processing of wastes that have been *source-separated*, as well as the separation of the *commingled wastes*, usually occur at materials recovery facilities (MRFs) or at large integrated materials recovery/ transfer facilities (MR/TF).

Materials recovery and transfer

Curbside collection

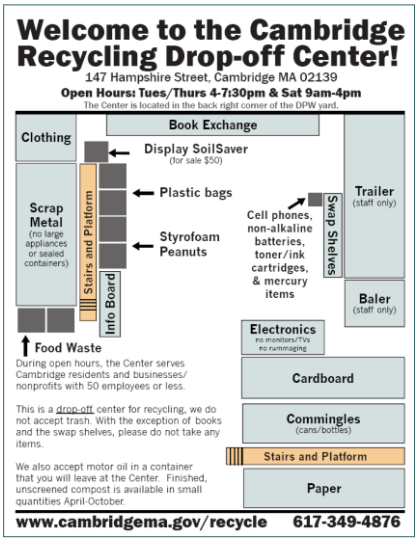

Buy-back

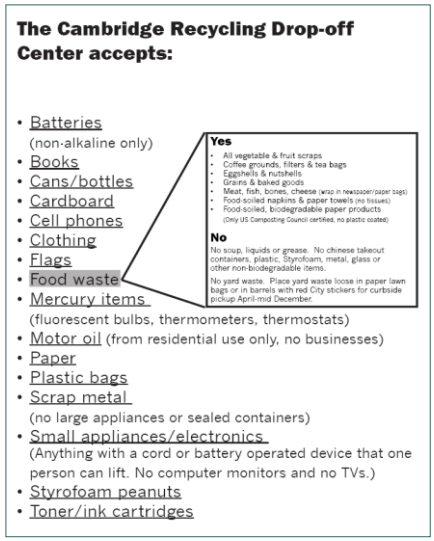
Drop-off

Drop-off and Buy-back

- *Drop-off* programs require residents or businesses to separate recyclable materials at source and bring them to a specified drop-off or collection center.
- *Buy-back* refers to a drop-off program that provides a monetary incentive to participate. Residents are paid for their recyclables either directly or indirectly through a reduction in monthly collection and disposal fees.

Drop-off and Buy-back





Materials recovery and transfer

Example 9.1 Home separation and delivery to drop-off centers

- A community of 1200 homes cannot pay for the initial and operating costs of the recycling collection vehicles that were to be used.
- Instead, residents are to haul recycling containers to a drop-off center operated by the community.
- Calculate the number of cars from which recyclable materials must be unloaded per hour at the recycling drop-off center.
- Assume the center is open for eight hours per day, two days per week, and that 40% of the residents will deliver recycling containers.
- Also assume that 75% of the participants will take their separated materials to the drop-off center once per week and that the remaining 25% of the participants will bring their separated materials to the drop-off center once every 2 weeks.

Example 9.1 Home separation and delivery to drop-off centers

Solution

- Determine the average number of trips per week.
  Trips/wk = [1200 homes * 0.40 * 0.75 * 1 trip/home.wk] + [1200 homes * 0.40 * 0.25 * 0.5 trip/home.wk]
  = 420 trips/wk
- Determine the average number of cars per hour.
  Cars/hr = 420 cars/wk / (2 day/wk * 8 hr/day)
  = 27 cars/hr

Comment

- Clearly, a small drop-off center cannot accommodate 27 cars/hr (equivalent to one car unloading every 2.2 minutes).
- Also, it is unlikely that the cars would arrive at a uniform rate.
- The most viable solution is to increase the number of hours per week that the drop-off center will be open.

Materials recovery and transfer

- Integrated Materials Recovery/Transfer Facilities (MR/TFs) may include the functions of;
  - drop-off center for separated wastes
  - materials separation facility
  - facility for the composting and bioconversion of wastes
  - facility for the production of refuse-derived fuel
  - transfer and transport facility

Separation of materials in MSW

- Waste separation at source is usually accomplished by manual means.
- MRFs and MR/ TFs are used for;
  - Further processing of source-separated wastes obtained from curbside collection programs and drop-off, pay-back centers w/o processing facilities.
  - Separation and recovery of reusable and recyclable materials from commingled MSW
  - Improvements in the quality of recovered waste materials

Uses for recovered materials

(Table 9-2, pp.250)

- Direct reuse
- Raw materials for remanufacturing and reprocessing
- Feedstock for the production of biological and chemical conversion products
- Fuel source for production of energy
- Land reclamation

Unit operations for separation and processing (Table 9.3, pp.256)

- Size Reduction
- Screening
- Density separation (air classification)
- Magnetic separation
- Densification (compaction)

Size reduction

- Collected waste materials are mechanically reduced in size using shredders, glass crushers, wood grinders, etc.

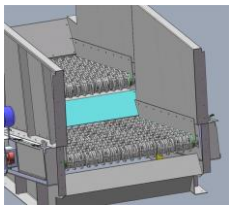
Hammer Mill Shredder

Crushers

Screening

- It is used to separate mixtures of materials of different sizes into two or more size fractions by means of one or more screening surfaces e.g. vibrating screens, rotary screens, disc screens, etc.

Rotary Screen

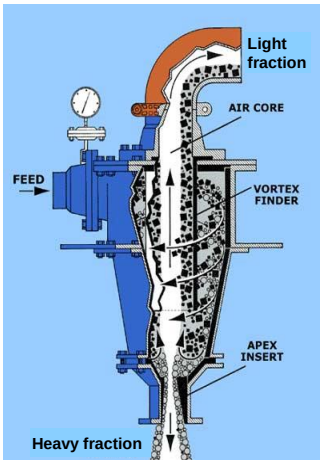


Disc Screen

Vibrating Screen

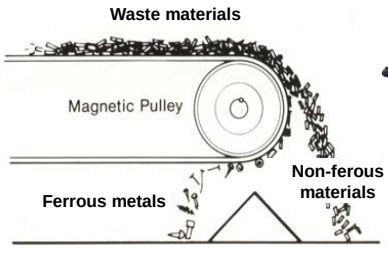
Density separation (Air classification)

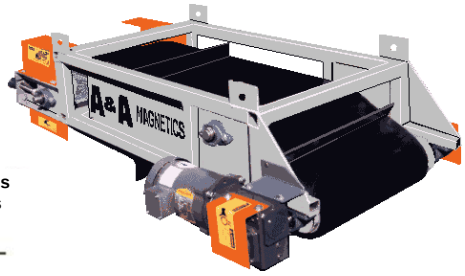
- It is used to separate light materials such as paper & plastics from heavier materials such as ferrous metals, based on weight differences of materials in air stream.



Magnetic Separation

- Ferrous metals are separated from other waste materials by utilizing their magnetic properties





Densification (Compaction)

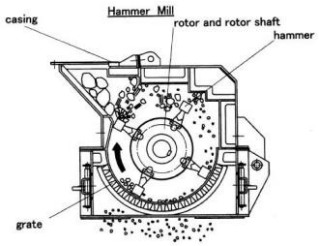
- It increases the density of waste materials so that they can be stored and transported more efficiently and as a means of preparing densified refuse-derived fuels (dRDF) (balers, can crushers, etc.)

Densified RDF

Compacted waste materials

Cardboard baler

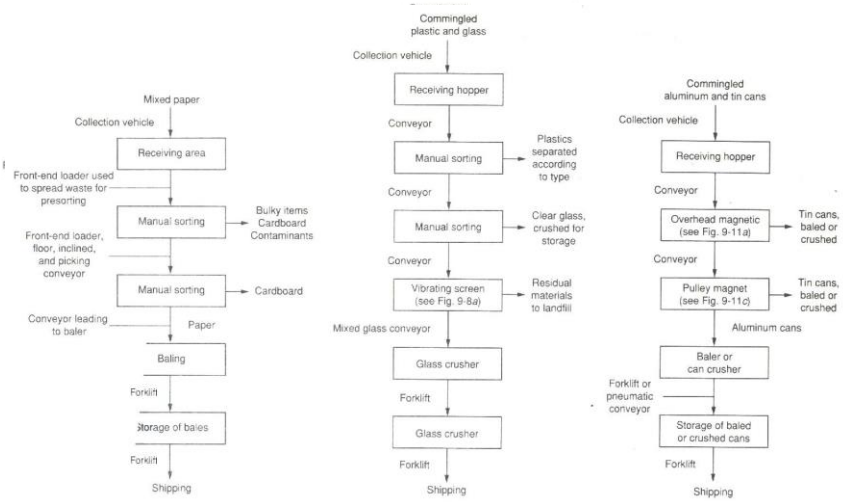
Table 9.3



Item	Function/material processed	Preprocessing
Unit operations		
Shredding		
Hammer mills	Size reduction/all types of wastes	Removal of large bulky items, removal of contaminants
Flail mills	Size reduction, also used as bag breaker/all types of wastes	Removal of large bulky items, removal of contaminants
Shear shredder	Size reduction, also used as bag breaker/all types of wastes	Removal of large bulky items, removal of contaminants
Glass crushers	Size reduction/all types of glass	Removal of all nonglass materials
Wood grinders	Size reduction/yard trimmings/all types of wood wastes	Removal of large bulky items, removal of contaminants
Screening	Separation of over- and under-sized material; trommel also used as bag breaker/all types of waste	Removal of large bulky items, large pieces of cardboard
Cyclone separator	Separation of light combustible materials from air stream/prepared waste	Material is removed from air stream containing light combustible materials
Density separation (air classification)	Separation of light combustible materials from air stream	Removal of large bulky items, large pieces of cardboard, shredding of waste
Magnetic separation	Separation of ferrous metal from commingled wastes	Removal of large bulky items, large pieces of cardboard, shredding of waste
Densification		
Balers	Compaction into bales/paper, cardboard, plastics, textiles, aluminum	Balers are used to bale separated components
Can crushers	Compaction and flattening/aluminum and tin cans	Removal of large bulky items
Wet separation	Separation of glass and aluminum	Removal of large bulky items
Weighing facilities		
Platform scales	Operational records	
Small scales	Operational records	
Handling, moving, and storage facilities		
Conveyor belts	Materials transport/all types of materials	Removal of large bulky items
Picking belts	Manual separation of waste materials/source-separated and commingled MSW	Removal of large bulky items
Screw (auger) conveyors (Use not well established)	Materials transport; also used as bag breaker/all types of waste	Removal of large bulky items
Movable equipment	Materials handling and moving/all types of waste	
Storage facilities	Materials storage/all types of recovered materials	Densification, glass crushing, etc.

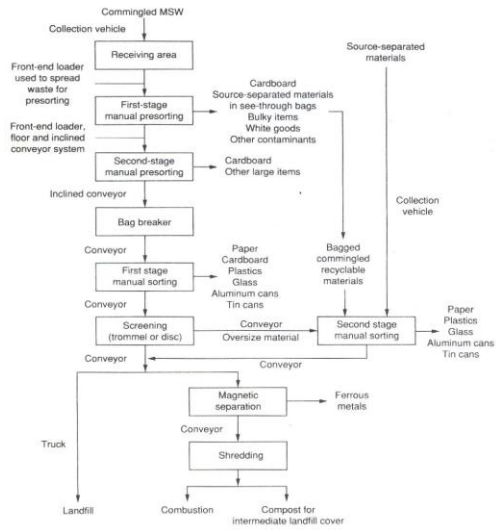
Separation of source separated MSW

(Figure 9.21,pp.278)



Separation of commingled MSW

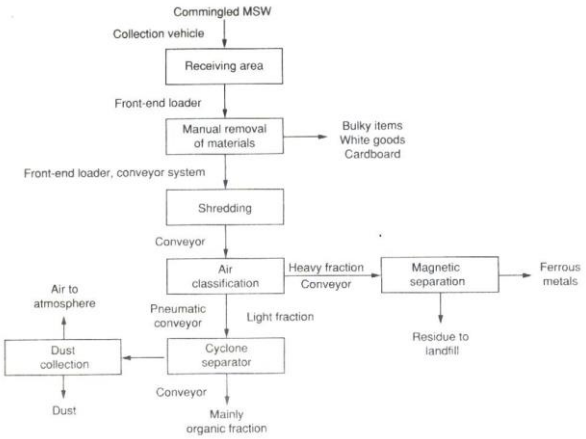
(Figure 9.28, pp.284)



Separation of commingled MSW

(Figure 9.29, pp.286)

Highly mechanized system



Single-stream recycling

- When the recyclables arrive at the MRF, they are dumped onto the “tipping floor”.
- Then they are pushed onto a conveyor belt.
- The conveyor belt takes the recyclables to the “sort line” where the materials are sorted by hand and by machines.

Single-stream recycling

- At first, the workers separate the paper and cardboard from the other materials. They throw them into the chutes.
- Then, they check to make sure that no glass, plastic, aluminum or steel is mixed in with the paper.

Single-stream recycling

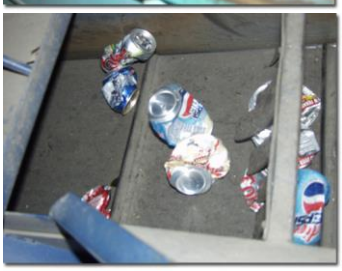
- The baler compacts the loose paper into huge rectangular bales. Bales keep their shape because they are tied with baling wire.
- Bales are stacked together until there is enough to fill a truck trailer.
- When there are enough bales, they are loaded and transported to a processor, where new paper is produced out of recycled paper.

Single-stream recycling

- After separation of paper, the plastics are separated manually according to their sorts, such as transparent and colored plastics.
- The rest is grouped together.
- After separation of plastics, glass bottles are separated manually into the three colors: clear, brown and green.

Single-stream recycling

- The steel is separated from the other materials by a magnet that sits above the sort line.
- Steel cans are grabbed off the line by the magnet. The magnet rotates from left to right and drops the steel cans into a bin on the right.
- Aluminum cans travel beneath the magnet and are not picked up, remain on the line.



Single-stream recycling

Bale of PETE plastic

Bale of aluminum cans

Bale of steel cans

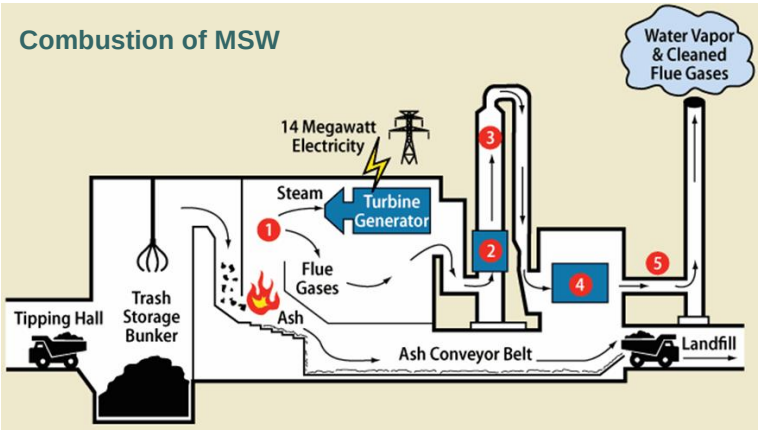
Video-1
https://www.youtube.com/watch?v=7CFE5tD1CCI

Video-2
https://www.youtube.com/watch?v=Jda_9_30-WU

Waste transformation through combustion

- The most commonly used chemical transformation process is combustion, which can be used to reduce the original volume of the combustible fraction of MSW by 85 to 95%.
- In addition, the recovery of energy in the form of heat is another attractive feature of the combustion process.
- Although combustion technology has advanced in the past two decades, air pollution control is a major concern in implementation
- **Chapter 13 - *Thermal Conversion Technologies***

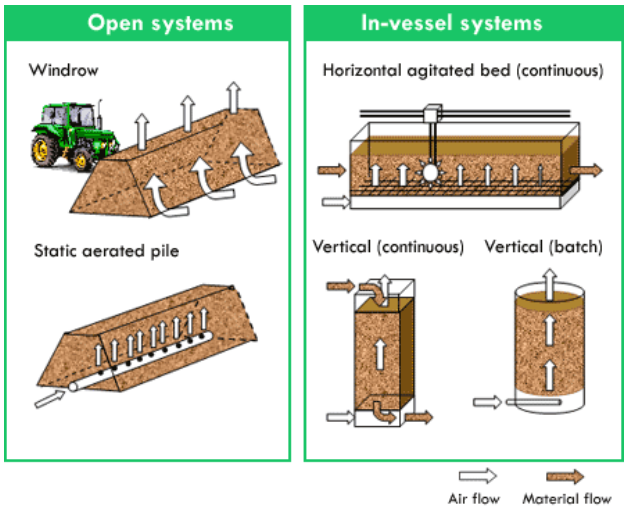
Thermal conversion - Combustion



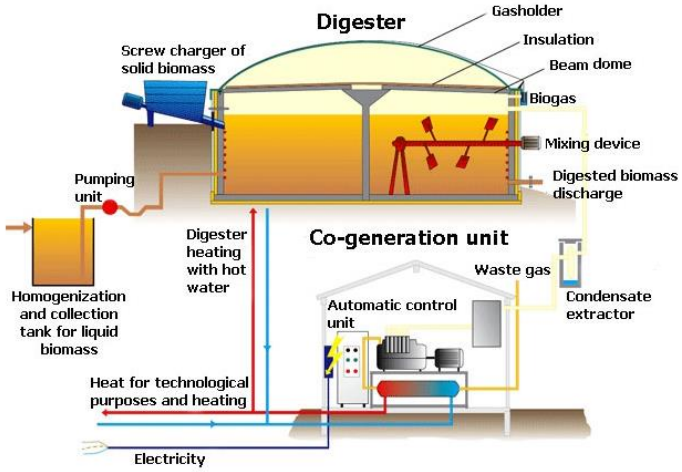
Waste transformation through anaerobic digestion/composting

- With the exception of plastic, rubber and leather components, the OFMSW is composed of proteins, lipids, carbohydrates, cellulose, lignin and ash.
- If these organic materials are subjected to anaerobic/aerobic microbial decomposition, the end product is a humus material known as compost.
- When added to soil, compost lightens heavy soils, improve texture of light soil and increase water retention capacity.
- **Chapter 14 - *Biological Conversion Technologies***

Biological conversion - Composting



Biological conversion - Anaerobic Digestion



Example 9.2 Determination of the stoichiometric amount of air required for the combustion of an organic solid waste.

- Determine the amount of (kg and m^3) of air required for the complete combustion of one ton of an organic solid waste
- Assume that the composition of the organic waste to be combusted is given by C_5H_{12}. Assume the density of air is 1.2 kg / m^3
- Write a balanced stoichiometric equation for the oxidation of the organic compound based on oxygen:

  $C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$

Example 9-2 Determination of the stoichiometric amount of air required for the combustion of an organic solid waste.

Solution

- Determine the amount of air required for combustion, assuming air contains 23.15% oxygen by weight.

  O_2 required = $\frac{256}{72} x 1000\ kg = 3555\ kg$

  Air required = $\frac{3555\ kg}{0.2315} = 15356\ kg$
- The amount of air required for combustion can also be computed using the factors, given previously.

  Air required for C = $\frac{60}{72} x\ 1000\ kg\ x\ 11.52 = 9600\ kg$

  Air required for H = $\frac{12}{72} x\ 1000\ kg\ x\ 34.56 = 5760\ kg$

  Total air required = $15360\ kg$
- Determine the volume of air required for combustion.

  Volume of air = (15356 kg) / (1.2 kg/m^3) = 12797 m^3

Example 9.2 Determination of the stoichiometric amount of air required for the combustion of an organic solid waste.

Solution

- Write a balanced stoichiometric equation for the oxidation of the organic compound based on oxygen:

  $C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$

- Determine the amount of air required for combustion, assuming air contains 23.15% oxygen by weight.

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  Air required for H = $\frac{12}{72} x\ 1000\ kg\ x\ 34.56 = 5760\ kg$

  Total air required = $15360\ kg$

Example 9.3 Determination of volume reduction and volume of residue after combustion.

- Determine the quantity and composition of the residue from a combustor used for MSWs with the average composition given below.
- Estimate the reduction in waste volume if it is assumed that the specific weight of the residue is 600 kg/m^3.

Component	%	Inert residue, %
Organic		
Food wastes	9	5
Paper	34	6
Cardboard	6	5
Plastics	7	10
Textiles	2	6.5
Rubber	0.5	9.9
Leather	0.5	9.0
Yard wastes	18.5	4.5
Wood	2	1.5
Inorganic		
Glass	8	98
Tin cans	6	98
Aluminum	0.5	96
Other metal	3	98
Dirt, ash, etc	3	68

Example 9.3 Determination of volume reduction and volume of residue after combustion.

Component	MSW, kg	Moisture content, %	Dry weight, kg	Inert Residue, %	Inert Residue, kg	% distribution in residue
Organic						
Food wastes	90	70	27	5	1,4	0,6
Paper	340	6	319,6	6	19,2	8,6
Cardboard	60	5	57	5	2,9	1,3
Plastics	70	2	68,6	10	6,9	3,1
Textiles	20	10	18	6.5	1,2	0,5
Rubber	5	2	4,9	9.9	0,5	0,2
Leather	5	10	4,5	9.0	0,4	0,2
Yard wastes	185	60	74	4.5	3,3	1,5
Wood	20	20	16	1.5	0,2	0,1
Inorganic			0			
Glass	80	2	78,4	98	76,8	34,7
Tin cans	60	3	58,2	98	57,0	25,7
Aluminum	5	2	4,9	96	4,7	2,1
Other metal	30	3	29,1	98	28,5	12,9
Dirt, ash, etc	30	8	27,6	68	18,8	8,5
Total	1000				221.7	100

Example 9.3 Determination of volume reduction and volume of residue after combustion.

- Estimate the original and final volumes before and after combustion. To estimate the approximate initial volume, assume that the average specific weight of the solid wastes in the combustor storage pit is about 250 kg/m^3.

$$\text{Original volume} = \frac{1000\ kg}{250\ kg/m^3} = 4.0\ m^3$$

$$\text{Residue volume} = \frac{221.7\ kg}{600\ kg/m^3} = 0.37\ m^3$$

- Estimate the volume reduction by using the following Eq.

$$\text{Volume reduction} = \frac{(4.0-0.37)}{4.0} x\ 100 = 91\%$$

Example 9.4 Estimate the change in the energy content of MSW for various levels of recycling

- Determine the energy content of the typical MSW given in Table 3-4 for the following levels of recycling.
- Also determine the overall recycle percentage, by weight, represented by each level of recycling.

	Level of recycling, %		
Component	**One**	**Two**	**Three**
Organic			
Food wastes	0	0	0
Paper	20	35	50
Cardboard	20	30	40
Plastics	20	30	40
Textiles	10	20	30
Rubber	10	20	30
Leather	10	20	30
Yard wastes	0	15	30
Wood	10	20	30
Inorganic			
Glass	20	30	40
Tin cans	10	20	30
Aluminum	50	70	90
Other metal	10	20	30
Dirt, ash, etc	0	0	0

Example 9.4 Estimate the change in the energy content of MSW for various levels of recycling **Solution:**

	Weight, kg (% by weight)							
Component	**No recycling**		**Level 1**		**Level 2**		**Level 3**	
Food wastes	9.0	(9.0)	9.0	(10.3)	9.0	(11.9)	9.0	(13.9)
Paper	34.0	(34.0)	27.2	(31.1)	22.1	(29.1)	17.0	(26.3)
Cardboard	6.0	(6.0)	4.8	(5.5)	4.2	(5.5)	3.6	(5.6)
Plastics	7.0	(7.0)	5.6	(6.4)	4.9	(6.4)	4.2	(6.5)
Textiles	2.0	(2.0)	1.8	(2.1)	1.6	(2.1)	1.4	(2.2)
Rubber	0.5	(0.5)	0.5	(0.6)	0.4	(0.5)	0.4	(0.6)
Leather	0.5	(0.5)	0.5	(0.6)	0.4	(0.5)	0.4	(0.6)
Yard wastes	18.5	(18.5)	18.5	(21.1)	15.7	(20.7)	13.0	(20.1)
Wood	2.0	(2.0)	1.8	(2.0)	1.6	(2.1)	1.4	(2.2)
Glass	8.0	(8.0)	6.4	(7.3)	5.6	(7.4)	4.8	(7.4)
Tin cans	6.0	(6.0)	5.4	(6.2)	4.8	(6.3)	4.2	(6.5)
Aluminum	0.5	(0.5)	0.3	(0.3)	0.2	(0.3)	0.1	(0.2)
Other metal	3.0	(3.0)	2.7	(3.1)	2.4	(3.2)	2.1	(3.3)
Dirt,ash, etc.	3.0	(3.0)	3.0	(3.4)	3.0	(4.0)	3.0	(4.6)
Total	100.0	(100.0)	87.5	(100.0)	75.9	(100.0)	64.6	(100.0)
Amount of waste recyled, %	0.0		12.5		24.1		35.4	

Example 9.4 Estimate the change in the energy content of MSW for various levels of recycling

Solution:

9 kg * 4652 kJ/kg = 41868 kJ

1178191 kJ / 100 kg = 11781.9 kJ/kg

		Total energy content, kJ			
Component	**Energy, kJ/kg**	**No recycling**	**Level 1**	**Level 2**	**Level 3**
Food wastes	4652	41868	41868	41868	41868
Paper	16747	569398	455518	370109	284699
Cardboard	16282	97692	78154	68384	58615
Plastics	32564	227948	182358	159564	136769
Textiles	17445	34890	31401	27912	24423
Rubber	23260	11630	11630	9304	9304
Leather	17445	8723	8723	6978	6978
Yard wastes	6513	120491	120491	102254	84669
Wood	18608	37216	33494	29773	26051
Glass	140	1120	896	784	672
Tin cans	698	4188	3769	3350	2932
Aluminum	0	0	0	0	0
Other metal	698	2094	1885	1675	1466
Dirt,ash, etc.	6978	20934	20934	20934	20934
Energy content, kJ/kg		11781.9	9911.2	8428.9	6993.8
kcal/kg		2816	2369	2015	1672

(11781.9 kJ/kg) / (4.184 kJ/kcal) = 2816 kcal/kg