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INTEGRATED WASTE MANAGEMENT FOR A SMART CITY

FOCUSSED ON MSW, C&D AND E-WASTE MANAGEMENT

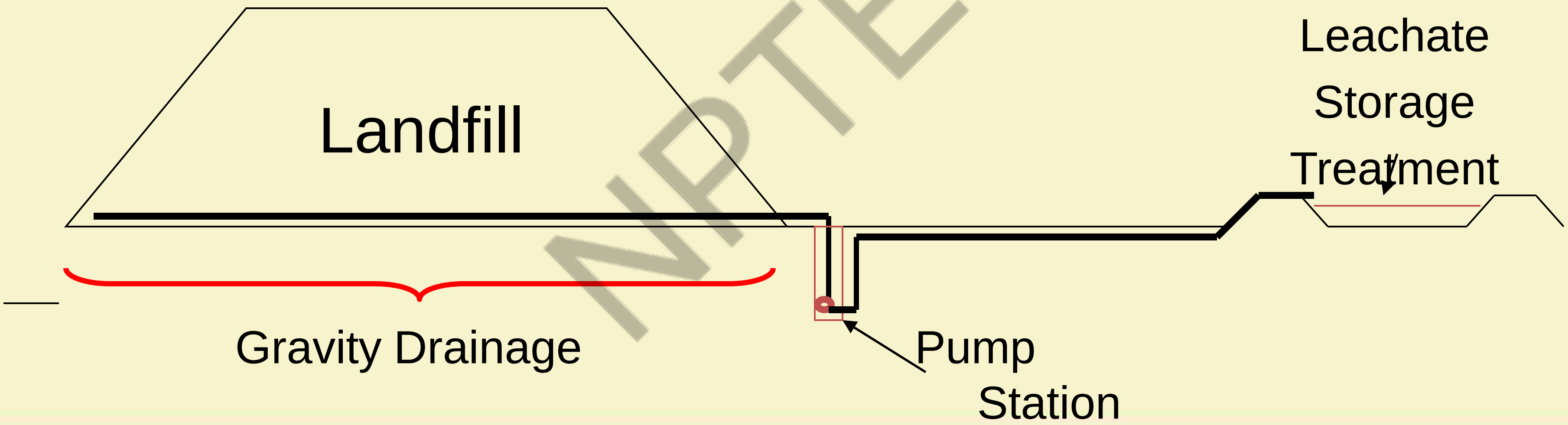
BRAJESH KUMAR DUBEY

DEPARTMENT OF CIVIL ENGINEERING

During this week (Week-2)

- Municipal Solid Waste Characteristics and Quantities
- Landfill Basics (items left from previous week)

Leachate is then sent to Treatment and/or Storage Facility




CAT

Leachate

- Can contain many compounds. The quality of leachate is dictated by the type waste. For MSW, leachate quality is very much dictated by the phase of landfill stabilization.

Waste Stabilization

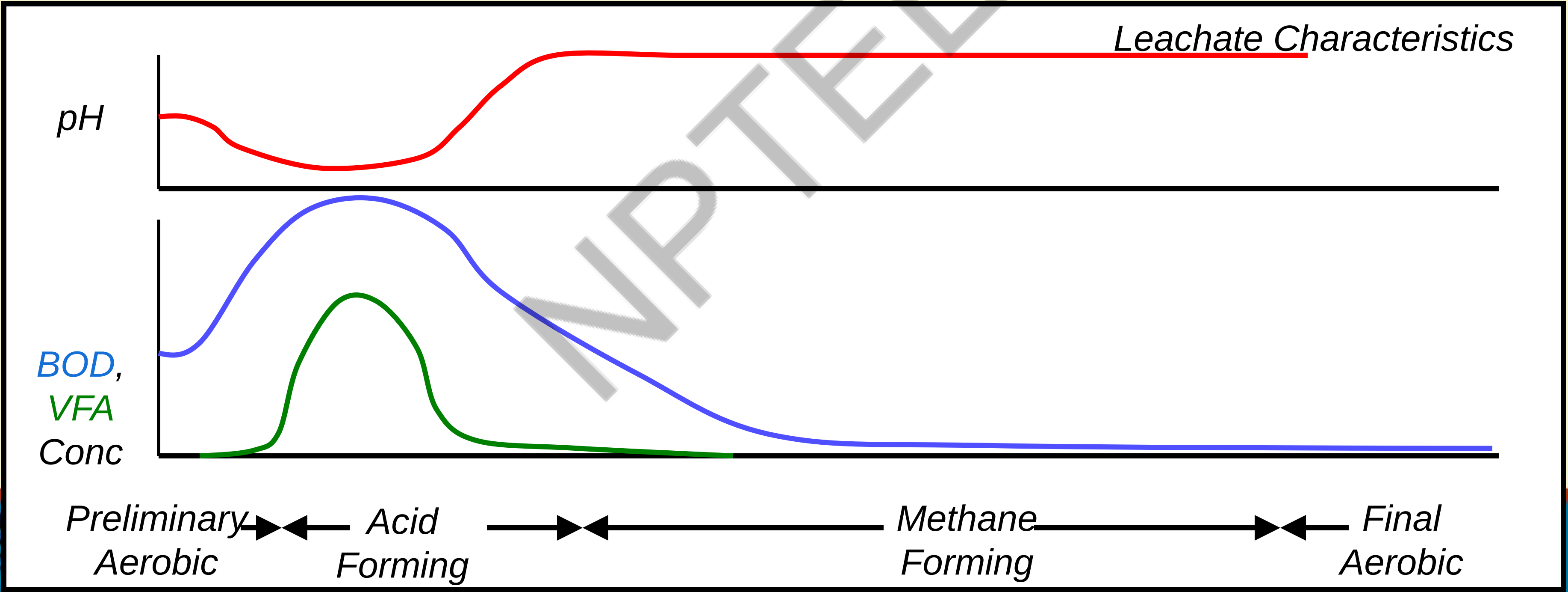
- Phases of Landfill Stabilization
  - Previous investigators have described different phases of landfill stabilization
  - Simplified version:

Preliminary Aerobic Phase → Acid Forming Phase → Methane Forming Phase → Final Aerobic Phase

Preliminary Aerobic Phase	Acid Forming Phase	Methane Forming Phase	Final Aerobic Phase
Aerobic	*Anaerobic*	*Anaerobic*	*Aerobic*

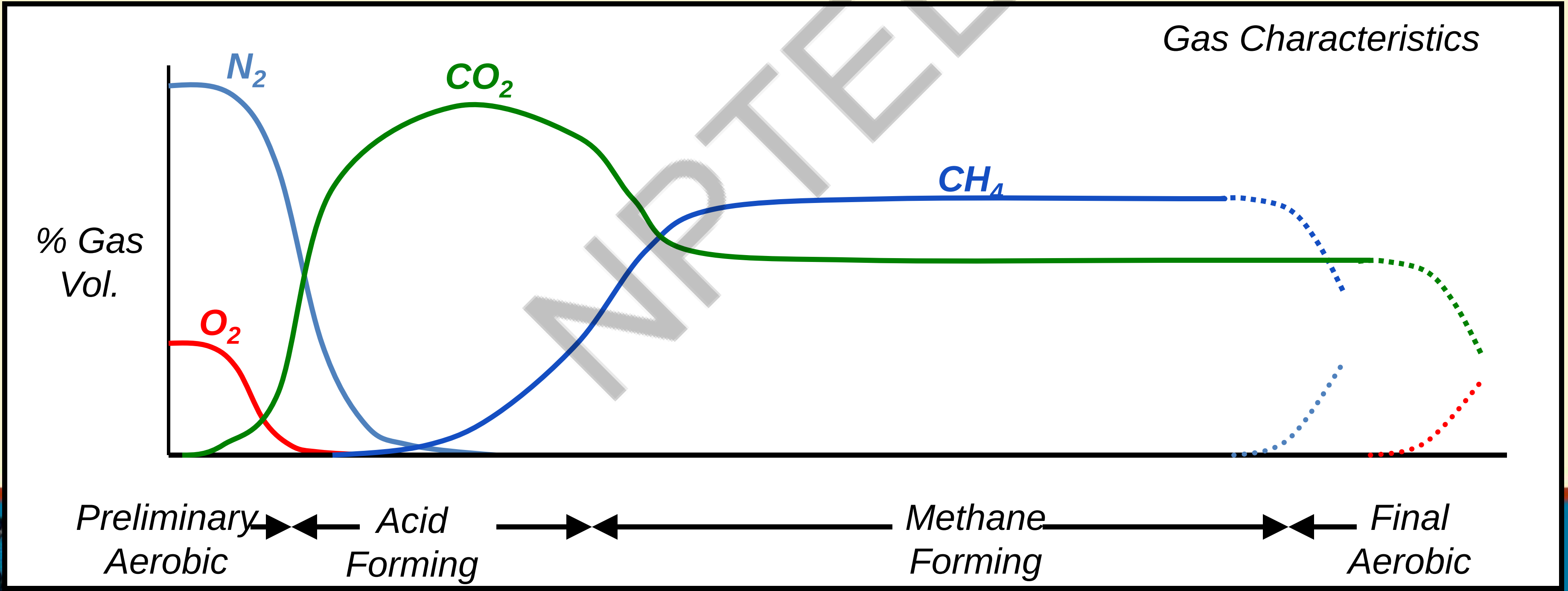
Waste Stabilization

- The phase of stabilization influences leachate and gas characteristics



Waste Stabilization

- The phase of stabilization influences leachate and gas characteristics



Landfill Gas

- Gas wells are typically installed after the landfill has been filled up
- A vacuum is pulled on these wells to extract the gas into a pipe system
- The gas is then flared or turned to energy

Landfill Gas

- What is Landfill Gas?

$$C_6H_{10}O_5 + H_2O \rightarrow 3CH_4 + 3CO_2$$

Landfill Gas Contains

- Methane
- Carbon Dioxide
- Water Vapor
- Hydrogen Sulfide
- NMOC (non methane organic compounds)
- heavy metals??

Why Bother with Landfill Gas?

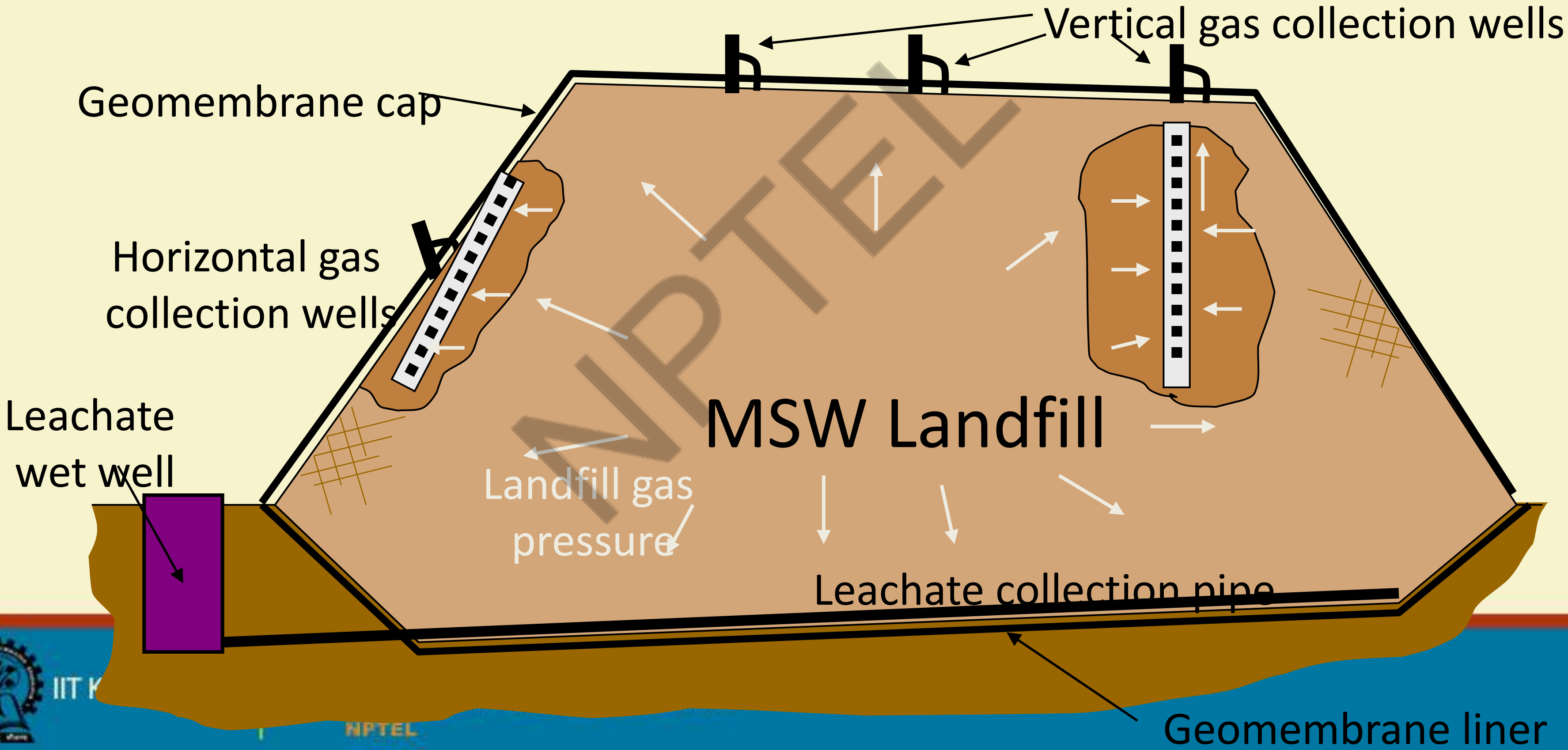
- Odor
- Toxics
- Greenhouse Gas
- Explosive Gas

- Potential Energy Source

How is Gas Collected?

- Typically use vertical wells.
- Installed after landfill has reached final grade.
- Use an auger.

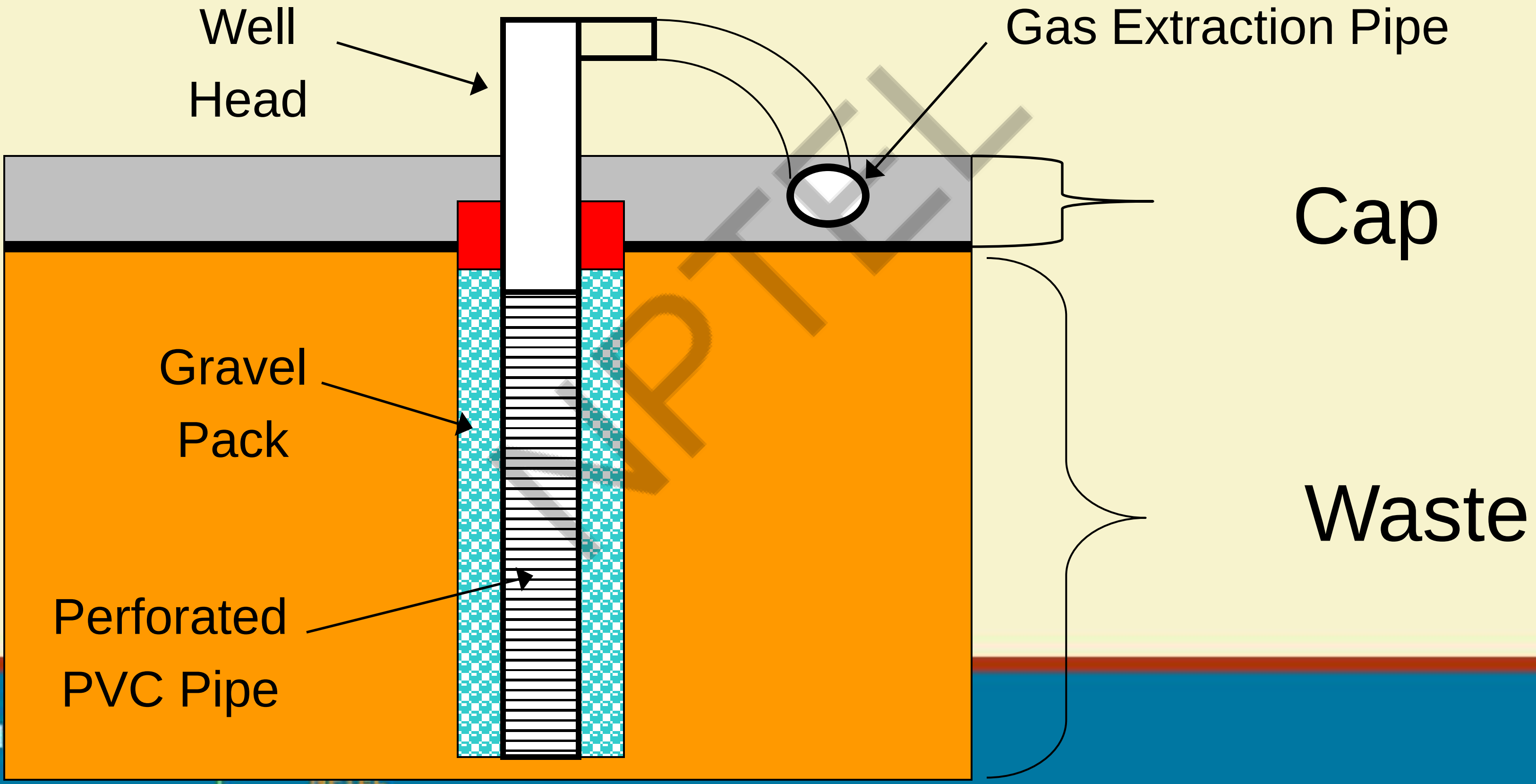
Landfill gas generation and flow



Wells

- Passive Wells (wells open to atmosphere)
- Active Wells (wells connected to a gas extraction system).

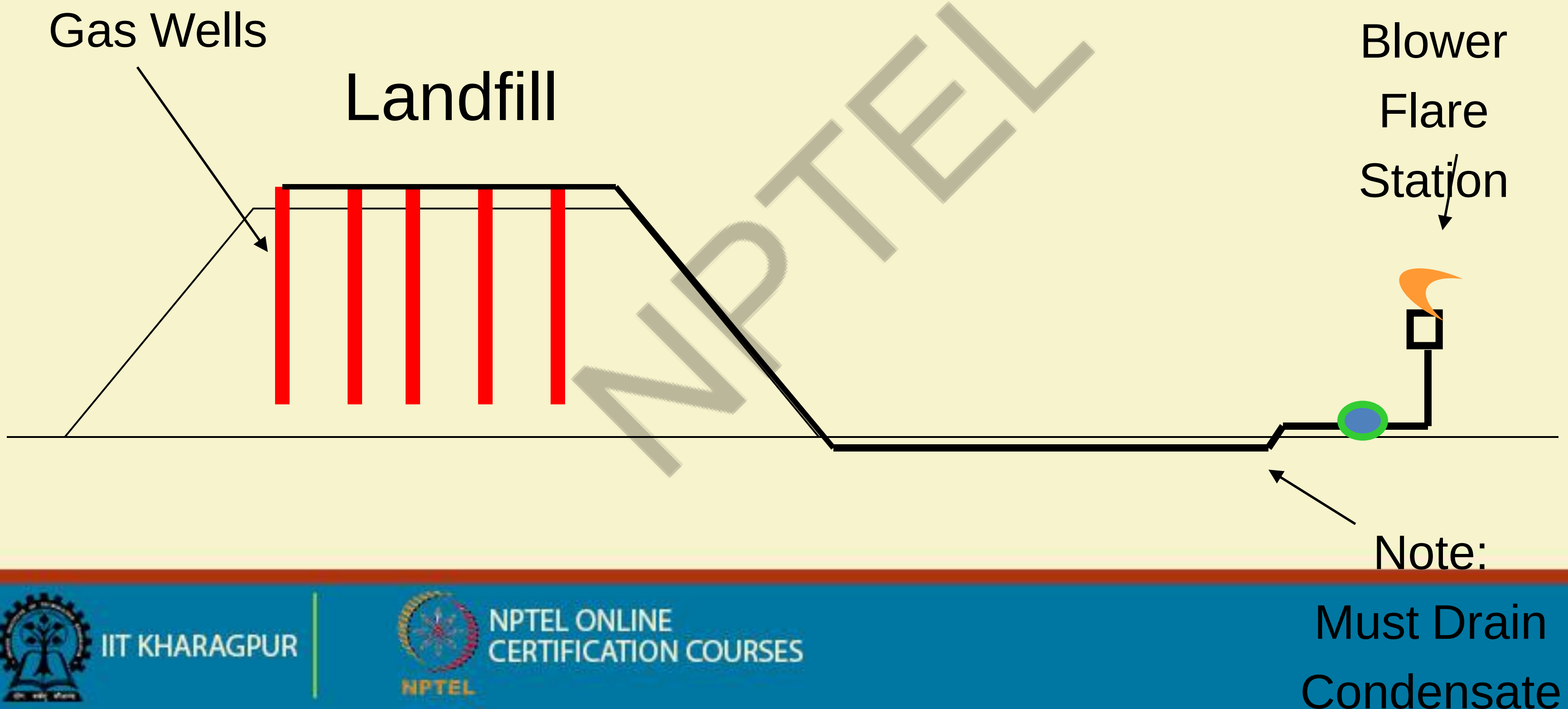
Typical Landfill Gas Well



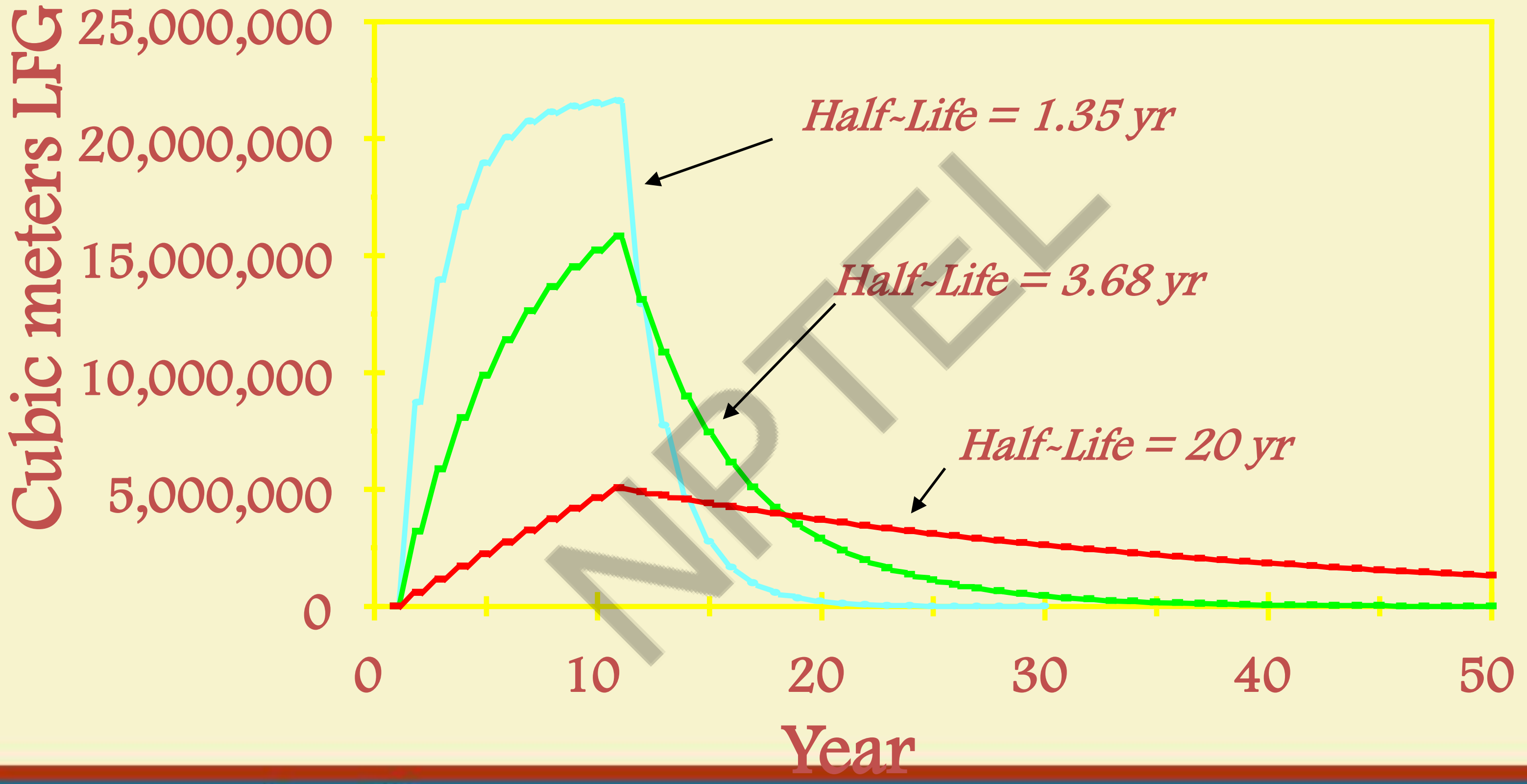
What is the Driving Force for Gas to Leave the Landfill?

- Pressure
- Without any wells, gas will find way to surface (or bottom)
- Wells provide path of escape (create pressure gradient)

Landfill Gas is Typically Extracted to a Blower-Flare Station



LFG Generation Curves

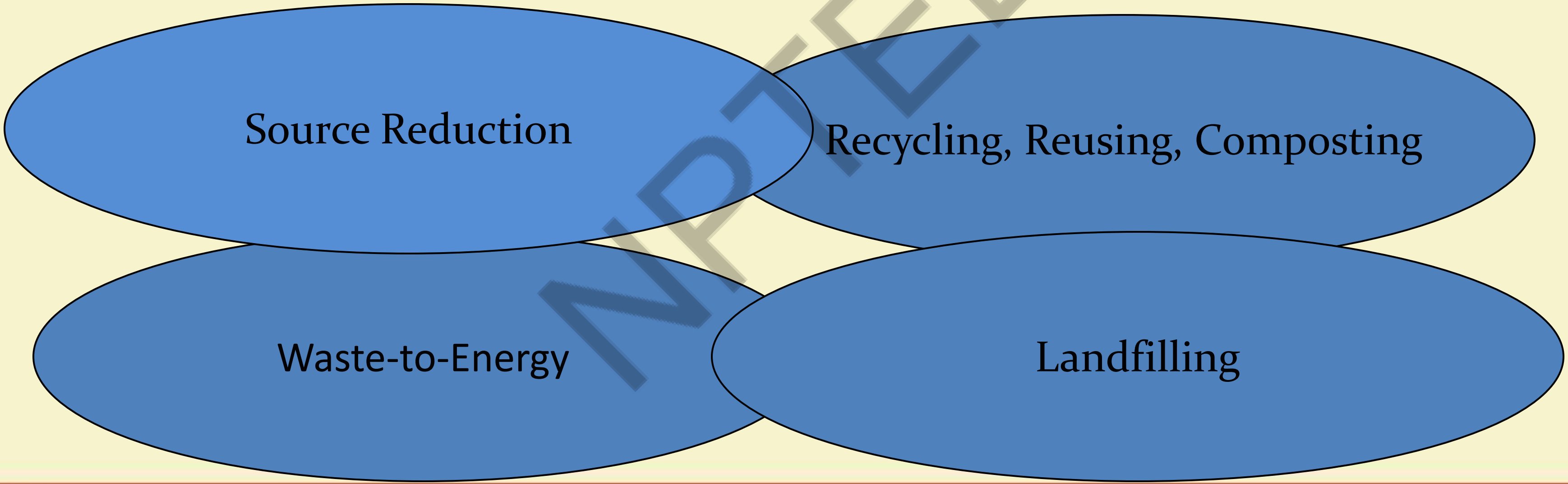


What is Condensate?

- Moisture that condenses from landfill gas when it cools.

Gas to Energy?

Integrated Waste Management



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DEPARTMENT OF CIVIL ENGINEERING

Solid Waste Characterization

- Regulatory
- By source or generator
- Physical Characteristics
- Component Composition
- Chemical Composition

Two Primary Mechanisms for being a Hazardous Waste

- Listed
- Characteristic

Criteria for Listing

1. The waste typically contains harmful chemicals which indicate that it could pose a threat to human health and the environment in the absence of special regulations.

Toxic Listed Waste

Criteria for Listing

2. The waste contains such dangerous chemicals that it could pose a threat to human health and the environment even when properly managed. These wastes are fatal to humans and animals even in low doses.

Acutely Hazardous Waste

Criteria for Listing

3. The waste typically exhibits one of four characteristics of hazardous waste:
    - Ignitability
    - Corrosivity
    - Reactivity
    - Toxicity

Criteria for Listing

4. Regulating agency has cause to believe that, for some reason, the waste typically fits within the statutory definition of hazardous waste

Listed Wastes are Assigned Hazard Codes

- Hazard codes indicate why a waste is listed.
  - T Toxic Waste
  - H Acute Hazardous Waste
  - I Ignitable Waste
  - C Corrosive Waste
  - R Reactive Waste
  - E Toxicity Characteristic Waste

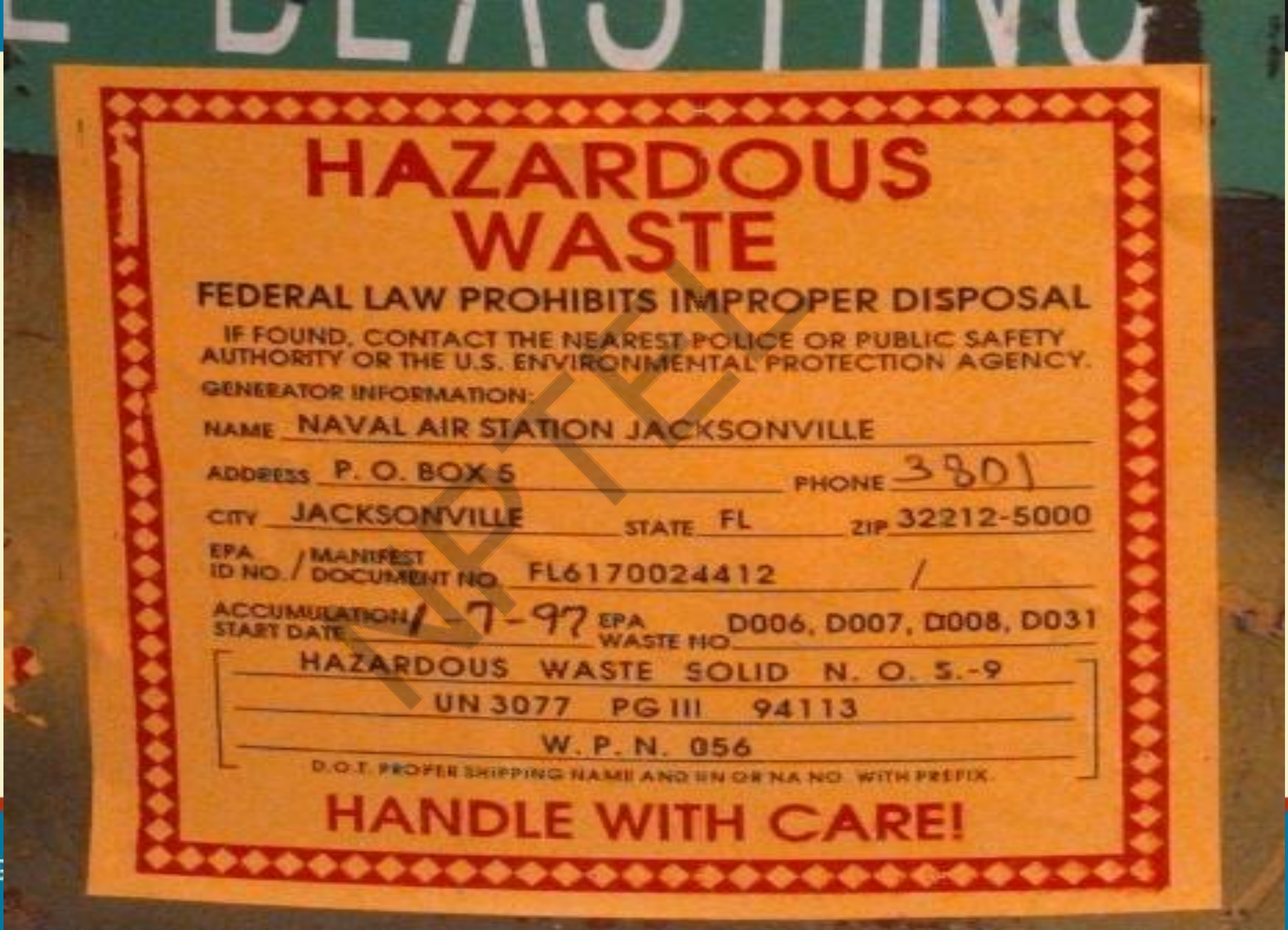
Toxicity

- The toxicity characteristic is determined using the Toxicity Characteristic Leaching Procedure (TCLP).

Toxicity Characteristic

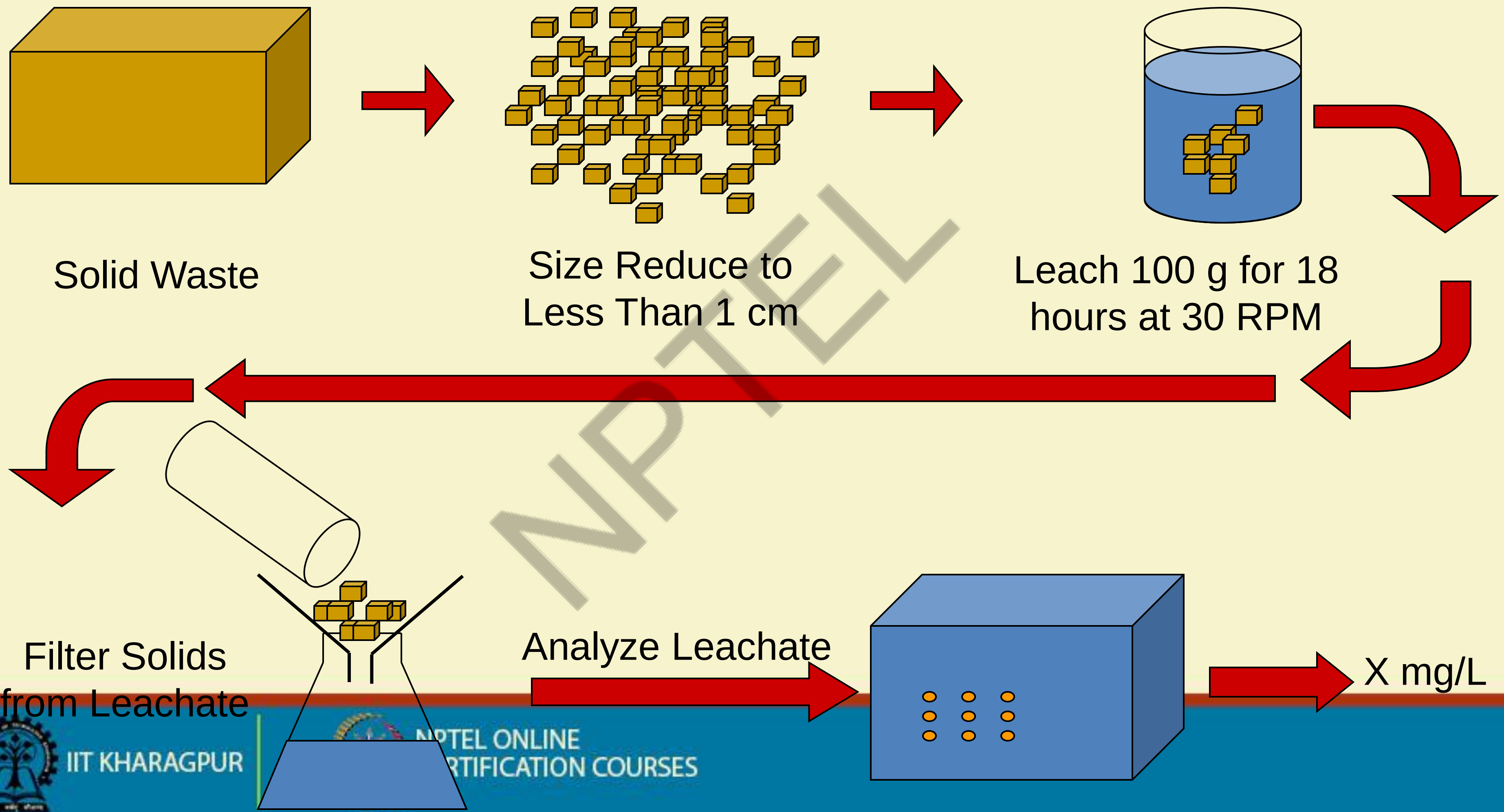
TABLE 1—MAXIMUM CONCENTRATION OF CONTAMINANTS FOR THE TOXICITY CHARACTERISTIC

EPA HW No.[1]	Contaminant	CAS No.[2]	Regulatory Level (mg/L)
D004	Arsenic	7440–38–2	5.0
D005	Barium	7440–39–3	100.0
D018	Benzene	71–43–2	0.5
D006	Cadmium	7440–43–9	1.0
D019	Carbon tetrachloride	56–23–5	0.5
D020	Chlordane	57–74–9	0.03
D021	Chlorobenzene	108–90–7	100.0
D022	Chloroform	67–66–3	6.0
D007	Chromium	7440–47–3	5.0
D023	o-Cresol	95–48–7	[4]200.0
D024	m-Cresol	108–39–4	[4]200.0
D025	p-Cresol	106–44–5	[4]200.0
D026	Cresol		[4]200.0
D016	2,4-D	94–75–7	10.0
D027	1,4-Dichlorobenzene	106–46–7	7.5
D028	1,2-Dichloroethane	107–06–2	0.5
D029	1,1-Dichloroethylene	75–35–4	0.7
D030	2,4-Dinitrotoluene	121–14–2	[3]0.13
D012	Endrin	72–20–8	0.02
D031	Heptachlor (and its epoxide).	76–44–8	0.008
D032	Hexachlorobenzene	118–74–1	[3]0.13
D033	Hexachlorobutadiene	87–68–3	0.5
D034	Hexachloroethane	67–72–1	3.0
D008	Lead	7439–92–1	5.0
D013	Lindane	58–89–9	0.4
D009	Mercury	7439–97–6	0.2


HAZARDOUS
WASTE
FEDERAL LAW PROHIBITS IMPROPER DISPOSAL
IF FOUND, CONTACT THE NEAREST POLICE OR PUBLIC SAFETY AUTHORITY OR THE U.S. ENVIRONMENTAL PROTECTION AGENCY.
GENERATOR INFORMATION:
NAME NAVAL AIR STATION JACKSONVILLE
ADDRESS P. O. BOX 5
PHONE 3801
CITY JACKSONVILLE
STATE FL
ZIP 32212-5000
EPA ID NO. / MANIFEST DOCUMENT NO. FL6170024412 /
ACCUMULATION START DATE 1-7-97
EPA WASTE NO. D006, D007, D008, D031
HAZARDOUS WASTE SOLID N. O. S.-9
UN 3077 PG III 94113
W. P. N. 056
D.O.T. PROPER SHIPPING NAME AND UN OR NA NO. WITH PREFIX.
HANDLE WITH CARE!

TCLP (Toxicity Characteristic Leaching Procedure)

- Determines Toxicity Characteristic (TC)
- Developed under the Resource Conservation and Recovery Act (RCRA)
- Representative of landfill conditions
- It is the most widely used waste leaching test in North America


Solid Waste
Size Reduce to Less Than 1 cm
Leach 100 g for 18 hours at 30 RPM
Filter Solids from Leachate
Analyze Leachate
X mg/L

Extraction Fluid Selection

- Fluid determination based on buffering ability of the waste
- Fluid #1
  - Acetic Acid + NaOH pH = 4.93 ± 0.05
- Fluid #2
  - Acetic Acid pH = 2.88 ± 0.05

Where Did EPA Get TCLP Concentration Limits?

- EPA defined what concentration would have to be placed in a landfill for it to exceed drinking water standards at a groundwater well.
  - The EPA applied a dilution factor of 100 to the Safe drinking water (SDWA) primary drinking water standards.
  - Although some SDWA standards have changed, the TCLP limits have not yet changed accordingly.

Where do you find descriptions (recipes) for laboratory methods?

- SW 846
- Test Methods for Evaluating Solid Waste
- Available on line at the EPA web site
- Example: TCLP is EPA Method 1311

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Solid Waste Characterization

- Elemental Composition
- Combustible Characteristics
- Biodegradable Characteristics

Note:

- It is also important to characterize the generation rate:
  - By Mass
  - By Volume

Characterize by Source or Generator

- Who created the waste:
  - Residential
  - Commercial
  - Industrial
  - Agricultural

Physical Characteristics

- Solid waste requires frequent conversion between mass and volume. This is not constant.
- What parameter describes this relationship?

Density

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Total Density (Bulk Density)

$$\rho_T = \frac{M_T}{V_T}$$

Dry Density

$$\rho_{dry} = \frac{M_S}{V_T}$$

Solid Density

$$\rho_s = \frac{M_s}{V_s}$$

Density or Specific Weight?

- Density is mass per volume
- Specific weight is weight (force) per volume

Why is Density Important?

Units of Density

- g/cm^3
- kg/m^3
- lb/ft^3
- lb/yd^3

Example Densities

• Water	1000kg/cu.m	1685 pcy
• Soil	1842 kg/cu.m	3105 pcy
• Concrete	2080 kg/cu.m	3510 pcy
• MSW Truck	325 kg/cum	550 pcy

MSW Landfill 650 – 770 kg/cum, 100 -1,300 pcy

Table 2-4 **Bulk Densities of Some Refuse Components**

Components	Condition	Bulk density (Kg/m^3)
Aluminum cans	Loose	30–44
	Flattened	150
Corrugated cardboard	Loose	210
Fines (dirt, etc.)	Loose	325–960
Food waste	Loose	130–490
	Baled	600–720
Glass bottles	Whole bottles	300–420
	Crushed	1080–1620
Magazines	Loose	480
Newsprint	Loose	12–33
	Baled	430–600
Office paper	Loose	240
	Baled	420–450
Plastics	Mixed	42–130
	PETE, whole	18–24
	Baled	240–300
	HDPE, loose	14
	Flattened	40
Plastic film and bags	Baled	300–480
	Granulated	420–450
Steel cans	Unflattened	90
	Baled	510
Textiles	Loose	42–100
Yard waste	Mixed, loose	150–300
	Leaves, loose	30–150
	Grass, loose	210–300

Specific Gravity

- The specific gravity of a material is the ratio of its density to the density of water (in the case of solid and liquids) or air (in the case of gases).

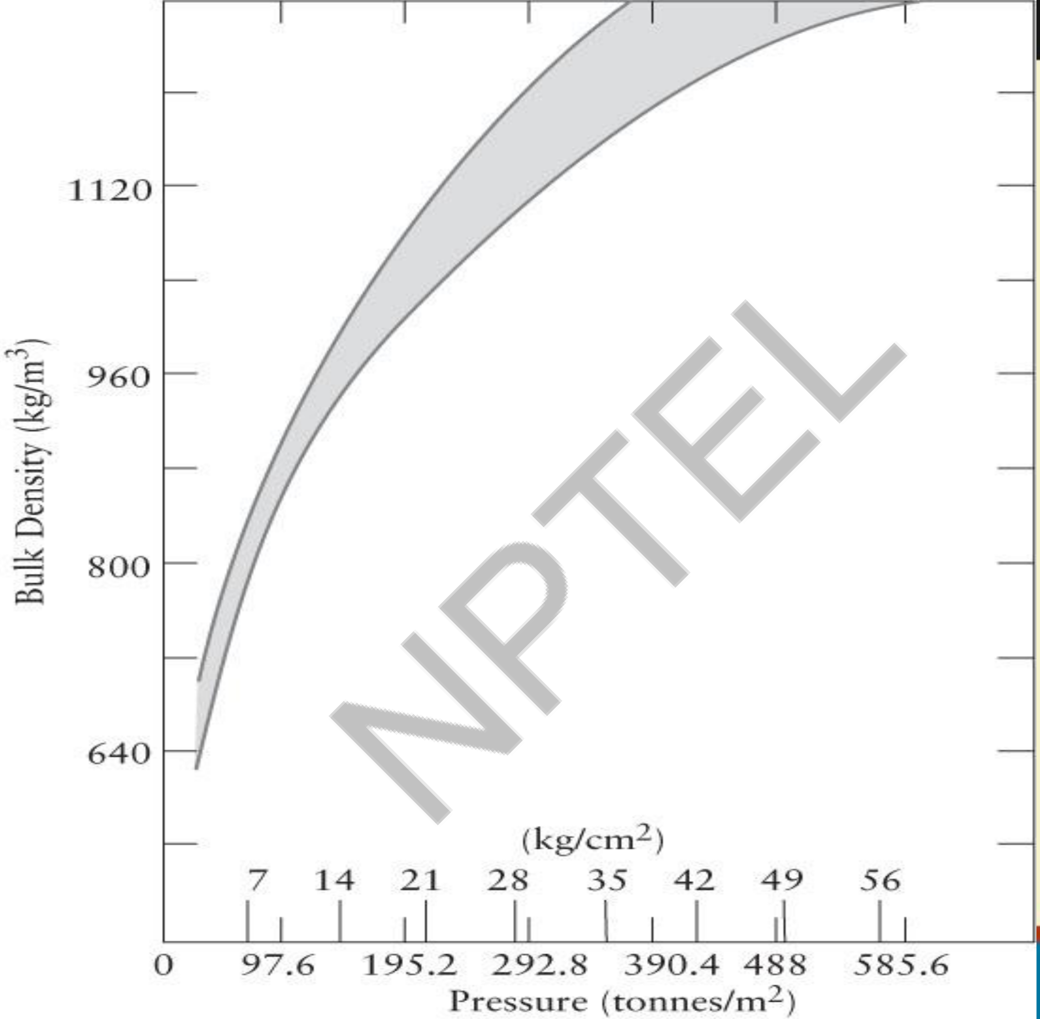

Figure 2-12 Compression of municipal solid waste. Source: [25]

Table 2-9 Refuse Bulk Densities

Condition	Density (Kg/m^3
Loose refuse, no processing or compaction	90–150
In compaction truck	360–540
Baled refuse	720–840
Refuse in a compacted landfill (without cover)	450–750

Table 2-10 Material Densities Commonly Found in Refuse

Material	Specific Gravity	Kg/m^3
Aluminum	2.70	2690
Steel	7.70	7685
Glass	2.50	2498
Paper	0.70–1.15	706–1150
Cardboard	0.69	689
Wood	0.60	593
Plastics		
HDPE	0.96	943
Polypropylene	0.90	895
Polystyrene	1.05	1041
PVC	1.25	1249

Another Important Physical Property

- The moisture content of a waste

Moisture Content (by mass)

$$MC = \frac{M_W}{M_T}$$

$$M_S = M_T(1 - MC)$$

$$M_T = \frac{M_S}{(1 - MC)}$$

Moisture Content (by volume)

$$\theta = \frac{V_w}{V_T}$$

Water Content

$$W = \frac{M_w}{M_s}$$

Table 2-5 Moisture Content of Uncompacted Refuse Components

Component	Moisture Content	
	Range	Typical
Residential		
Aluminum cans	2–4	3
Cardboard	4–8	5
Fines (dirt, etc.)	6–12	8
Food waste	50–80	70
Glass	1–4	2
Grass	40–80	60
Leather	8–12	10
Leaves	20–40	30
Paper	4–10	6
Plastics	1–4	2
Rubber	1–4	2
Steel cans	2–4	3
Textiles	6–15	10
Wood	15–40	20
Yard waste	30–80	60
Commercial		
Food waste	50–80	70
Mixed commercial	10–25	15
Wood crates and pallets	10–30	20
Construction (mixed)	2–15	8

Source: [20 based on 21]

Some Important Moisture Contents

- Field Capacity
- Saturation
- Wilting Point

Solids Content

Solids Content = 100 – Moisture Content

(by total weight)

- *Sludges are often measured in terms of solids content.*
- *e.g. A domestic wastewater sludge with a solids content of 12% would have a moisture content of 88%*

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Porosity

$$\eta = \frac{V_V}{V_T}$$

Other Physical Characteristics

- Particle Size (and Size Distribution)
- Hydraulic Conductivity (Permeability)

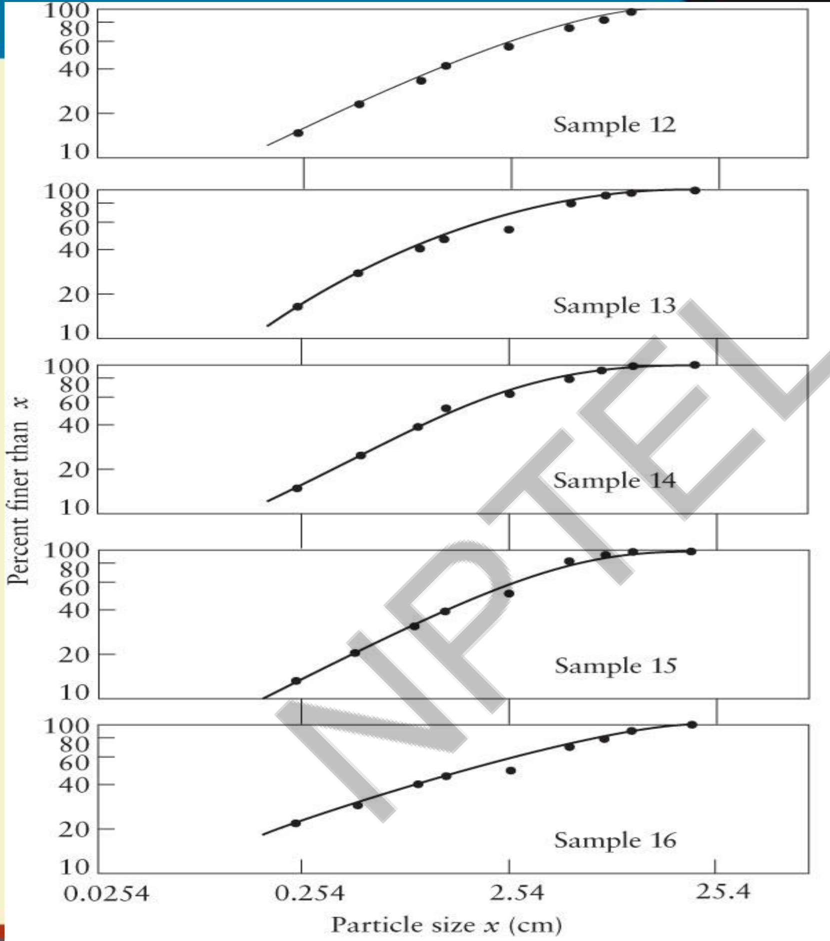


Figure 2-10 Particle-size distribution curve for unprocessed refuse. Source: Vesilind, P. A., A. E. Rimer, and W. A. Worrell. 1980. "Performance Characteristics of a Vertical Hammermill Shredder." Proceedings 1980 National Waste Processing Conference. Washington, D.C.: ASME. With permission from ASME.

EXAMPLE 2-4

Consider nonspherical particles that are uniformly sized as length, $l = 2$; width, $w = 0.5$; and height, $h = 0.5$. Calculate the particle diameter by the previous various definitions.

SOLUTION

$$D = l = 2;\ D = \frac{w + l}{2} = 1.25;\ D = \frac{h + w + l}{3} = 1.0$$

$$D = \sqrt{lw} = 1;\ D = \sqrt[3]{hwl} = 2.12$$

Note that the "diameter" varies from 1.0 to 2.12, depending on the definition.

Table 2-6 Proximate and Ultimate Chemical Analyses of Refuse

Proximate Analysis (percent by weight)	
Moisture	15–35
Volatile matter	50–60
Fixed carbon	3–9
Noncombustibles	15–25
Higher heat value (HHV)	3000–6000
Ultimate Analysis (percent by weight)	
Moisture	15–35
Carbon	15–30
Hydrogen	2–5
Oxygen	12–24
Nitrogen	0.2–1.0
Sulfur	0.02–0.1
Total noncombustibles	15–25

Source: [24]

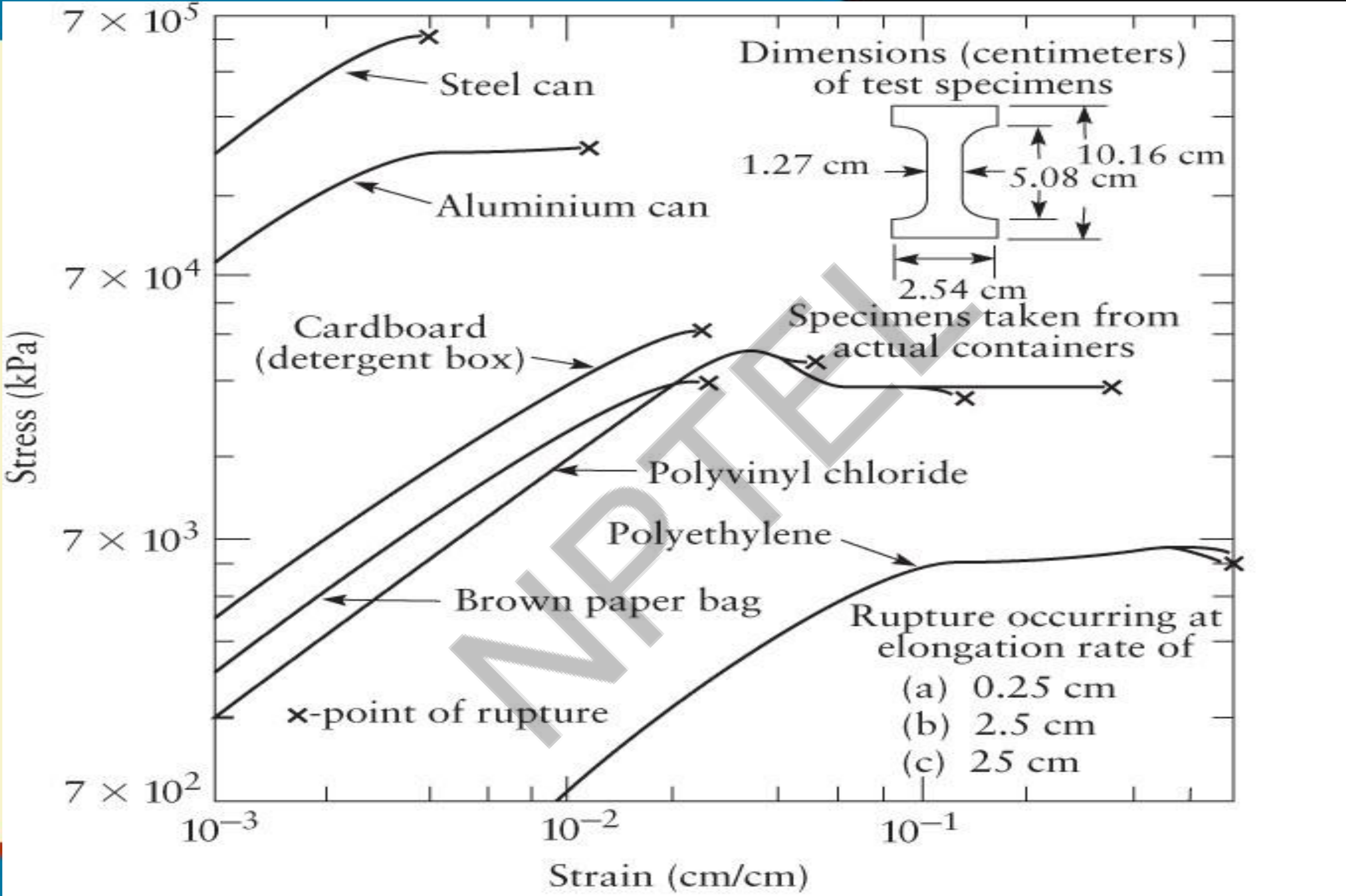


Figure 2-14 Tensile strength of some municipal solid waste components. Source: [26]

How do you determine the average property of a mixed waste stream?

Average Moisture Content

$$\overline{MC} = \frac{\sum MC_i \bullet M_{T,i}}{\sum M_{T,i}}$$

EXAMPLE 2-2

A residential waste has the following components:

Paper	50%
Glass	20%
Food	20%
Yard waste	10%

Estimate its moisture concentration using the typical values in Table 2-5.

SOLUTION

Assume a wet sample weighing 100 kg. Set up the tabulation:

Component	Percent	Moisture	Dry weight (based on 100 kg)
Paper	50	6	47
Glass	20	2	19
Food	20	70	6
Yard waste	10	60	4
			Total: 76 kg dry

The moisture content (wet basis) would then be

$$M = \frac{w - d}{w}(100) = \frac{100 - 76}{100}(100) = 24\%$$

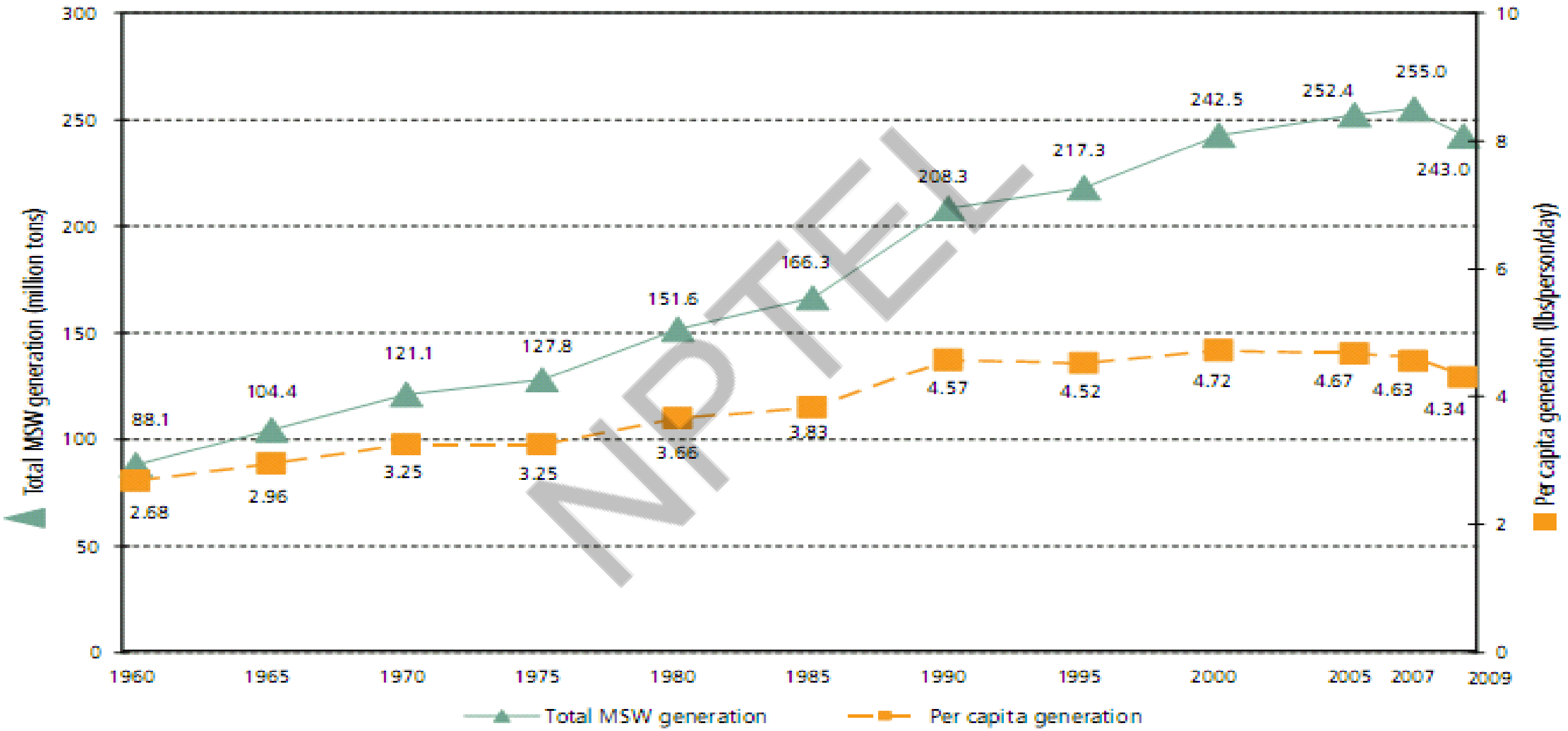
Average Density

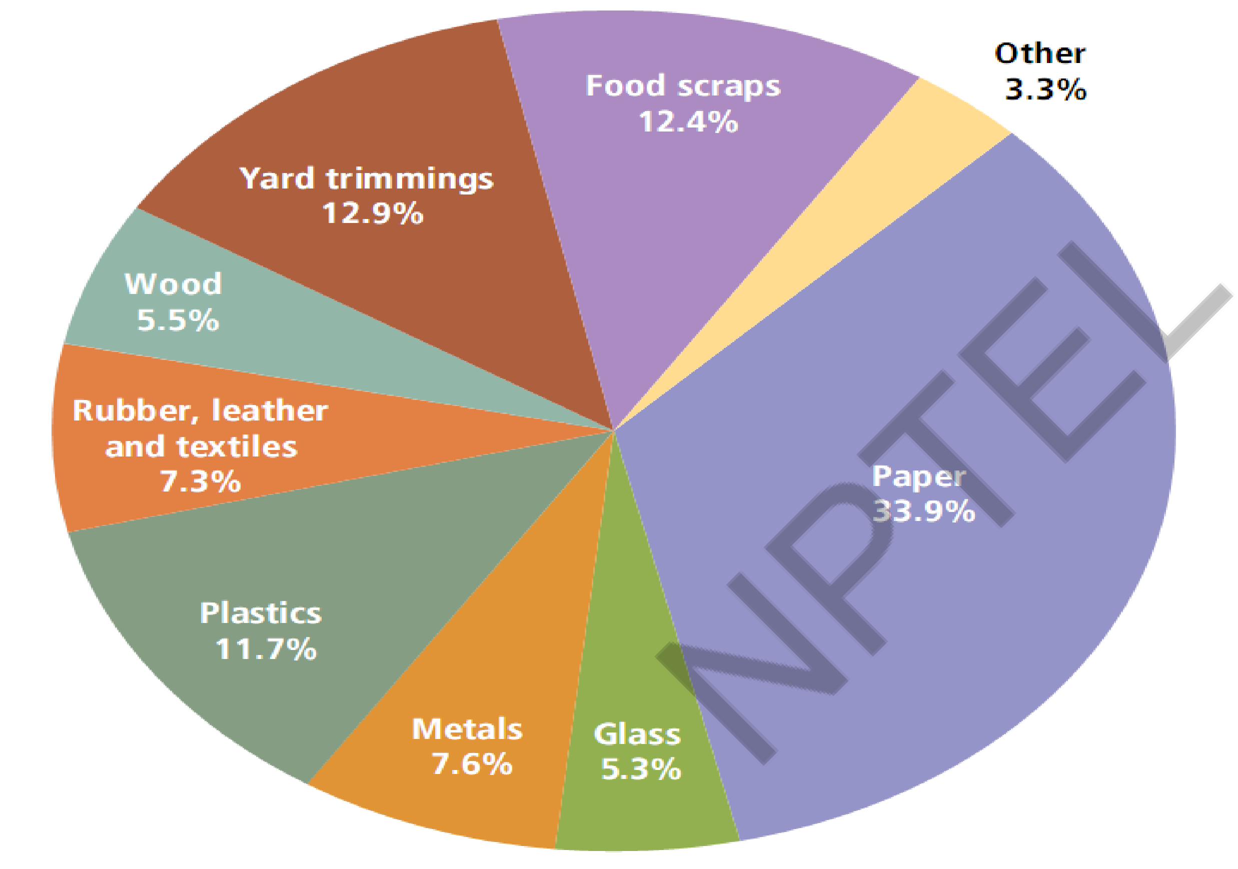
$$\bar{\rho} = \frac{\sum M_{T,i}}{\sum \left(\frac{M_{T,i}}{\rho_i} \right)}$$

Component Composition

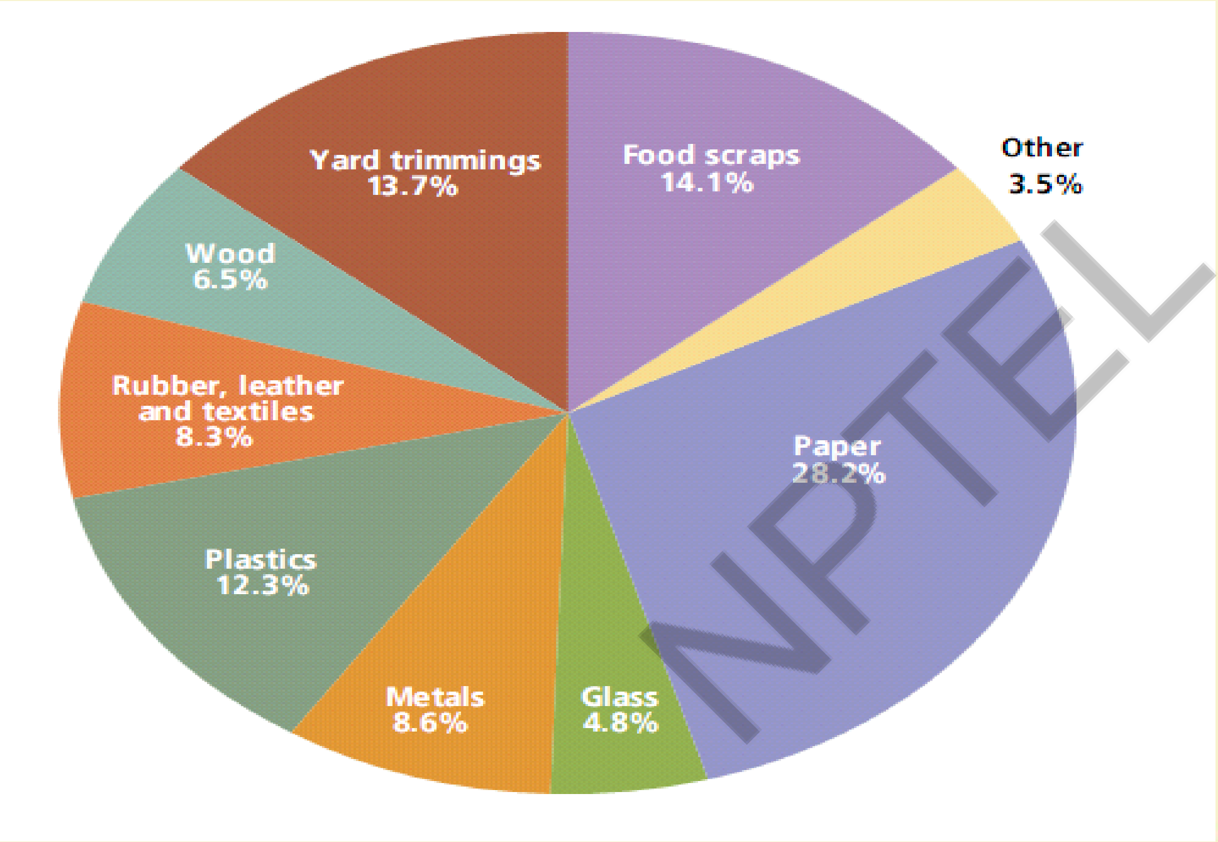
- What is the composition of the waste by different identifiable waste components?

Figure 1. MSW Generation Rates, 1960 to 2009

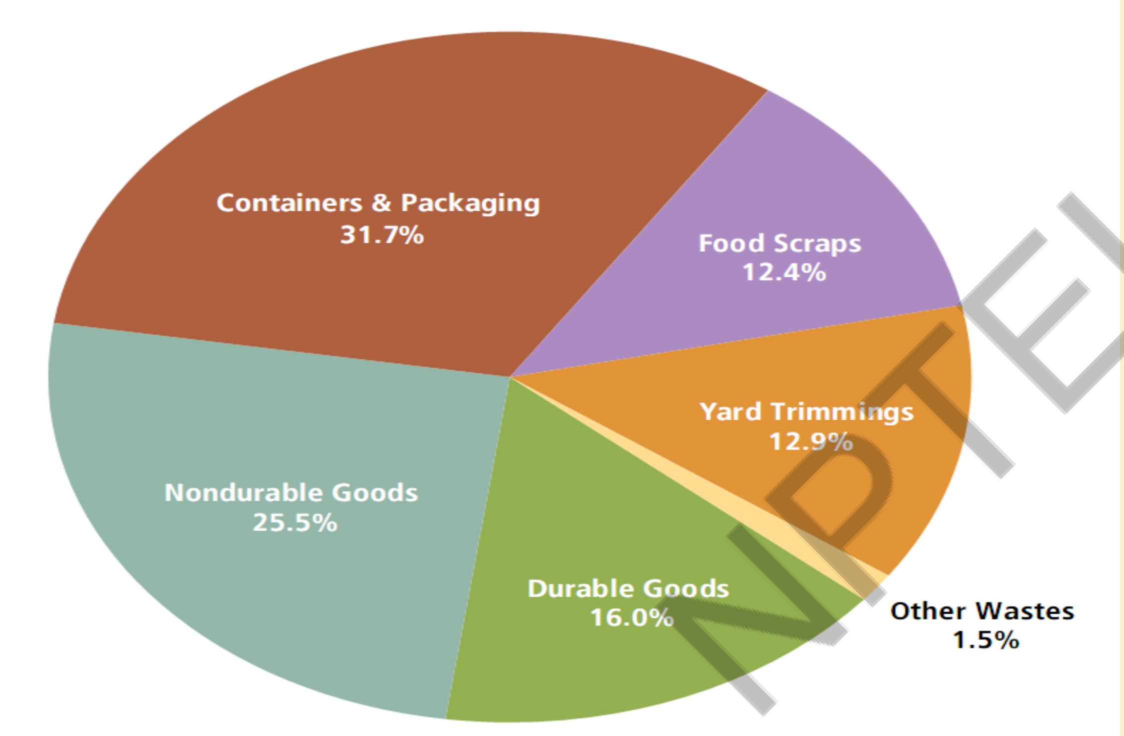




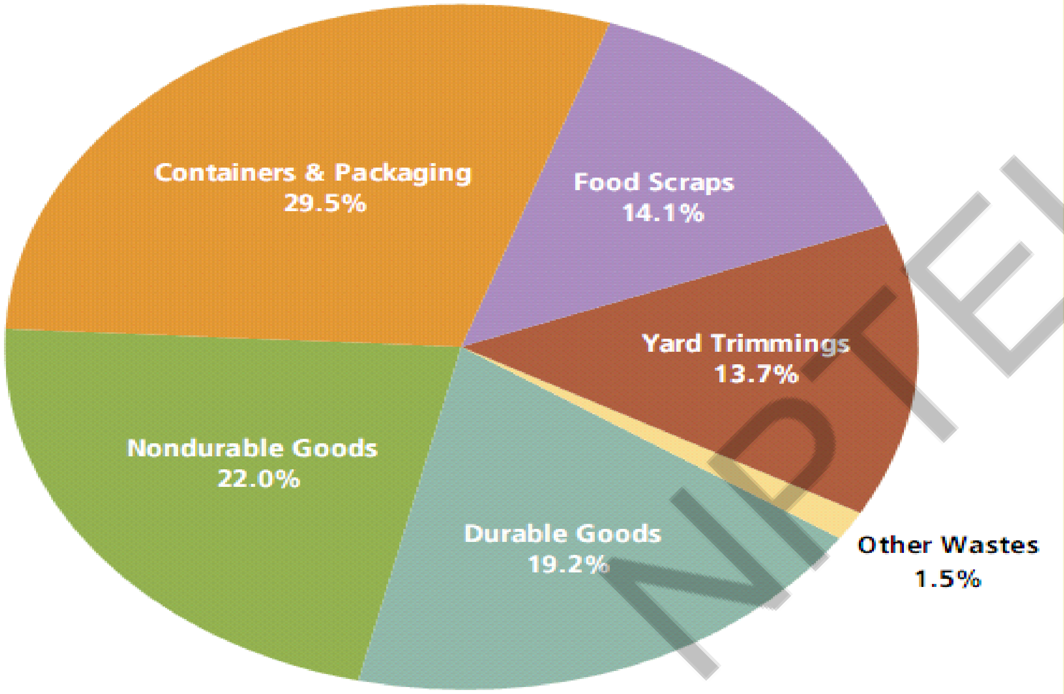
Total MSW Generation (by Material) in USA, 2006
251 Million Tons (Before Recycling)



Total MSW Generation (by Material) in USA, 2009
243 Million Tons (Before Recycling)



Total MSW Generation (by Category) in USA, 2006 251 Million Tons (Before Recycling)



Total MSW Generation (by Material) in USA, 2009
243 Million Tons (Before Recycling)

Measuring Waste Composition

- Source Specific Approach
- Materials Flow Methodology

When a materials flow approach is used, the mass of materials entering the waste stream are estimated from the amount of materials predicted to be discarded based on the amount of the materials produced. In other words, a certain number of aluminum beverage containers are produced every year in the US, and these products have a certain life span before they enter the waste stream. Thus the magnitude of the waste can be estimated from production statistics.

Source Specific Approach

Waste audit by Students


REFRIGERATE
UPON
ARRIVAL


IMMEDIATE
TOW AWAY
U.G.
ARBAGE
ONLY


RBAGE
NLY
Fisher Scientific
www.fishersci.ca

40
NO
PARKING
IMMEDIATE
TOW AWAY


NO
PARKIN
IMMEDIATE
TOW AWA
RECYCLAB


U.G.
NO PARKING
409
IMMEDIATE
TOW AWAY
RECYCLABLE
ONLY


20


100
ES SERIES


IBERVILLE


IBERVILLE


IBERVILLE


V2


20


GEARS

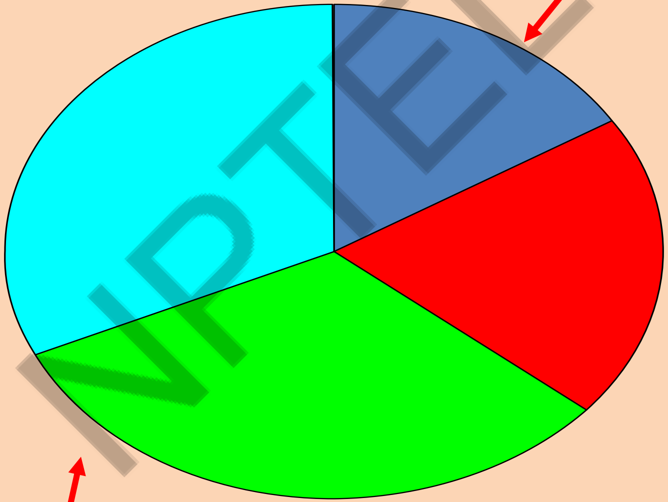
Characterizing a Waste by Biodegradability

- Biodegradable Components
  - Paper
  - Cardboard
  - Food Waste
  - Yard Waste
  - Wood, Leather, Rubber?

Conceptual Waste Composition for Biodegradability Characterization

Biological Volatile Solids (BVS)
(Organic fraction of biodegradable components "destroyed" during treatment)

Water



Inorganic
(glass, metal, dirt + inorganic part of biodegradable materials)

Residual Volatile Solids (RVS)
(Organic fraction of Biodegradable components that remains after treatment + plastic)

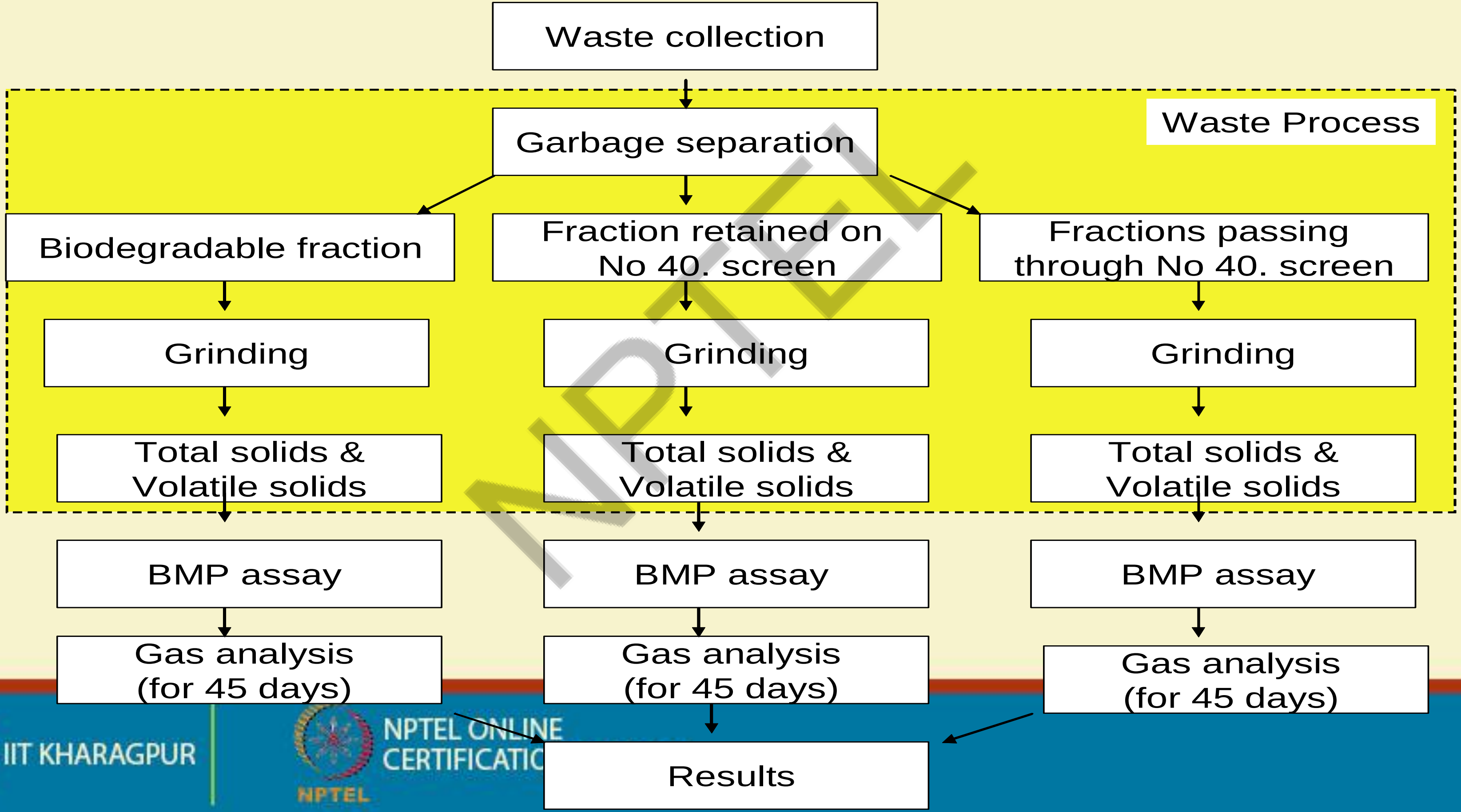
How do you determine BVS?

- Run a test in the lab and measure
- Analyze a surrogate parameter and estimate
- Lignin content has been used as a surrogate parameter

$$BF = \frac{BVS}{VS} = 0.83 - 0.028\left(LC\right)$$

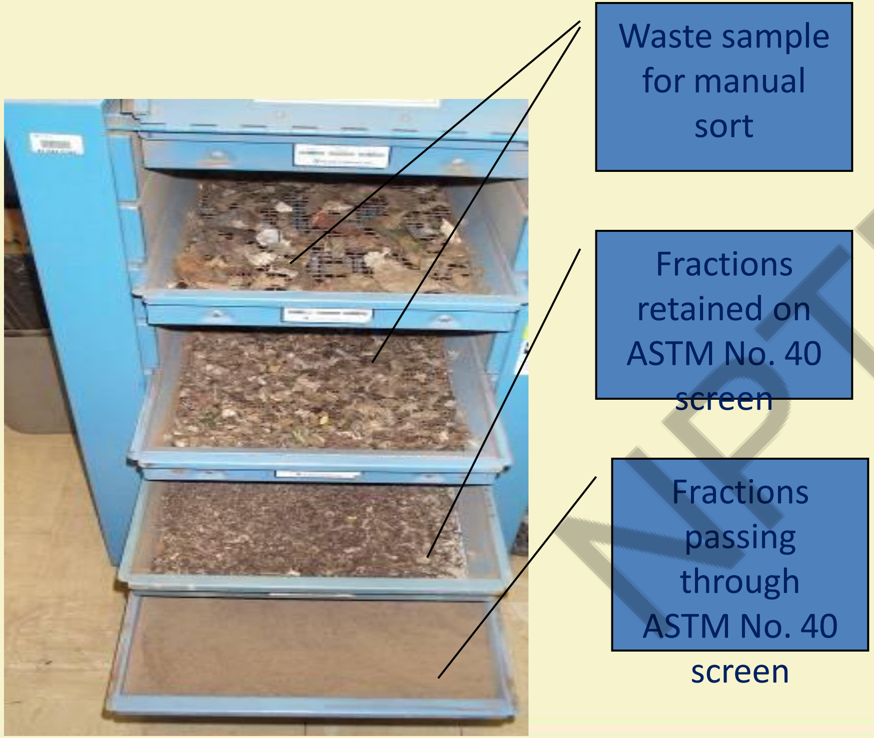
LC = Lignin Content (%)

Waste Process & BMP assay - overview



MSW sample collection

Waste Sample Processing



Dried waste samples are placed in a shaker and separated by size.

Waste sample fraction retained on No. 40 screen is collected and assigned as "R" sample and other fraction passed through No. 40 screen is classified as "P" sample

Waste components manually separated

Biodegradable Fraction

Grinding separated samples

A grinder being used for grind biodegradable materials and "R" fractions

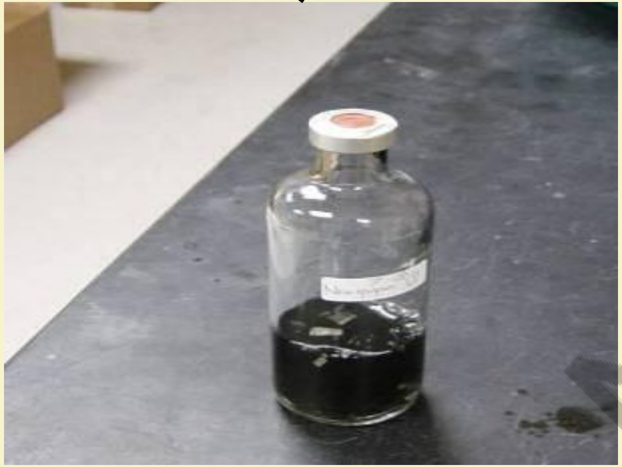
An example of ground sample (paper)

Sample preparation for the BMP assay

Ground raw materials

Gas generation

Analysis of gas for methane using the GC-TCD



Sample in a serum bottle after sludge addition
(incubating under 35^{o}C)

Methane potential example graph

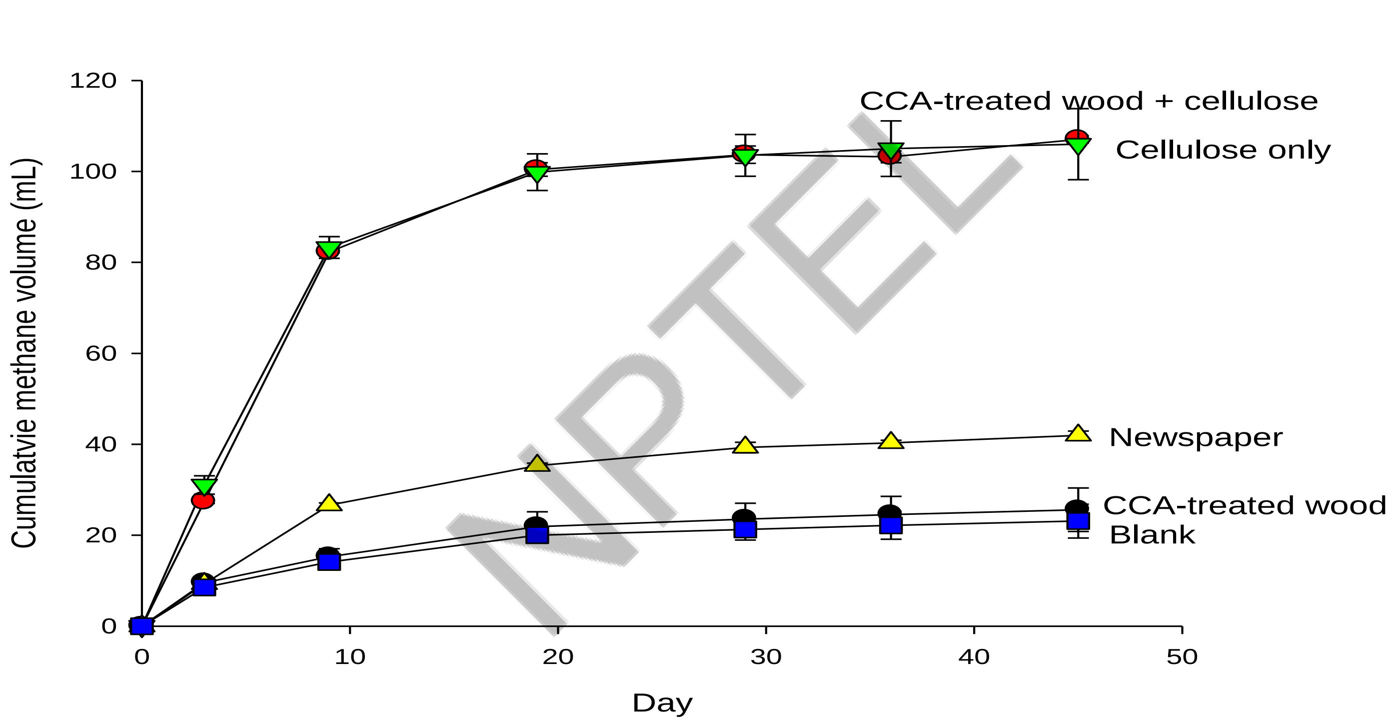


Table 2-11 Calculation of Biodegradable Fraction of MSW

Component	Percent of MSW	Percent of each component that is biodegradable
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	0.5
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	

Source: [20, 28]

INTEGRATED WASTE MANAGEMENT FOR A SMART CITY

FOCUSSED ON MSW, C&D AND E-WASTE MANAGEMENT

BRAJESH KUMAR DUBEY

DEPARTMENT OF CIVIL ENGINEERING

End of Week-2 Material