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Municipal Solid Waste – A Review of Classification System

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Abstract. *The present study is performed to review existing municipal solid waste (MSW) classification systems in Canada and other countries and if desired, propose a novel classification system that could assist municipalities to make informed decisions regarding MSW processing and utilization. MSW is highly non-homogenous since it consists of residues of nearly all materials used. The content of MSW varies with location, lifestyle, season, trends in packaging, local recycling schemes and local authority collection policy. Therefore, detailed classification and quantification of MSW is desired in order to obtain accurate data concerning estimates of present and future production and composition of MSW for long-term efficient and economical waste management planning. In addition, universal classification systems are required that can be implemented by any municipality, irrespective of national or regional variations.*

Keywords. Municipal Solid Waste (MSW), Classification System, Waste-to-energy, Reuse, Recycle, Thermal Treatment, Advanced Thermal Treatment, Landfill

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1. Introduction

Municipal solid waste (MSW) usually consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scrapes, newspapers, appliances, batteries, etc. Not included are materials that also may be disposed in landfills, but are not generally considered MSW, such as construction and demolition debris, municipal wastewater treatment sludge, and non-hazardous industrial wastes (US EPA, 2001).

The total annual generation of MSW in USA in 2003 is 236 million tonnes per year, which is 50% higher than MSW generated in 1980 (US EPA, 2003). Similar trends of an increase in MSW generation have been reported all over the globe. The increased generation of MSW is reflected in the growth in population (OECD, 2004) and directly related to Gross Domestic Product (GDP) (Statistics Canada, 2005; Stanners and Bourdeau, 1995). Canada reported a 5% increase in MSW generation from 365 kg/person in 2000 to 383 kg/person in 2002. On the other hand MSW generation in the USA remained relatively constant since 1990 at 741 kg/person/year. From 1995 to 2003 MSW generation in European Union (EU 25) has constantly grown by about 2% per year from 204 million tonnes (457 kg/person) in 1995 to 243 million tonnes (534 kg/person) in 2003. Generation is higher in the old EU 15 member states with 574 kg/person compared to 312 kg/person in the new EU 10 member states (European Commission, 2003). These data should be compared with those from the developing world where waste generation weights are very low. For example, the annual per capita production of MSW in Delhi, India has been estimated at 136 kg/person/year, Kathmandu, Nepal it has been estimated at 109 kg/person/year and in Wuhan, China at 200 kg/person/year (Williams, 2005; Rushbrook and Finney, 1988). A comparison of MSW generation per capita per year for various countries is shown in Figure 1.

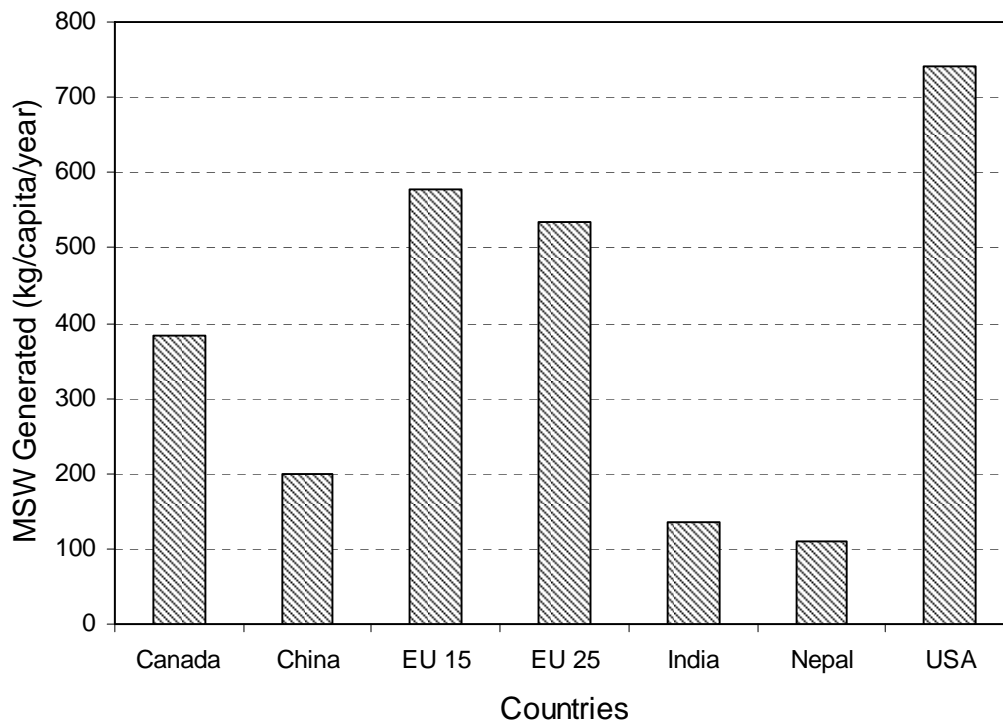


Figure 1. MSW generated per capita per year by various countries

The generation of MSW per capita of population has increased for most European countries and in some cases the increase is quite significant. For example, Spain, Denmark and Finland have shown a recent annual average increase in the per capita generation of MSW of 5%. Whilst most countries of Western Europe have shown an increase in generation of MSW, some countries have shown a decrease. For example, the Czech Republic, Hungary, and Poland showed a decrease between 5 and 9% in MSW generation per capita between 1999 and 2001 (European Commission, 2003). Within EU 25 members, the generation totals in 2003 varied considerably between countries ranging from 260 kg/person in Poland to 1040 kg/person in Iceland. With the exception of Belgium, all EU 15 countries reported considerable higher amounts for 2003 than for 1995. In the new EU 10 member states, the development differed from country to country. Clear increases are reported by Malta, Latvia, Cyprus, and Estonia. Most other countries reported declines in MSW generation that were highest in Bulgaria, Slovenia and Lithuania (European Commission, 2003).

Accurate data, concerning estimates of present and future production and composition of MSW is essential. The estimates are used by both planners and waste treatment and disposal engineers to determine the type, size, design and location of waste treatment and disposal facilities. The information is also used to determine the associated transport infrastructure and personnel requirements (Williams, 2005). The U.S. Environmental Protection Agency's (EPA) tiered integrated waste management strategy includes source reduction (including reuse of products and backyard composting of year trimmings), recycling of materials (including composting), and disposal (including waste combustion, preferably with energy recovery and landfilling) (Figure 2) (US EPA, 2001). Majority of municipalities have recognized landfilling as the last option in the ladder of waste management strategies. Therefore, emphasis should be given to waste reduction, re-use, and recovery (Waste Not Want Not, 2002).

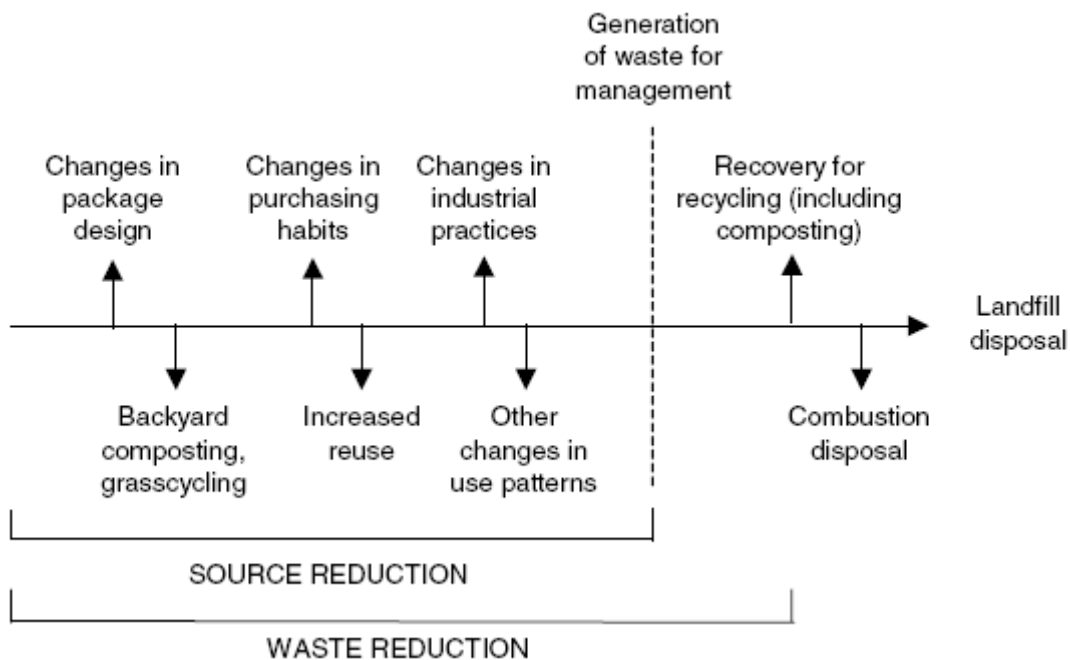


Figure 2. EPA's tiered integrated MSW management diagram (US EPA, 2001).

Whilst detailed classification, quantification, and compositional analyses are clearly desirable, it is another matter to obtain accurate data from the producers of the waste. In most countries throughout the world, there is no statutory requirement for waste producers to record waste statistics. By its inherent nature waste is heterogeneous and the components of the waste can have a large variance; therefore, a large number of samples are required for statistical accuracy. However, for a large waste source population, this may not be possible and therefore representative samples, with their consequent errors, are used. There are many problems associated with data related to waste generation. Since MSW can vary on a daily, monthly and seasonal basis, on the size of the population, the type of housing stock, etc (US EPA, 2001; Williams, 2005).

MSW is highly non-homogenous since it consists of residues of nearly all materials used. Therefore, detailed classification and quantification of MSW is desired in order to obtain accurate data concerning estimates of present and future production and composition of MSW for long-term efficient and economical waste management planning. In addition, universal classification systems are required that can be implemented by any municipality, irrespective of national or regional variations. The aim of this study is to conduct an extensive review of existing MSW classification systems in Canada and other countries with prime focus on energy recovery systems and if desired, propose a novel classification system that could assist municipalities to make informed decisions regarding MSW processing and utilization.

2. MSW Classification

Classification of MSW will depend on the type of processing technologies such as physical, biological, chemical, thermal or advanced thermal, and landfill that any municipality may use for waste reduction, utilization, or disposal (Gartner Lee, 2004). Every technology has certain desired criteria to consider for efficient execution of the MSW value-addition or disposal process.

A number of existing classification systems are simply based on material groups (e.g. paper, plastic, metal, etc.) or on the distinction between soil-like (3-D structure) and non-soil-like (2-D structure), or fibrous, appearance (Dixon and Langer, 2006). Table 1 provides a summary of existing classification systems including the parameters defined.

Table 1. Overview of existing classification systems of municipal solid waste (Dixon and Langer, 2006)

Basis for differentiation	Parameters used for differentiation	Author
Waste type	Density, shear parameters, liquid/plastic limit, permeability	Turczynski, 1998
Material groups	Part of composition	Siegel et al., 1990
Organic, inorganic materials	Degradability (easily, slowly, non) Shape (hollow, platy, elongated, bulky)	Landva and Clark, 1990
Degradable, inert, deformable material groups	Strength, deformability, degradability	Grisolia et al., 1995
Material groups	Size, dimension	Kolsch, 1996

Soil-like (3-D structure), other	Index properties	Manassero et al., 1997
Soil-like (3-D structure), non-soil-like (2-D structure)	Material groups	Thomas et al., 1999
Mechanical Properties	Material properties, weight, size, shape, organic, inorganic, soil-like, non-soil-like	Dixon and Langer, 2006
Material type, product type	Part of MSW composition	US EPA, 2001

Some of the classification systems are MSW component-based systems that are primarily used to facilitate physical (reuse and recycle), biological (compost) and chemical (chemical additives) processing of majority of waste material (US EPA, 2003; European Commission, 2003). Component based systems identify MSW as: 1) material type; 2) product type (US EPA, 2001). Material type classification may include paper and paperboard, glass, metals, plastics, rubber and leather, textiles, wood, and others. Product type classification may include durable goods (e.g. appliances, furniture, tires), non-durable goods (e.g. newspaper, office papers, trash bags, clothing), containers, and packaging (e.g. bottles, cans, corrugated boxes), and other wastes (e.g. yard trimmings, food scraps and miscellaneous inorganic wastes). The rest of available classification systems are used to facilitate landfilling process with minimal damage to protective landfill base-liner.

2.1. Physical Processes

Physical processes are primarily designed to separate components of the mixed residual waste into utilizable (recyclable) and non-utilizable (non-recyclable) materials streams (excluding putrescibles and green waste). The process may also involve additional pre-treatment of the segregated materials stream to make it more suitable for a designated utilization such as reuse or recycle of waste. Some of these types of processes may function as stand alone strategies for further diverting and reducing the amount of waste destined for disposal (Gartner Lee, 2004). Recycling processes use energy to a greater or lesser degree, and in many cases this energy is derive from the burning of fossil fuels. In many circumstances however, the energy used for recycling will be significantly less than that used for extraction (and import) of virgin materials. And production processes using secondary materials can be less energy intensive than those using primary resources. In these cases there tends to be a net climate benefit from recycling (UK Environment, 2000).

2.2. Biological and Chemical Processes

Biological process-based technologies target the organic fraction of the waste stream, which generally forms the largest portion of residual waste stream (European Commission, 2003; Statistics Canada, 2005). In the USA the paper and paperboard accounted for 35 percent of the waste stream, with yard trimmings and food scraps together accounting for about 24 percent (US EPA, 2003). The marketable end product from biological processes is generally compost or fuel. The three types of biological technologies used are MSW aerobic composting, anaerobic digestion and ethanol fermentation. Open composting is not environmentally friendly. It produces carbon dioxide, a greenhouse gas, with no associated energy recovery and also spreads harmful airborne spores and bacteria. The green alternative to composting is anaerobic digestion to produce methane, preceded by thermal treatment to sterilize the waste

and hydrolyse the complex organics (Biffa, 2005). With the exception of paper, wood, and some textiles, most biodegradable organic materials cannot easily be recycled. However, these materials can be made into compost, which growers can use to replace peat and fertilizers (UK Environment, 2000). Chemical technology includes combining chemical additives to physical processes to produce construction materials or panels (Gartner Lee, 2004).

2.3. Energy Recovery Process

Recovery of energy from MSW is an important area for efficient use of waste resource. A review of literature revealed that a classification system based on energy recovery or thermal application of MSW is required, which could guide municipalities to implement various processes that could lead to high quality feed material for economical generation of energy. The resulting energy reduces the amount needed from other sources, and the sale of the energy helps offset the cost of operating the facility.

Majority of municipalities around the world primarily dispose off their MSW in landfills (Figure 3). Japan is an exception, where majority (77%) of the 52 million tons of MSW generated is incinerated (Statistical Handbook of Japan, 2003). A great emphasis is now been placed on waste energy recovery options or thermal technologies in order to mitigate environmental concerns associated with landfilling and reap economic benefits. In addition, energy recovery processes can reduce the volume and weight of MSW by 90% and 75%, respectively (Cheremisinoff, 2003).

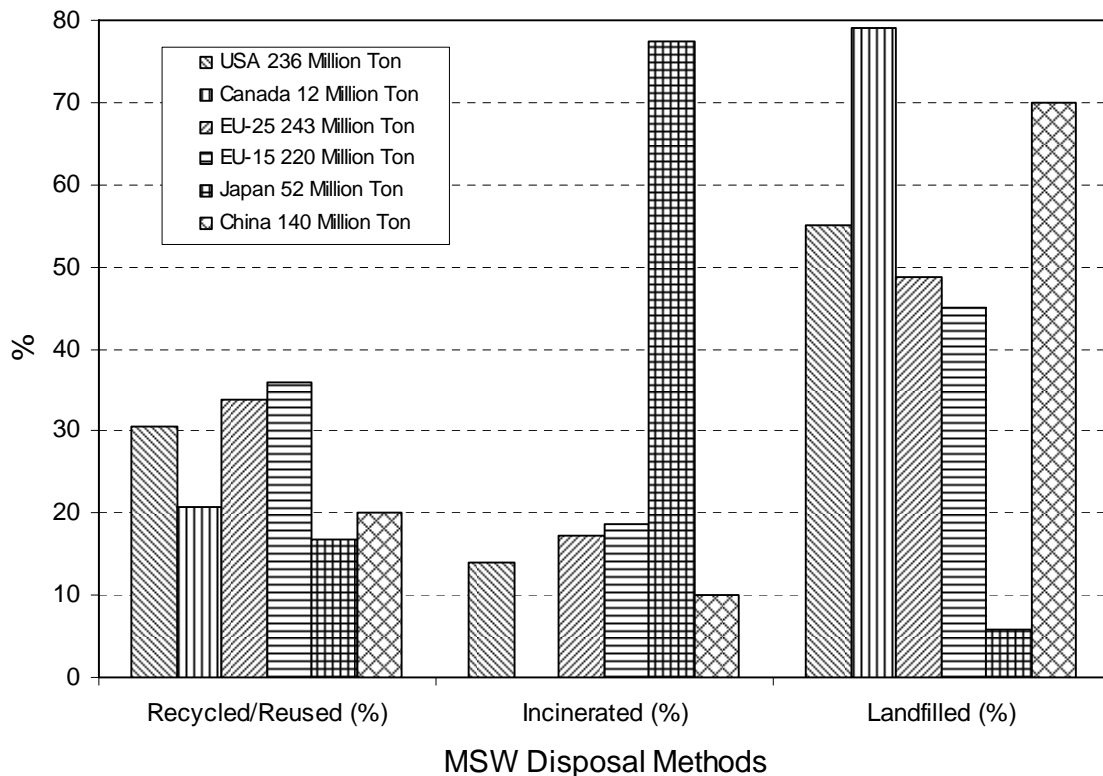


Figure 3. MSW disposal methods currently used in various countries (Note: the 79% MSW landfilled in Canada also includes incinerated waste) (US EPA, 2001; Statistics Canada, 2005; European Commission, 2003; Nie et al., 2002).

Thermal technologies include conventional incineration and waste-to-energy technologies and more recent developments typically characterized as advanced thermal treatments (ATT). Incineration is a process that involves the complete degradation or combustion of carbon-based material in MSW through the application of heat in an oxygen-rich environment. Ash residue, including bottom ash and fly ash, inert materials, metals and flue gases are the principal residual waste streams. Excess heat is also produced, and may be recovered if the process is configured as a waste-to-energy facility (Gartner Lee, 2004). Advanced thermal treatment (gasification and pyrolysis) processes are designed to convert, through partial combustion or thermal degradation, the carbon-based solids in MSW into energy-rich primary products, notably hydrocarbon gases (syngas) and hydrogen liquids (bio-oils). These primary products have the potential, depending on technical and economic factors, to be further processed into a range of marketable products, such as electricity, hydrogen, fuel alcohol and chemicals.

Energy from waste plant (primarily incinerators, but also gasification and pyrolysis plant) release carbon dioxide from burning fossil carbon (primarily waste oils and plastics) and biogenic carbon (from wood, paper, food and green wastes). However, energy from waste plant can displace the need to use more polluting fossil fuels to generate heat. Energy recovery operations (incineration, waste-to-energy, gasification/pyrolysis) includes a wide range of practices, from low-technology open burning, which emits pollutants directly into the air to controlled combustion processes using mass burn systems (without processing waste before combustion) and refuse-derived fuel (RDF) (separating out non-combustibles and sometimes compressing into pellets) (Statistics Canada, 2005). Not all wastes will be suitable for use as a fuel. In particular, inorganic wastes such as glass and metals have no calorific value. These wastes are also highly suitable for recycling, and it would only be appropriate to incinerate them in rare circumstances, for example when they cannot easily be separated from other combustible materials (UK Environment, 2000). For efficient and economical operation of energy recover systems, it is important to have waste with sufficient heating value that will burn without using additional fuel (Cheremisinoff, 2003). Therefore, refuse-derived fuel (RDF) content is manipulated to give it a high calorific value.

2.4. Landfilling Process

Landfill disposal is seen in many respects as the bottom rung of the hierarchy of waste disposal options, when considering the concept of sustainable waste management (Figure 2). However, landfilling is still the main option for the disposal of MSW. In 2003, EU-25 and USA landfilled nearly 49 and 55%, respectively (European Commission, 2003; US EPA 2003). Canada on the other hand landfilled 79% of MSW (includes incinerated MSW) (Statistics Canada, 2005) (Figure 3). In countries where waste landfill is important as a major route for waste disposal (60-95%), for example, Greece, Ireland, Italy, Portugal, Spain and the UK, there is likely to be a trend towards smaller numbers of larger landfills (Eunomia, 2003). This is attributed to the higher costs of land fill resulting from the imposition of the EC Waste Landfill Directive (1999), leading to higher costs.

Older sites which are, in some cases, still under current use or have long been disused, were constructed before the environmental impacts of leachate and landfill gas were realized. Many of these sites are now sources of pollution with uncontrolled leakages. Landfill gas methane is also a 'greenhouse gas', contributing to the global warming problem, but with about 30 times the effect of carbon dioxide (Williams, 2005). Methane is produced when biodegradable materials such as paper, food wastes and green wastes, decompose in the absence of oxygen (UK Environment, 2000).

Modern landfill sites use advanced treatment and disposal options, and are designed and managed as engineering projects. Essential to the design of a waste landfill site is the containment barrier systems at the base, side and eventually the cap of the waste landfill, which contains the products of the biodegradation and physical and chemical degradation processes of the waste (Williams, 2005). Dixon and Langer (2006) developed a unified classification system that could improve the structural stability and integrity of landfills and alleviate the environmental concerns. The proposed system explains and evaluates the mechanical properties of MSW components, groups waste components with similar mechanical properties, and facilitates the exchange and interpretation of measured properties. According to this system, the information required to classify MSW can be summarized as follows (Whitlow, 2000; Dixon and Langer, 2006):

- A distinction is required between the material groups (i.e. based on typical component material properties), with dominant groupings established. Information is then required on the proportion (e.g. by weight) of different size components in each material group.
- Knowledge of component shape is required to distinguish between soil-like (three dimensional, e.g. granular) and non-soil-like (two dimensional, e.g. sheet) components. This allows classification of components in relation to their potential for influencing mechanical behaviour of the waste mass (e.g. compressibility, shear and tensile strength).
- Grading by size is required for each group of components (size assessment of each component).
- An assessment of component compressibility and hence the potential for components to change shape during placement and/or burial.
- An assessment of degradation potential for both organic and inorganic components.

3. Classification of MSW for Energy Recovery

The enormous amounts of MSW have internationally increased the interest for (with a fraction of MSW being subjected to) reuse, recycling, or combustion with energy recovery at the expense of landfilling. Many countries have banned landfilling of wet organic waste (EC Landfill Directive, 1999). This alone will influence the composition of MSW going to mass burn incinerators as it normally constitutes approximately 20 to 30% of the total MSW composition (IEA, 2001). In addition, changing consumer patterns and new products will alter the composition of MSW. Classification of combustible fraction of MSW can serve as a foundation, when decisions on waste management are made and should be included in a total life cycle evaluation of a product. The combustible portion of MSW contributes up to 80% of the total waste generated (Figure 4).

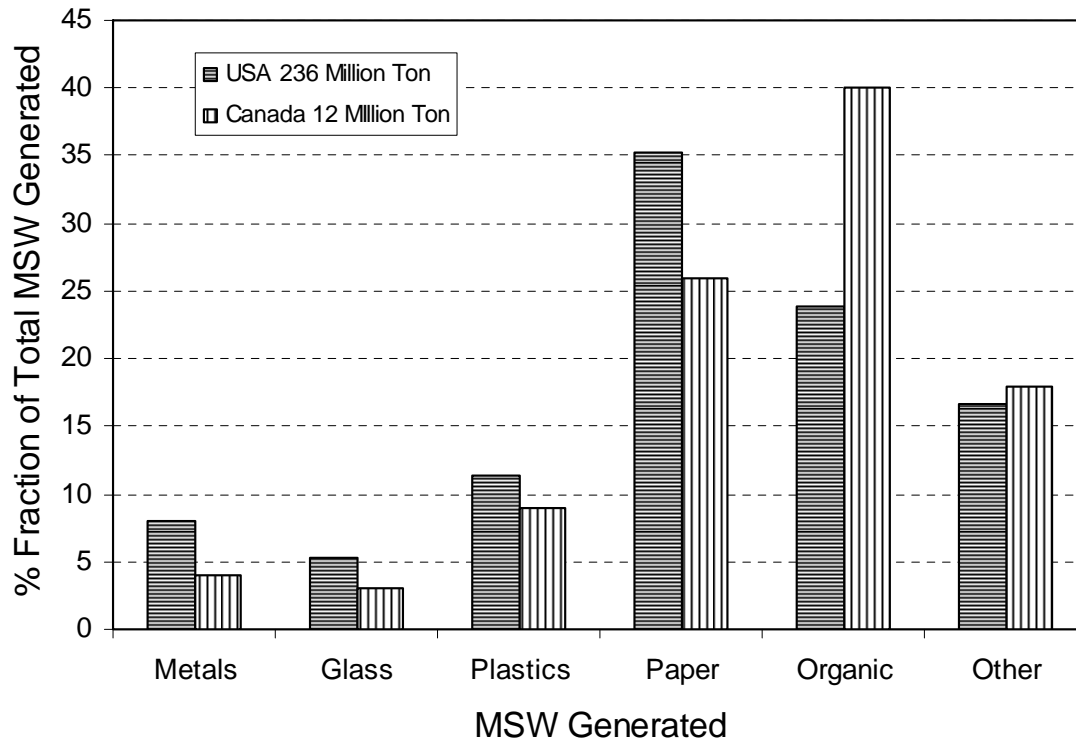


Figure 4: Combustible and non-combustible fractions of MSW generated in North America (Other waste includes: animal waste, leather, rubber, textiles, tires and wood) (US EPA, 2001; Statistics Canada, 2005).

The need for classification of MSW is demonstrated through the diversity of components constituting MSW. Landva and Clark (1990) proposed a classification system that differentiates between organic and inorganic components. They subdivided these into putrescible and non-putrescible within the organic components, and degradable (corrodible) and non-degradable within the inorganic components (Figure 5). This system provides detailed information on degradation and compressibility potential of components but does not consider the energy aspect of MSW. A new classification system for energy recovery has been proposed (Figure 6), which is loosely based on system proposed by Landva and Clark (1990). Thermal technologies primarily involve the separation of MSW into combustible/organic and non-combustible/inorganic material streams. The combustible portion of MSW can be classified as putrescible and non-putrescible waste material. The putrescibles and a portion of non-putrescibles can be classified as cellulosic/lignocellulosic (paper, wood, wet organic fractions, etc.) and the rest of non-putrescibles can be classified as non-cellulosic (different plastics, rubber, leather, etc.) material. The cellulosic (lignocellulosic) matter can be divided into three different substances, namely cellulose, hemicellulose and lignin, which all have different thermal decomposition characteristics. The non-cellulosic portion of combustible MSW mainly consists of different plastics, leather and rubber. The plastic fraction constitutes of several different types with varying composition. The most common plastic types are the pure hydrocarbon plastics such as HDPE (high density polyethylene), LDPE (low density polyethylene), PS (polystyrene) and PP (polypropylene) and the chlorine containing PVC (polyvinylchloride) (IEA, 2001). The combustible stream is typically shredded, dried and processed into pellets, fibre or fluff suitable for use as fuel in subsequent processes.

According to new directives or legislations introduced by many countries, putrescible or biodegradable portion of MSW should be subjected to aerobic composting, anaerobic digestion or ethanol fermentation instead of incineration or landfill. The high moisture content of putrescible material would relatively consume a large portion of energy during drying or preparation process for thermal combustion or gasification, which may not be justified.

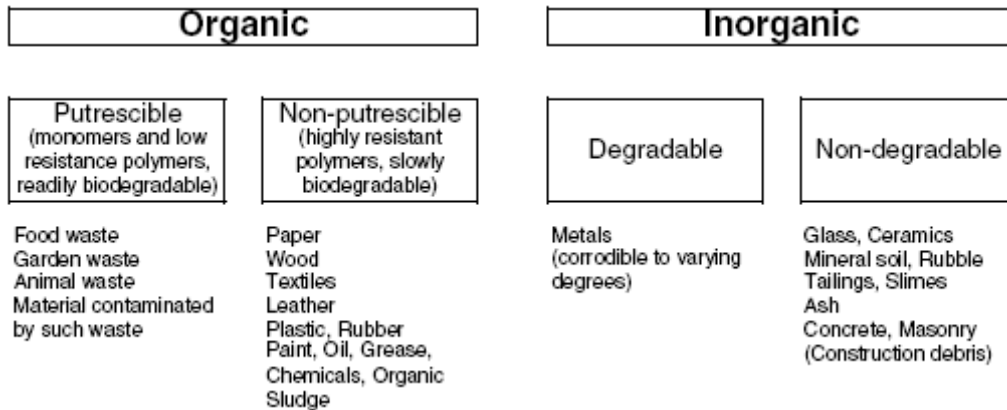


Figure 5. Waste classification based on degradability of material (Landva and Clark, 1990).

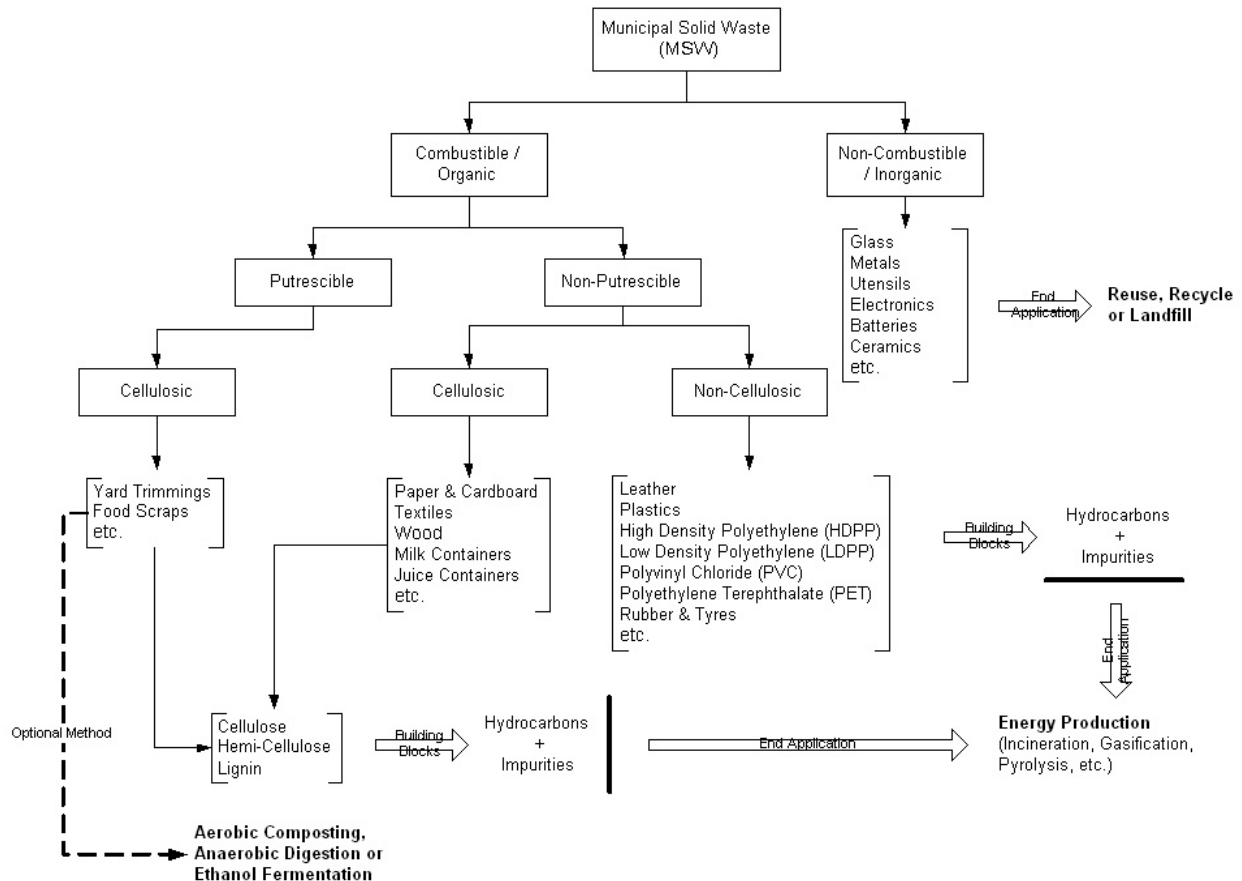


Figure 6. MSW classification system for Energy Recovery

4. Conclusion

An extensive review of existing classification systems was performed with a prime focus on energy recovery systems. A review indicated that numerous systems are available; however, all of these systems were designed to facilitate physical (reuse and recycle), biological (compost) or landfilling processes. It was realized that municipalities around the world are actively using and introducing thermal or advanced thermal technologies for energy recovery to efficiently utilize the hidden potential of MSW, instead of landfilling. Therefore, a new MSW classification system targeting various energy recovery processes is suggested.

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