

The 3Rs as the Basis for Sustainable Waste Management: Moving Towards Zero Waste

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Introduction

On a global scale, we currently are facing three major environmental crises: global warming, depletion of resources, and destruction of our ecosystem (Tanaka, 2010). These crises are interrelated and connected to waste and waste management.

Additionally, the Earth's population is soon expected to reach 7 billion and projections indicate that the population will be close to 7.2 billion by 2015 (UNEP, 2005a). Additionally, this population trend is accompanied by a substantial increase in the urban population. It has been estimated that more than 60% of the world's population will be living in cities by the year 2025. This rapid urban growth is straining the ability of public officials to provide adequate water supply, wastewater collection and solid waste management services. Population increases combined with economic development lead to increases in the amount of solid waste generated. The management of municipal solid waste is a difficult task that requires a variety of approaches.

In 1987, the United Nations Commission on Environment and Development indicated that economic development generally leads to a deterioration, not an improvement, in the quality of people's lives. Consequently, the Commission defined sustainability and stressed that: *"sustainable development is that which meets the needs of the present without compromising the ability of future generations to meet their own needs."*

Since 1987, various regions and countries around the world have decided to use the concept of "sustainable development". However, the type and level of implementation of sustainable concepts varies. Furthermore, there are different interpretations and uses of the concept to different disciplines. For example, in the European Union (EU), the implementation of sustainability has been developed in several stages.

In a meeting in Gothenburg in 2001, the European Council (EC) adopted a strategy for the European Union aimed at sustainable development. In addition, the EC added an environmental component to the Lisbon strategy (which up until that time dealt only with social and economic dimensions).

In 2002, the EC stressed that the strategy for sustainable development means that all of the EU's policies needed to be consistent with its long-term objectives. Economic, social, and environmental considerations had to receive equal attention in policymaking and in decision-making processes.

The conclusions of the "Spring Council" emphasized that the strategy suggested in Gothenburg still is one of the European Union's priorities. The Council's objectives include protecting the environment in the interest of growth and employment.

The EC has reiterated the importance of achieving economic growth without causing negative environmental impacts, improving energy efficiency, and also increasing the use of renewable sources of energy. Consequently, the application of sustainability principles in production processes has been placed in a much broader perspective than before. In addition to the focus on social and on economic aspects, a third aspect has been included, namely environmental. These three aspects constitute the three “pillars” of sustainability. In addition, a link has been made between the environmental pillar and environmental protection.

One of the concepts that was introduced into solid waste management was that of the “hierarchy of waste management” also known as the 3Rs (Reduce, Reuse, and Recycle). In general, this concept suggests that there is a preferred order of waste management that should be followed by us all. The concept points out that, unlike usual practice of blindly relying on disposal of all solid wastes in landfills, we should give priority to reduction, reuse and recycling (in that order). The concept of the 3Rs eventually led to the concept of “zero waste”. Plans to achieve “Zero Waste” now are being prepared in a number of municipalities throughout the world. These two strategies and their interrelationship in sustainable solid waste management will be discussed in the following sections.

Sustainability in Solid Waste Management

Currently, one of the most important criteria in the selection of technologies associated with the treatment and final disposal of municipal solid waste (MSW) in several industrialized countries is that of sustainability. For example, EU member states are experiencing a transition from relying mostly on sanitary landfills to waste minimization, reuse, recycling, and relatively complex treatment technologies. However, some of us working in solid waste management still are trying to determine whether or not the different pillars of sustainability are properly interpreted and applied to all of these approaches.

With regard to economic aspects, in general landfilling is the simplest, least expensive, and most cost-effective method of waste disposal (Allen, 2002). As will be described later, the flushing bioreactor landfill offers a good return for the investment and therefore scores well as part of the economic pillar. This is based on data from the EU indicating that the average amount of waste disposed in landfills still is at about 67%.

With respect to social acceptability, waste treatment is regarded by some as a continuous burden. As can be expected, economically developing countries generally focus on recycling and reuse (mostly through the informal sector) and disposal in uncontrolled disposal sites. In industrialized countries, whatever the choice of waste treatment is, those responsible for waste management face the NIMBY (not in my back yard) syndrome. Pereira et al. (1997) report that the application of waste prevention in Portugal is essential due to adverse public opinion to both landfilling and incineration. Therefore, Carabas-Hütter and Winistörfer (2001) recommend that a social compatibility analysis (SCA) be performed in conjunction with an LCA (life cycle analysis).

In solid waste management in industrialized countries, the motivation for shifting to higher (i.e., more complex) technological solutions is based on focusing primarily on only the environmental pillar. Hutter (2002) describes it as follows: *“until now policy making in waste management in the EU is mainly driven by environmental objectives. As a result of this approach rather expensive high-technology solutions are practiced with the final goal of reducing landfilling to a minimum. The question whether the environmental benefits outweigh the financial cost is hardly asked.”*

In the EU, the intention is to set these technologies as global standards. The landfill directive stipulates a reduction in the amount of household waste to be landfilled of more than 60% within 10 years. Thus, reuse, recycling, composting, and incineration are favored instead of landfilling. Ness and Bramryd (2001) question the evolution towards incineration in Sweden: "*The study has demonstrated that the current path that nations such as Sweden are following in MSW treatment may not be the most optimal path for both more sustainable and cost-effective waste treatment systems.*"

In the current approach to waste treatment in the EU, the focus seems to be on the environmental pillar, neglecting the other two pillars (social and economic) of sustainability to a certain degree.

Application of the 3Rs

The concerted application of the 3Rs in every type of waste generator can make substantial contributions to meeting all of the pillars of sustainability in several regions around the world. In addition, knowledgeable design of these strategies can help achieve important reductions in the quantities and types of materials requiring final disposal and thus contribute to approaching zero waste discharge.

Reduction or minimization involves all actions aimed at decreasing the amount of waste production. Waste reduction, after prevention, is one of the most important strategies to achieve sustainable development. In practice, waste reduction can be carried out by conducting life-cycle analyses or very thorough mass or material balances. These types of analyses and balances have been used in various sectors and at any scale – for instance in a manufacturing plant or in a single-family dwelling. There are a variety of benefits that can be gained from trying to achieve waste prevention. Two important benefits include: economic and environmental benefits. For instance, a comprehensive waste prevention plan in a manufacturing plant would lead to savings in the use of feedstock as well as a reduction in waste generation.

The strategy that follows reduction is reuse. In theory, the strategy of reuse would be applied once all possibilities for reduction have been exhausted. The concept of reuse is the process of "reusing" an item or material that has been discarded but the reuse must be in its original state either in the same manner for which it was designed or in a new manner but without any physical or chemical modifications. This strategy, although it has various applications and can lead to substantial savings, it has some limitations in particular those related to public health and sanitation. On the other hand, reuse offers a great number of social, economical and environmental benefits as long as the reuse programs are well-thought-out. Reuse was practiced several years ago around the world under a variety of situations; however, in many countries labor costs, fads, and other factors led to the abandonment of this practice. The application of this concept can also result in an important reduction in the demand for raw materials, the generation of employment and, of course, a decrease in the amount of materials discarded in a landfill or partially destroyed in a thermal conversion facility. Care must be observed in the reuse of certain items as they are related to safety, durability and performance guarantees. Examples that should be followed under most circumstances include: repair of furniture, electrical and electronic appliances. In this particular case, properly trained individuals would earn decent wages, would contribute to resource conservation, and help in the reduction of waste placed in landfills or in thermal treatment facilities.

In the event that reduction and reuse cannot be applied, then recycling is the next available option. Recycling of discarded materials is the process whereby the materials are recovered and processed such that the materials can be converted into new products. In the recycling option, the recovered item or material can be processed either physically or chemically in order to salvage the valuable components or

materials. Up to now, this option has been the most widely strategy used for the treatment of solid waste around the world. Recycling and thermal treatment certainly are the most widely treatment methods used in industrialized countries while different methods of low-technology recycling are the most common methods of treatment in developing countries. Recycling in most developing countries is carried out by the “informal” sector during different stages of the management process (storage, collection and final disposal). In addition, in some locations, scavengers travel the streets announcing the purchase of certain materials before they are discarded. The work of scavengers in final disposal sites generally is carried out under very difficult and unsanitary conditions. The outputs from recycling activities feed a variety of industries around the world such as the paper and steel industries.

Experience indicates that the application of the 3Rs is particularly difficult in developing countries. The author has observed that, in some locations those responsible for waste management, attempt to use the 3Rs concept to the letter and thus begin with “Reduction”. The inexperienced and often hurried official either does not see immediate results or cannot define practical waste reduction strategies and eventually stops all efforts and even does not go on to the next possible strategies.

As previously discussed each one of the 3Rs makes important contributions to sustainability and helps meet the goals of zero discharge. Reduction of waste conserves valuable resources and contributes to a decrease in collection and treatment (equivalent to reduction in gas emissions, consumption of fuel and other items vehicles and cost savings by the collection; a reduction in treatment requirements also saves energy and, in some technologies, reduces emissions). In addition, the fact that residues are not produced obviously results in a decrease in the amount of materials that require final disposal. On the other hand, reliance on reuse, albeit limited in some instances, if properly integrated into a comprehensive waste management program also can make important contributions to waste reduction, material conservation, cost savings and environmental protection. Finally, recycling in all of its forms also helps to conserve materials and energy, reduce the quantities of materials going to landfills, contributes to the economy, generates jobs and helps protect the environment.

As has been demonstrated, the 3Rs are critical components of an integrated solid waste management plan. A properly designed plan can make sizeable contributions to sustainable waste management and help reach the objective of zero waste. However, for these approaches to be successfully applied, it is of utmost importance that they be properly designed and thoughtfully integrated. In addition, in several countries, these programs must be complemented with comprehensive and frequent information, education and communication activities. Additionally, under most circumstances, the majority of these strategies will result in some type of residue that must be disposed. Given the state of the art of solid waste management, the only available final disposal method is a landfill. However, care must be taken that the landfills of the future must also be sustainable. A brief discussion of sustainable landfilling follows.

THE ROLE OF LANDFILLS IN SUSTAINABLE SOLID WASTE MANAGEMENT

Regulations in Europe and in other parts of the world have established that the aftercare phase of a municipal solid waste (MSW) landfill should be 30 or 40 years after completion of operations. However, after 30 or 40 years liquid and gaseous emissions from a typical landfill still do not meet the standards of acceptable quality for the receiving environment. Currently, it is fairly well recognized that length of time is not a good indicator as to whether or not a landfill may be considered sufficiently biologically and/or chemically stabilized (Fourie and Morris, 2003).

The need to reduce emissions from a landfill to levels below certain limits within a certain period of time is an ethical matter directly related with the concept of sustainability. It is now recognized that it is not morally or ethically acceptable to leave to the next generation environmental conditions that are inferior to those left to us by previous generations. If we, as a society, were to continue to follow these practices, they would lead to practically intolerable living conditions in the near future.

In the mid-1980s, Baccini, Henseler, and others associated with the Swiss working group on landfills developed the term “final storage” (Eka, 1986). The term final storage has, little by little, evolved over time to mean “a state of the waste in which the emissions are acceptable for the environment in the short term (1-10 years), in the medium term (10-100 years) and in the long term (100-10.000 years)” (Sabbas et al., 1999). Acceptable impact implies that all the emissions from a landfill do not have a substantial effect on the quality of the air, soil, and water. This means that the emissions from a landfill would not produce significant negative impacts on the surrounding environment and the risks associated with the emissions would be considered negligible. Once the value of “acceptable risk” is fixed, the objective of final storage can be defined. Legislators, in cooperation with technicians, will have the task of quantifying this threshold of acceptability and of defining the duration of the aftercare period.

The difference between this new approach and the current one in the North American and European Regulations is clear. In the decrees, in order to determine the duration of the aftercare phase, a timeframe is defined without taking into account the risk that will still be present after that time. On the other hand, in sustainable waste management, acceptable emission limits must be established for determining the time when the aftercare period has been attained.

Figure 1 presents a comparison between the approaches described in the European Regulation with that obtained from the concept of final storage. In the figure, the time denoted as “0” corresponds to the time of cessation of landfilling operations and the commencement of the aftercare period.

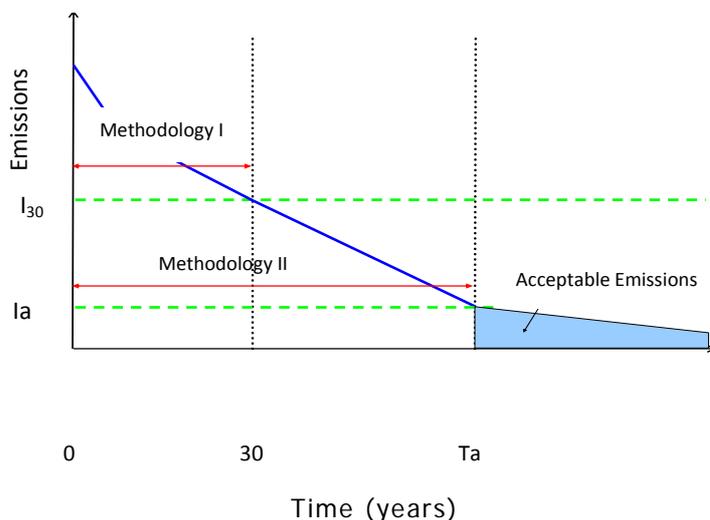


Figure 1. Comparison between the methodology presented by European Regulations and that obtained from the concept of “final storage”

Source: Cossu, et al., 2005

4. THE CONCEPT OF SUSTAINABLE LANDFILL

Agreement on the definition of “sustainable landfill” has not been reached on an international level. Furthermore, a variety of alternatives have been proposed to reduce emissions from landfills. Some of these alternatives include waste minimization; reuse; recycling; thermal, mechanical and biological pretreatment; leachate recirculation; and others. These alternatives are presented in Table 1. Some of the alternatives listed in the table may be used alone or may be used in various combinations to try to reach zero discharge and achieve sustainability requirements.

The traditional technology for landfilling of raw waste leads to the development of anaerobic degradation processes. These anaerobic processes persist in the waste mass producing leachate and biogas for a relatively long time. According to some authors, the long-term environmental impact caused by MSW landfills may last for centuries (Kruempelbeck and Ehrig, 1999).

Synthetic and natural liners, typically used in the construction of landfills, might leak and the drainage systems may clog. In addition, there are several other negative environmental impacts such as dust generation, noise, traffic, production of offensive odors which invariably render landfill siting and public acceptance problematic. Consequently, the sustainability of a landfill, whereby no environmental problems should be left to future generations, represents the main goal to be achieved by modern landfilling strategies.

Different options are available for reaching the target of the sustainable landfill. In Table 1, the influence of different alternatives for waste and landfill management on the main parameters in the mass balance is considered. The main options considered are waste minimization and pretreatment, leachate management (recirculation, flushing), and alternative landfill management such as in-situ aeration.

Table 1. Influence of different treatment options on the main parameters in the mass balance of a landfill (“+” indicates a positive effect)

Option	Conc. Of Components.	Input mass	Uncont. emissions	Leachate out	Contamin. in gas	Biogas out	Accumulation (fixed)	Reaction
Waste minimization		+						
Mechanical pretreatment			+		+		+	+
Biological pretreatment	+							
Thermal pretreatment	++	++						
Leachate recirculation			+					+
Open landfill/flushing				++				+
In situ aeration						+	++	++
Anaerobic landfill			+		+		+	+

There still is a considerable amount of discussion associated with the degree of the pretreatment step. This step may involve mechanical, biological, thermal, and physical-chemical (inertization) processes.

Mechanical pretreatment such as size reduction (shredding) results in a positive influence on the size distribution of the material, on the acceleration of biochemical processes that take place in the body of the landfill and on the enhancement of the conversion of biodegradable matter into the gaseous and the liquid phases.

Biological pretreatment reduces the amount of readily available organic materials, enhances the waste degradation processes, increases the permeability of the waste mass and, by giving rise to a methanogenic leachate, reduces the clogging effect in the granular bed of the drainage system. However, in order to obtain a well-stabilized waste with a relatively low emission potential, the biological pretreatment should last at least four months. This process might be too costly and consequently unacceptable. A biological pre-treatment step shorter than four months might be combined with subsequent disposal of the treated material into an aerated landfill, in order to have the stabilization process completed in situ.

Thermal pretreatment achieves a dramatic reduction in the amount of available organic matter, as well as on the volume and mass of waste to be disposed. The leaching potential of incineration residues still has to be thoroughly assessed, especially when deposited in combination with other waste. The environmental significance of this type of co-disposal still needs to be further evaluated.

Leachate recirculation also has a positive contribution on the transfer of the contaminants into the liquid phase, moreover it provides an increase of moisture content and a better diffusion of substrate and nutrients in the entire landfill body and consequently the degradation processes are enhanced. Flushing provides an improvement in the degradation processes for the same reasons; moreover, the mass of pollutants extracted with the liquid phase increases dramatically.

Aerobic conditions in the landfill body provide the acceleration of biological degradation processes in comparison to the traditional anaerobic landfill; the formation of non-mobile compounds (humic substances) is also enhanced. The maximization of carbon transfer into the gaseous phase is obtained by means of forced aeration and collection of the exhaust gas.

Some of these alternatives have been evaluated at different scales (from laboratory to field-scale). Following is a brief description of some of the studies and of their findings.

Currently, under Dutch regulations, aftercare for a landfill is eternal. As such, the Dutch Association of Waste Management Companies carried out a contest with the goal of developing new concepts for the "*landfill in the 21st century.*" Some of the concepts proposed included new solutions for containment and ideas to influence the processes that occur in the waste (Scharff, 2005). The key for the development and implementation of a sustainable landfill seemed to be in the implementation of processes that would lead to the achievement of equilibrium with the environment within a reasonable time period such that aftercare could be stopped. After several years of research, three field-scale projects were started (Scharff, 2005):

- Bioreactor: primarily organic waste trying to stabilize the organic matter
- Equifill: mostly inorganic waste trying to reach equilibrium of all contaminants
- Monolith: immobilization of inorganic waste by cementation of contaminants

The results of this work thus indicated that: 1) biodegradation processes can be accelerated so that most of the methane generation potential is achieved within years instead of decades. The bioreactor can be considered as a pretreatment method that produces a material that meets final storage quality (FSQ). As an alternative, the organic matter can be pretreated prior to disposal in the land (i.e., in a bioreactor). Some areas that still require attention include: long-term nitrogen release, preferential pathways, and homogeneous degradation. On the other hand, the results of the Equifill and of the Monofill indicate that it is possible to meet FSQ requirements.

Knox et al. (2005), report that there is no benchmark for the last 5 to 10 years of the degradation of organic matter in the landfills. Tests presently available for determining the extent of stabilization may be too imprecise and inconsistent to determine when the landfill has reached FSQ. Additional testing procedures and methods need to be developed. Studies conducted in the UK suggest that even with active acceleration measures, it may be difficult to reach complete degradation of organic matter in less than 20 years.

Some of the most common types of landfill are:

- Traditional landfill placing waste that has been pretreated by means of either mechanical-biological processes or by thermal processes (Leikam and Stegmann, 1997; Scheelhaase and Bidlingmaier, 1997)
- Semiaerobic or aerated landfill (Matsuto et al., 1991; Matsufuji et al., 2000; Hanashima, 1999; Hudgins and Harper, 1999)
- Bioreactor landfill using in situ flushing of the waste mass (Blakey et al., 1997).

5. CONCLUSIONS

Population growth, migration from rural to urban areas, consumption patterns and others are placing substantial pressure on our ability to preserve a clean environment. These phenomena lead to substantial consumption of resources and the generation of both liquid and solid waste.

Proper management of solid waste is one of the most important challenges faced by a number of municipalities around the world. The concept of the solid waste management hierarchy also known as the 3Rs offers viable solutions to the sustainable management of the wastes and at the same time meet goals towards achieving zero waste discharges.

Reduction or sometimes known as waste minimization is an elusive strategy to meet but one that, if properly implemented can offer, in particular, economic and environmental. Of course, waste reduction offers social benefits such as contributing to a high quality of life, but, unfortunately the level of waste reduction and its impact often is difficult to measure. Reduction is more easily determined in "closed systems" such as industries and factories.

Reuse also contributes to sustainable development and helps meets the goals towards zero discharge. Examples of waste reuse that can be relatively easily established and evaluated include: furniture and electric and electronic appliances. Reuse (through repair) can be easily measured and evaluated. The benefits from reusing some waste materials cover all three pillars of sustainability.

Recycling is one of the most common strategies used all over the world. Recycling can be attained using relatively simple approaches to complex and costly installations. In either case, recycling contributes to sustainable waste management and, as it has been demonstrated in some urban areas around the world, it can divert on the order of 70% (byweight) of municipal solid waste from land disposal.

The key issue in the application of the 3Rs is its design by experienced and knowledgeable professionals who can evaluate and integrated possible alternatives so that they are sustainable and approach zero waste discharges.

The use of the 3Rs concept must be complemented by comprehensive information, education and communication programs which should be carried out frequently and for a number of years.

During the last few years, the trend in the EU with respect to the management of organic residues has been to decrease the amount disposed in landfills and to rely on relatively complex treatment alternatives based on the principle of sustainability. Considering the three pillars of sustainability (social, economic, and environment), some authors conclude that the trend has been brought about by environmental aspects, and to a certain degree ignoring the two other pillars (social and economic).

The results of some research studies show that:

- mechanical pretreatment may be considered as the only treatment step necessary before MSW landfilling, provided that aerobic conditions are maintained in the landfill for a certain time period; biodegradation processes can be accelerated such that most of the methane generation potential is reached within years rather than decades;
- the bioreactor can be considered as a pretreatment process that produces a material that meets FSQ;
- the organic matter may also be pretreated (i.e., in a bioreactor) prior to disposal on the land;
- some areas that still require additional research and development include: long-term nitrogen release, preferential pathways, and homogeneous degradation;
- disposal sites with primarily inorganic waste trying to reach equilibrium of all contaminants as well as sites using cold immobilization of inorganic waste trying to reach cementation of contaminants are capable of achieving FSQ requirements.

One major challenge that still remains to be solved is how to deal with the legacy left by sanitary landfills for future generations to manage. This challenge includes a variety of aspects such as: scientific, technical, environmental, economic, operational, financial, and ethical. The solution to this challenge requires setting criteria for the completion of landfill aftercare. Once this problem is solved, it would allow to calculate the "real" costs of landfilling and thus conduct comparisons with other types of solid waste management options.

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