Integrated environmental biotechnology-oriented framework for solid waste management and control in Nigeria

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4 AUTHORS, INCLUDING:

Ikechukwu Noel Emmanuel Onwurah

University of Nigeria

O. Otitoju Olawale

Federal University Wukari

Integrated environmental biotechnology-oriented framework for solid waste management and control in Nigeria

Ikechukwu Noel Emmanuel Onwurah*

Pollution Control and Biotechnology Unit,
Department of Biochemistry,
University of Nigeria,
Nsukka, Enugu State, Nigeria
E-mail: iyknuelo@yahoo.com
*Corresponding author

Victor Nwadiogbu Ogugua and
Olawale F. Otitoju

Department of Biochemistry,
University of Nigeria,
Nsukka, Enugu State, Nigeria
E-mail: oguguavictor@yahoo.com
E-mail: amb_otitoju@yahoo.com

Abstract: Several environmental problems arising from man's activity have to be solved in a cost-effective and an environmentally friendly approach. In this paper, a framework for an integrated management and control of solid waste in the south-east zone of Nigeria is presented. The major activities include collection and transportation of solid waste to designated areas, separation of reusable components (recycling) and bioconversion of biodegradable (biowaste) components into organic fertiliser and biogas. These activities will involve the communities, the industries, Small- and Medium-Scale Enterprises (SMEs) having the capacity of 'process and production integrated environmental technologies'. Biotechnological conversion of biowaste into enriched humus end product and biogas, and production of other goods and services using solid waste components as raw materials by the SMEs are the areas of 'additive environmental technologies'. The overall framework entails the application of modern- and future-oriented technologies that would provide the appropriate tools and direction for managing any backlog of solid waste and future pile-ups. Cooperation among government, public and research organisation is paramount.

Keywords: solid waste; recycling; biotechnological conversion; biogas; organic fertiliser; landfill.

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Biographical notes: Ikechukwu Noel Emmanuel Onwurah received his PhD in Biochemistry from the University of Nigeria in 1996. He is a Member of Nigerian Environmental Society (MNES), Society of Environmental Toxicology and Chemistry (MSETAC) and Nigeria Society of Biochemistry and Molecular Biology (MNSBMB). From 2000 to 2003 he is a Senior Lecturer and is also awaiting confirmation of a successful appraisal for Professorship Position with effect from 01 October 2003. His areas of interests include environmental biotechnology.

Victor Nwadiogbu Ogugua received his BSc (Hons) in Biochemistry (1990), MSc in Medical Biochemistry (1994) and PhD in Medical Biochemistry (2000). He is the recipient of the Vice Chancellor's award and the Faculty of Biological Sciences best graduating PhD Student 2000. He is a member of Nigerian Society of Biochemistry and Molecular Biology and Nigerian Environmental Society. His areas of research include medical biochemistry, free radical, environment and medically challenged people.

Olawale F. Otitoju is an Assistant Lecturer at Kogi State University, Anyigba, Nigeria. He received his BSc (Hons) in Biochemistry (2000), MSc in Biochemistry (2004) from the University of Nigeria, Nsukka. Currently, he is a Doctorate Student at the University of Nigeria, Nsukka. His research areas include environmental toxicology. He is a member of the Nigerian Society of Biochemistry and Molecular Biology and Nigerian Environmental Society. He is also a member of Society of Environmental Toxicology and Chemistry (SETAC).

1 Introduction

1.1 Waste generation in Nigeria

Wastes obtained from numerous activities can be gaseous such as carbon dioxide (CO_2), hydrogen sulphide (H_2S), carbon monoxide (CO); liquid (e.g. industrial effluents) or solid (e.g. municipal waste). There are ongoing biotechnological research activities for clean up of these air pollutants and odour abatement, using microorganisms. The availability and overconsumption of relatively cheap agricultural products and other amenities have contributed to the problems of environmental pollution and degradation. Streams of solid waste are generated from households, shops, offices, schools, market and industries. A typical solid waste can include sand, gravel, iron, aluminium, cardboard and biodegradable organics (biowaste). In the south-east zone of Nigeria, one can observe a huge backlog of solid waste dumps, as a result of the rapidly growing population, increasing urbanisation and industrialisation, combined with improper disposal systems. It is apparent that land disposal and incineration could be adequate long-term solutions, if put in place and managed properly, to counter the increase in rate of solid waste generation and its attendant environmental degradation in Nigeria. As a clean environment is dependent on sound environmental management, waste generators, researchers and the government must consider and implement effective and economic alternatives.

1.2 Government attitude

According to Iwu (2003), the Nigerian government has not paid due attention to environmental protection policies especially in the areas of integrated programmes and the development of local capacity in managing institution programmes. Assigning institutional mandates for multisectoral problems has always been a significant challenge, as government departments and agencies are organised along classical sectoral lines without effective mechanisms for handling complex issues that overlap agency jurisdiction. The economy of a country is fundamentally linked and largely dependent on its environmental health but policymakers often overlook this. Maintenance of the integrity of the nation's environment is essentially important for a sustainable development. As per Decree No. 58 of 1988 (as amended) of the Federal Environmental Protection Agency (FEPA), Nigeria confers what is now the Federal Ministry of Environment (FME) with the responsibility of the protection and development of the environment. Although the FME is empowered with the overall responsibility for environmental protection, some environmental activities fall within the mandates of other ministries such as the Ministry of Industry and Commerce, the Ministry of Science and Technology or other agencies such as the National Biotechnology Development Agency (NABDA).

1.3 Environmental issues in solid waste management

The rate of solid waste generation in the south-east zone of Nigeria has greatly surpassed the rate of effective collection, treatment and disposal; hence, large quantities of solid waste are accumulating in unauthorised areas. It has reached the point that humans and natural ecosystem are negatively impacted. For example, poisonous gases such as hydrogen sulphide, ammonia and odour are inherent to domestic and industrial wastes, and according to Vandevivere and Varstraete (2001), biotechnological cleanup of such gases is an area of current research activities. Also, toxic leachates pollute groundwater and surface water. The populace is now very much aware of the potential danger of these wastes to the general quality of the ambient environment, and there is a growing demand for proper disposal and/or resource recovery systems to be implemented in a cost-effective and an environmentally safe manner.

2 A framework for solid waste management for South-East, Nigeria

2.1 Management options

Source reduction in solid waste generation, especially from industries, is a management approach in waste minimisation referred to as 'pollution prevention'. This approach is ideal because it prevents a high rate of solid waste generation and provides for resource conservation. It is also more economical, environmentally safe and legally sound. Source reduction can involve modifying a process, substituting easily biodegradable materials for those that are resistant to degradation or replacing products that create a large quantity of waste with those that do not. Table 1 gives a comprehensive list of waste generating points, biowaste and the integrated technologies of the Small- and Medium-Scale Enterprises (SMEs) and the likely products.

2.2 Integrated activities

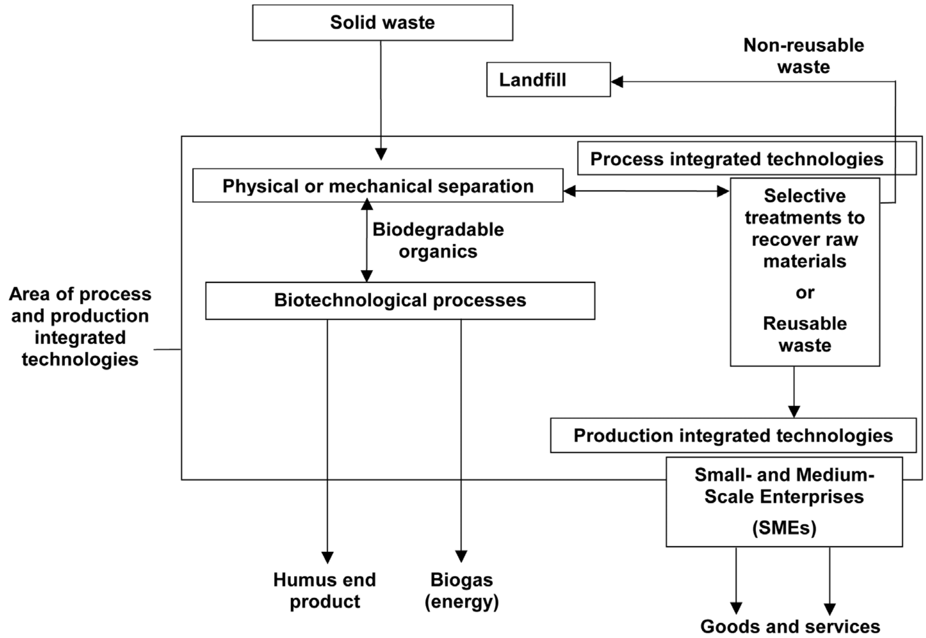
Waste management activities include minimisation, source reduction, recycling and transport and a safe disposal of non-recoverable residues. These will have an increasingly important input in the functioning of our 'internal market'. For example, solid waste prevention or minimisation will require biotechnology application (see Figure 1), especially for biodegradable organics. Also required is a membrane technology for the removal of toxic constituents of leachates from waste dumps or landfills containing used cans or tins made of different metals. Corrosion of these metals produces toxic substances (Onwurah, 1999a) such as Fe^{3+}, Cu^{2+} Hg^{2+}, Pb^{2+}, etc. Other activities include basic research, development of technical facilities or tools and making the necessary regulatory laws.

Table 1 Solid waste-generating points, biodegradable/non-biodegradable components and their utility in SMEs

1 Solid waste generating points	
• Industries	
• Households	
• Markets	
• Schools, etc.	
2 Separable solid wastes	
a Biodegradable components (biowastes) (60–70%)	
• Vegetables	→ Humus product
• Fruits	&
• Garden waste	→ Biogas
• Food remains, etc.	
b Non-biodegradable or not easily biodegradable (30–40%)	
• Sand and gravel	For integrated technologies (SMEs)
• Iron aluminium/non-ferrous metals scraps	
• Cardboard/paper	
• Plastic materials, including cellophane bags	
3 Process/production integrated technologies	
SMEs	*Products*
• Metallurgy industry	plastic buckets
• Paper industry	→ cable insulators, tyres
• Plastic industry	→ carton, toilet paper
• Construction industry	→ printing paper
• Smelting industry	→ machine parts
	iron sheets, aluminium sheets

Solutions to solid waste problems must take into account the technological, social, political and economic factors involved without neglecting its generation. Considering only the waste disposal technologies is like a medical practitioner treating a patient having constant headache without addressing the cause. This implies that everybody, including the government, must be involved in all aspects of waste management. There is no single comprehensive treatment technology for general mix of solid waste. It is therefore necessary to separate the solid waste components according to their physical and chemical characteristics, whereby each group is treated with a process designed for such unique characteristics. The treatment technologies can be grouped into three broad areas – physical, chemical and biological. These three together can constitute 'process and product integrated environmental technologies' (Vandevivere and Varstraete, 2001) and can be applied by SMEs.

Figure 1 Process and production integrated technologies for waste minimisation in industries and municipal solid waste management



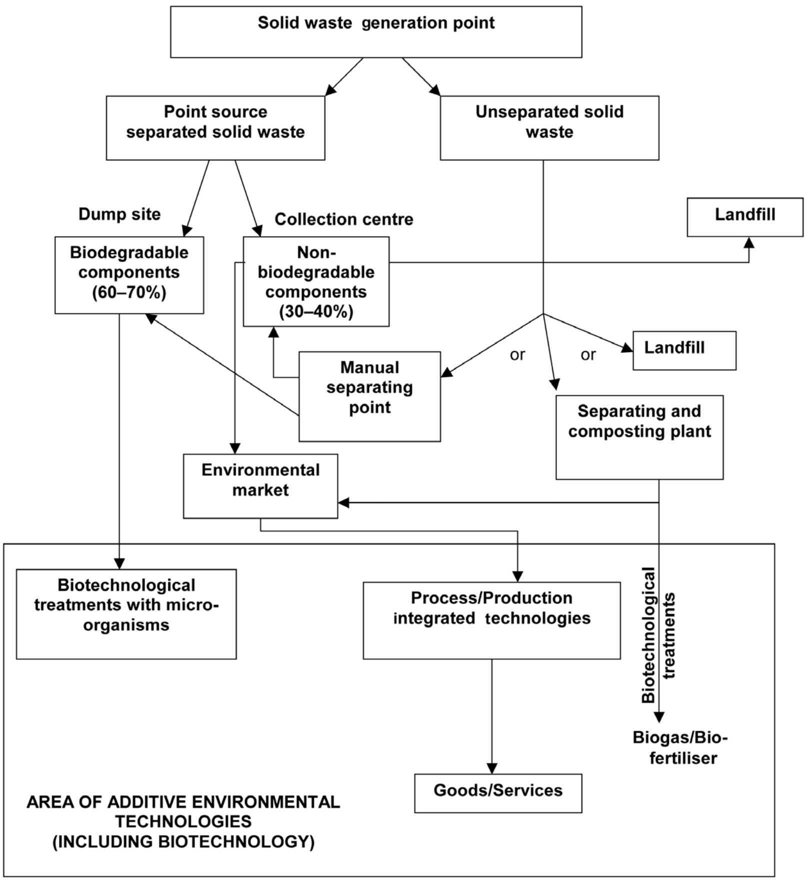
2.3 Waste collection and transportation

Collection and transportation are two areas of solid waste management that need special attention in Nigeria. They require at least 95% of accurate knowledge of the types and quantity of solid waste being generated on daily basis. The number of vehicles and machines for haulage and transportation and their maintenance can then be projected to a higher degree of accuracy. Collection of solid waste in this context means prompt removal from dumpsites within urban areas to sorting centres or landfill. Weak financial base and undedicated staff have militated against the success of this approach. To increase the financial base of the refuse-transporting agency, residents are to pay special taxes directly or indirectly. Indirect payment can be through payment for the special bags or containers for household solid waste. This can be enforced by legislation. When the bags are filled with waste, fresh ones would be bought. Hence, the more bags returned, the more the payment. Solid waste so collected could be sorted before final transportation to the landfill site outside the urban area.

2.4 Source reduction and recycling

A sustainable approach to solid waste management is expected to be an integrated system (see Figure 2). Separated components of solid waste can be used as raw materials for producing new goods and services, thereby generating revenue and creating employment opportunities. The areas of recycling and reuse in solid waste management are the 'process integrated and production integrated environmental technologies' (see Figure 2). Recycling, which involves separation, collection and transport, requires funding for wages, fuel, vehicles and infrastructure. Trained personnel can evaluate the cost of recycling schemes for solid waste components. Recycling makes financial sense if the net financial cost of recycling and disposal is less than the financial costs of the least disposal option. For household wastes, sorting out the biodegradable organics from other solid waste before depositing the waste in an approved dumpsite should become mandatory. This approach reduces or prevents environmental pollution. However, for urban settlements, where suitable landfill disposal sites are located too far away, disposal costs will be relatively high. The community will have to pay for the bulk haulage of the solid waste over long distances.

Figure 2 Framework for municipal solid waste management, showing the relevance of biotechnology and integrated technologies



Reduction in the volume of waste generation at the point source is a more realistic management approach than recycling. This 'waste minimisation' approach, as it is called, reduces disposal of 'total solid' by industries into the collection point. The least cost of disposal, without jeopardising environmental safety should be considered (Pearce and Turner, 1990; Turner, 1981) for the industries not having the capacity for reducing volume of their waste. Industries would be required to recycle the reusable components of waste they have generated, whereas those not needed after sorting could be sold to the SMEs that need them for their own production, or the waste components can be transported by the company or industry to the central dumpsite for further sorting/collation, before final disposal of the unwanted non-biodegradable into a landfill. Other designated sites such as erosion gullies can also serve as disposal sites if they are non-putrescible and could serve the purpose of erosion control. When source reduction is not feasible, especially with domestic solid waste, the management options are treatment, recycle and reuse. Reuse involves recovery without any need for treatment, or it can be an exchange that can be practised in-house or among different industries or SMEs. In all cases of sorting, the solid waste components could be separated mechanically or manually on the basis of physical or chemical characteristics. Hence, they can be grouped as plastics, ferrous and non-ferrous metals (cans), paper and cardboard, bottles, biodegradable organics and others.

2.5 Engineered landfill for biowaste disposal and biogas production

Landfill disposal of solid wastes still remains an important component of any future management strategy in the south-east zone of Nigeria. However, it will require a much more sophisticated and an engineered set of operations than it is currently used. 'Secure landfills', as they are called, are synthetically lined depression (or pits) in the ground for burying solid waste. The leachate should be collected through a series of pipes buried above the liner and regularly pumped to the surface for treatment. Secure landfills differ from sanitary landfills in that the former can be used for different mix of solid wastes while the latter cannot. Secure landfills if not engineered, should be located in areas with impermeable clay or silt soil that provides natural containment of waste so that liquid leachate cannot exit the containment area. Thus, the average cost of solid waste disposal in engineered landfills will rise. In a total landfill option, with recycling or reuse of waste components, cost would even be higher with less energy recovery.

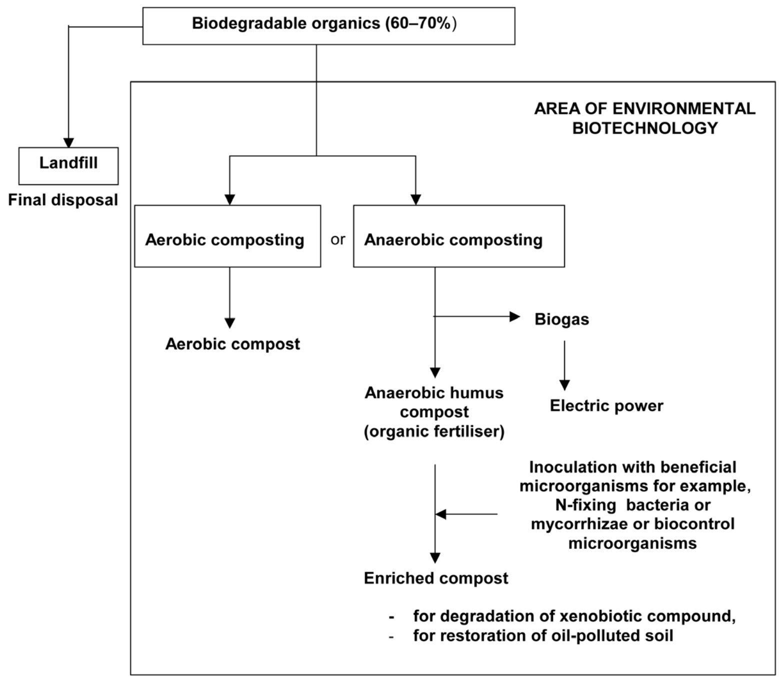
An engineered landfill can be constructed for the purpose of final disposal of biodegradable organics as an alternate for anaerobic or aerobic composting plants. In landfills, the humus compost may not be recovered but may become a future site for forestry (Shanks and McEwan, 1998). Landfill site will normally have several pits or cells, each having a depth of approximately 30 m with an area of 64 m and void of about 8 million m^3. A 2-m thick seal is required at the base and at the sides of the pits with a permeability not exceeding 10^{-9} m/sec. Also a clay cap (designed to keep water and landfill gas out) of 1 m thickness is required with a permeability not exceeding 10^{-9} m/sec. For biogas production, control and utilisation, an environmental gas control system is installed. This is extended to each cell after completely filled and sealed. When as many as 60 wells are drilled at maturity, a reasonable quantity of gas can be supplied to the generating station. Gas supply can reach about 5600 m^3/hr and can generate about 2.7 MW of electricity (Shanks and McEwan, 1998). This is a good example of non-fossil power generator.

3 Technological components of the framework

3.1 Biotechnology

The broad area of environment biotechnology also can be applied for the sustainable management of biodegradable solid wastes. In some urban areas of Nigeria, biodegradable components of solid waste are between 55.4% and 64.7% of the total mix (Egunjobi, 1987; Haskoning and Konsadem, 1988). Figure 3, which is an extension of Figure 2, shows all the pathways of the biotechnological processes involved in the conversion of biowaste into organic compost and biogas. Treatment of 200–400 g/l concentration of biowaste in a Dry Anaerobic Composting (DRANCO) plant in a one-stage fermentation at 55°C can be accomplished within two weeks (Vandevivere and Varstraete, 2001). Other commercialised anaerobic digesters with capacities range of 50–400 g/l and operating at temperature range of 35–55°C with one or two stages of fermentation can also be used. Although aerobic digesters can be used, the advantages of the anaerobic ones outweigh that of the former. One basic advantage of the former is that it does not demand high energy. The humus compost from the anaerobic digester contains a very low or no weed seeds and no microbial pathogens (Varstraete et al., 1996). The humus compost can be enriched through further inoculation with beneficial nitrogen fixing diazotrophs such as *Azotobacter sp* (Onwurah, 1999b,c; Onwurah and Nwuke, 2004), mycorrhizae or biocontrol microorganisms. The enriched humus compost has been shown to be an excellent soil conditioner with respect to plant germination and yield, and it has also been used for bioremediation of oil-polluted soil or coastal water (Pearl et al., 1996), and in degradation or its immobilisation of xenobiotic in soil.

Figure 3 Areas of environmental biotechnology for harnessing biodegradable organic solid waste



3.2 Information technology

The success of any integrated process will depend on adequate data. Increased precision about the quantity and quality of solid waste being generated from different communities is essential for rational decision-making and efficient and economical waste collection, processing and disposal systems. It is not clear whether any statistically significant waste generation rates have ever been estimated or if such was made recently for any of the cities within the south-east zone of Nigeria. At least 95% of accurate information is urgently needed for per capita solid waste generation and composition for effective management strategies to be implemented. Similarly, a good communication is essential to achieve success. Installation of modern communication technologies, which will permit information exchange on waste generation, recycling/reuse products, the biodegradation programme and the landfill system, will allow a good cooperation among SMEs functioning within the environmental industry. The use of Information Technology (IT) systems has already proven invaluable within the biological sciences and also helped to clarify the immense possibilities that exist in using biological systems as catalysts of industrial processes. Electronic mail and the internet are expected to play critical roles in communication and information dissemination as they are more interactive (Ozoguz and Krull, 2002). They can strengthen relationships between cooperative SME partners. Table 1 illustrates the likelihood of improving the available marketing services and materials in the environmental arena.

3.3 Projection from the framework

3.3.1 A new approach

'Process Integrated Environmental Technology' and 'Production Integrated Environmental Technology' refer to green technologies to convert solid waste into useful raw materials and useful products, respectively. In Germany (Ozoguz and Krull, 2002), the income of workers associated with environmental technologies is on the order of US$ 37 billion, and these individuals are mainly SMEs. These practices are also consistent with the tenets of sustainable development and permit energy to be conserved. For example, in newsprint production, there is clear energy saving associated with the use of waste paper. This is also the case for recycling of ferrous and non-ferrous metals. Process energy savings are very high for recycled aluminium. When aluminium cans are smelted in a reverberating furnace, the energy requirement is about 8.72 million BTU. This is far below the 244 million BTU necessary to produce ingot from primary ore (Turner, 1981). The issue of recyclable and non-recyclable plastics is not well resolved; hence, separation of plastics is targeted to a few product types. Mechanical separation plants have so far failed in separating both plastics and aluminium adequately. However, an elegant alternative for separating solid wastes is the so-called 'separation and composting plant' (Vandevivere and Varstraete, 2001). This type of facility would consist of a conglomeration of sophisticated large plants that could handle between 100,000 and 300,000 tonnes of solid waste per year. It would include a battery of physical separation units to recover sand and gravel, iron, aluminium, cardboard and paper, hard and soft plastics and biodegradable organics. Such facilities are already in use in Germany, the Netherlands and Belgium, where they have been shown to reduce the quantity of recyclable or reuseable fractions of solid waste that are landfilled.

The following are typical examples of integrated environmental technologies that could be developed in the south-east zone of Nigeria:

- biological anaerobic processes
- biological aerobic processes
- acid leaching of bimetal cans
- rubber production processes
- bottle manufacturing and
- extrusion processes (mixed plastic and glass).

The establishment of these SMEs while improving the environment will also reduce unemployment and increase the capital base of the south-east zone.

4 Conclusion

The government can operate production and process integrated environmental technologies jointly, with private sectors (including SME) and the local communities to process municipal and industrial solid waste sustainably. This approach will likely support the establishment of many SMEs employing processes such as those listed above. These changes can be accomplished by employing pollution control framework that utilises Best Availability Technology Not Entailing Excessive Costs (BATNEEC) (Pearce and Turner, 1990) such as waste minimisation at point sources and recycling and reuse of waste components. Provision for alternatives can also be considered based on the Best Practical Environmental Option (BPEO) such as the use of a separation and composting plant or manual separation, digestion of the biodegradable waste and composting in landfills. This approach creates opportunities for energy or material recovery for resale. The entire operation is most likely to promote property values, quality of air, water and food through anaerobic humus production.

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