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Unlocking the resource potential of organic waste: a South African perspective

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In many countries, especially on the Asian continent, waste is considered a valuable renewable energy resource. At present 40% of waste generated in South Africa comprises organic material which, when digested supplies biogas. The biogas produced can either be used as it is, or it can be delivered as electricity using gas turbines. The electricity generated can be added to the national grid. In light of the increased demand for energy in South Africa, alternative sources of energy are required. When taking the examples of the Asian countries, where anaerobic digestion of waste is applied in rural areas to produce energy for cooking and lighting, it can be hypothesized that this technology could be transferred especially to the rural areas of South Africa. Small-scale anaerobic digestion is presently being implemented by a private company in Ivory Park, South Africa, illustrating that anaerobic digestion in South Africa may be a means of unlocking the energy potential of organic waste. This paper evaluates the requirements for an enabling governance environment to unlock the full potential of organic waste as renewable energy resource.

Keywords: Anaerobic digestion, biogas, renewable energy, organic waste, wmr 08–0088

Introduction

Solid waste management has become one of the main environmental concerns during recent years (Hartmann & Ahring 2006). In South Africa, the Department of Water Affairs and Forestry (DWAF 1998), refers to Municipal Solid Waste (MSW) as general waste that does not pose a significant threat to the public environment if properly managed (Von Blottnitz *et al*. 2006). Landfilling is generally considered the most practical waste management method in South Africa. However, the scarcity of available land in close proximity to areas of waste generation as well as the uncontrolled landfill gas (CH_4) and leachate emissions from organic waste have caused landfilling to become a less attractive option (Hartmann & Ahring 2006).

Moving towards a sustainable waste management regime, the internationally accepted hierarchy of waste management has shifted the emphasis from disposal to minimization, recovery, recycling and treatment (Sakai *et al*. 1996, DEAT 1999a). Anaerobic digestion as a biological treatment technology applied to the organic fraction of municipal solid waste (OFMSW), has become an established treatment process worldwide. The products generated from this technology comprise biogas (methane), which is a potential energy source and a nutrient-rich sludge, which has beneficial value as a fertilizer. Thus, the recovery of biogas as well as the recovery of nutrients makes anaerobic digestion of organic waste a sustainable waste treatment concept (Hartmann & Ahring 2006).

The anaerobic digestion technology for the treatment of OFMSW was developed in the 1980s and early 1990s and has been the major development within waste treatment facilities in Europe during the last few decades, resulting in more than 120 waste facilities presently in operation across European countries (De Baere 2006). A recent publication from Canada indicated that biogas production from waste has also been introduced in that country, where 1000 – 2000 tonnes of grape skin waste from a wine producing area, originally shipped to landfill sites, is now used to produce biogas, to generate electricity or to process it to natural gas (Reuters 2007).

The aim of this study was to establish the required governance environment to unlock the resource potential of organic waste in South Africa, potentially to produce a renewable source of energy.

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The state of the art of waste management in South Africa

Waste generation

The production of waste is directly related to economic development and income levels, not only in developed countries, but even in developing countries (DWAF 2001). Waste generation in South Africa amounts to about 427 million tonnes per annum of which the majority comprises mining waste (approximately 88%) whereas domestic and trade waste represent only 1.5% and sewage sludge about 0.1% (Oelofse 2008). Although the domestic waste contribution seems insignificant in comparison with the vast amounts of industrial waste, the middle class in South Africa generates in the order of 2.7 million tones year^{-1} of domestic waste (DEAT 2006). This translates to about 0.7 kg waste day^{-1} produced per person, which is comparable to 0.73 kg person^{-1} day^{-1} produced in developed countries such as the UK (Austin *et al*. 2006). The generation of waste in South Africa will probably increase, due to the expected population and economic growth: two key drivers of waste generation (DEAT 1999b). Von Blottnitz *et al*. (2006) stated that the six largest South African metropolitan municipalities (Johannesburg, City of Tshwane, Nelson Mandela Municipality, Ekurhuleni Municipality and eThekwini Municipality) were estimated to have disposed of 8.9 million tonnes of MSW (including: consumer waste, domestic, commercial, institutional and industrial waste) during 2005. The organic fraction of MSW contributes approximately 40% (by mass) of this waste stream (Mata-Alvarez *et al.* 2000, DWAF 2001, Van Nes 2006).

Waste management

Waste management techniques as applied in more developed countries are not always directly applicable on developing countries, due to social, economic and cultural differences. Waste management in developing countries has only been addressed since the mid to late 1980s (Thomas-Hope 1998). South Africa is no exception in that The Environment Conservation Act, 1989 (Act No. 73 of 1989) was the first South African law that required waste disposal sites to require permits. Implementation of this legal requirement for disposal site permits has proved to be challenging. Domestic waste in South Africa is disposed of on approximately 1203 landfills of which only 524 were permitted in 2006 (DEAT 2006) whereas the remaining 679 sites continue to operate illegally. Moreover, about 39% of the whole South African population (Statistics, SA 2007a) does not receive any waste collection service, while in the Limpopo province, only 17.3% of the population are reported to have access to waste removal services (Statistics, SA 2007a). The consequence of inadequate services is illegal dumping and waste disposal sites, from which the so-called scavengers recover recyclable waste materials which is sold, providing a source of income (Fiehn & Ball 2005).

In order to deal with the increased demand – an estimated 13% per annum increase in waste generation in Johannesburg alone based on the projected increase in population (Statistics SA 2007a) – the present landfill sites need to be expanded or new ones established. Landfills need to be properly engineered and operated to avoid negative impacts, such as groundwater contamination caused by leachate percolation (Fiehn & Ball 2005). The South African Department of Water Affairs and Forestry reported that only 10% of landfills in South Africa are managed in accordance with the prescribed minimum requirements (DWAF 2001), which was first published in 1994 (DWAF 1998). The White Paper on Integrated Pollution and Waste Management for South Africa (DEAT 2000), which adopted the internationally accepted waste management hierarchy, namely waste minimization at source, recovery, reuse and recycling of unavoidable waste, with disposal to landfill as the last resort, reflects the South African government policy on waste management (Oelofse 2008). Different waste treatment options exist depending on the nature of the waste types recovered during separation of the waste. In this paper the focus is directed to the feasibility of the biological treatment of organic waste in South Africa, applying the anaerobic digestion technology.

Biological waste treatment

Biological treatment of the OFMSW (40% by mass), has become an established technology in many European and Asian countries (Mata-Alvarez *et al.* 2000, Van Nes 2006) while this form of treatment is only marginally recognized in the USA and South Africa. This observation can possibly be ascribed to relatively inexpensive landfill fees and lack of an energy policy that recognizes organic waste as an (energy) resource rather than a waste material (DiStefano & Ambulkar 2006). It does, however, seem that the thinking around biological treatment of waste for energy recovery in South Africa is starting to change. A biogas digester converting human waste into energy was being tested in Ivory Park Urban Ecovillage in Midrand, Johannesburg, in 2006 (Resource, August 2006), and a pilot-scale digester converting manure and human faecal matter into energy is being tested in Giyane, Mpumalanga, South Africa (Figure 1) (personal communication, Jotte van Ierland, 2008). The mindset change in this regard

Fig. 1: The construction of a digester in Mpumalanga, South Africa (Picture: Jotte van Ierland).

can possibly be ascribed to the current electricity shortages experienced in South Africa. Von Blottnitz *et al*. (2006) have undertaken a study for the South African Department of Science and Technology to evaluate the opportunities for energy from waste in South Africa to influence policy in this regard. They concluded from their investigation that waste to energy has an 'exciting future' in South Africa, when approached innovatively and responsibly.

Anaerobic digestion of OFMSW

Anaerobic digestion technology

Anaerobic digestion is the natural process which, in the absence of oxygen, decomposes organic matter. The main products from this process are biogas and a reduced amount of bacterial biomass, often referred to as digestate (Mata-Alvarez *et al*. 2000). The biogas comprises methane and carbon dioxide with a small amount of hydrogen and occasionally of hydrogen sulfide (H_2S) and ammonia (NH_3) as shown in Table 1. The biogas can be used in many different applications depending on the cost, economy, safety, geographical position and availability. The digestate is a liquid, rich in nutrients and can be used as a fertilizer, although this is dependent on the quality of the materials being digested.

During the anaerobic digestion process organic materials are digested by a range of different species of naturally occurring bacteria, such as fermentation and acid- and methane-producing micro-organisms, each group being responsible for different steps in the digestion process. Factors, such as the lignocellulose content in garden waste, the C : N ratio, ammonia inhibition (manure) and particle size can influence the degradation rate of the waste (Hartmann & Ahring 2006). Food waste has been shown to give the highest biogas yield, which decreases with increasing amounts of garden waste added. Garden waste is less easily degradable due to the relatively higher concentrations of lignin as compared to cellulose and hemicellulose (De Baere 2006; Matekenya & Voster 2006).

In South Africa, anaerobic digestion has been an established technology since the early 1990s, as a way to reduce the amount of organic matter produced at sewage plants (Ross *et al*. 1992). Sadly, many of these digesters are presently not operated properly or are even entirely non-operational or simply not in use. The study by Snyman *et al.* (2006) revealed that at sewage plants in South Africa, the main challenges relate to operation and maintenance of infrastructure. Technology failures – anaerobic digestion systems at sewage plants in South Africa is a case in point – in developing countries can often be ascribed to some of the following observations.

- Education and skills level of plant operators.
- Maintenance problems with complex and expensive systems/equipment.
- Technical and financial constraints.
- Social considerations.
- Infrastructure requirements.

Table 1: Typical composition of biogas from OFMSW (Cecchi *et al.* 2003).

Components	Symbol	Concentration (vol. %)
Methane	CH_4	55–60 (50–75)
Carbon dioxide	CO_2	35–40 (25–45)
Water	H_2O	2 (20 °C)–7 (40 °C)
Hydrogen sulfide	H_2S	20–20 000 ppm (2%)
Nitrogen	N_2	< 2
Oxygen	O_2	< 2
Hydrogen	H_2	< 1

Co-digestion of different organic waste fractions

Co-digestion is defined as anaerobic treatment of a mixture of at least two different organic waste types. With the large volumes of sewage sludge produced at wastewater treatment facilities and the large number of existing anaerobic digesters at these facilities to stabilize the sludge, the anaerobic co-digestion of OFMSW with sewage sludge is especially attractive (Hamzawi *et al*. 1998). The substrate characteristics of OFMSW and sewage sludge are complimentary and therefore co-digestion is beneficial towards the anaerobic digestion treatment process and biogas generation. The OFMSW typically has high solid concentrations whereas sewage sludge is low in total solids, but contributes high microbial concentrations. Moreover, the higher concentration of macro- and micro nutrients in the sludge will compensate for the lack of nutrients in OFMSW contributing to a mutually beneficial co-digestion system (Rivard *et al*. 1990, Kayhanian & Rich 1995). Although digested sludge has a stabilizing effect on the digestion process, primary sludge increases the methane yield. Moreover, the addition of primary sewage sludge significantly decreased imbalances during the start-up of digesters (Demirekler & Anderson, 1998). The optimal mixture of OFMSW and sewage sludge is dependent on the specific waste characteristics and the process concept used. Several researchers observed the best performance with a volume of 25% OFMSW and 75% sewage sludge, respectively (Diaz *et al*. 1981, Demirekler & Anderson 1998, Hamzawi *et al*. 1998). Co-digestion can also be applied at existing treatment facilities without excessive investment costs, combining the treatment of the two largest municipal waste streams.

The advantages of co-digestion in the anaerobic degradation process are summarized in the following list.

- Improvement of the process stability.
- Increase of the methane yield.
- Achievement of a better handling of the waste.
- Combination of different waste streams that have diverse characteristics in one common treatment facility.
- Treatment of larger waste amounts in centralized large-scale facilities (Ahring 1995, Bozinis *et al*. 1996, Angelidaki & Ahring 1997, Hamzawi *et al*. 1998, Gavala *et al*. 1999).

Co-digestion of OFMSW with livestock waste

Anaerobic digestion of livestock waste (cow, pig and chicken manure) is an applied technology with proven excellent degrading characteristics (Ahring & Johansen 1992). Manure is an excellent basic substrate for the co-digestion process for the following reasons.

- High buffering capacity originating mainly from the ammonia.
- High water content with total solids content typically 3–5% for livestock waste from pigs and 6–9% for livestock waste from cattle and dairy cows.
- Rich in a wide variety of nutrients necessary for optimal bacterial growth.

The methane yield of livestock waste on its own is low due to the low solids and high fibre content, of which the latter is highly resistant to anaerobic degradation (Ahring & Johansen 1992). The biogas yield per cubic metre feedstock is higher with the addition of OFMSW to livestock waste (Mathrani *et al*. 1994) and can be as high as 25 m^3 CH_4 $tonne^{-1}$ feedstock (Ahring & Johansen 1992). Poggi-Varaldo *et al*. (1997) showed that anaerobic digestion was successful when adding a mixture of MSW, paper sludge and sewage sludge to a mixture of equivalent amounts of cow manure, soil and waste activated sludge as inoculum. Co-digestion of sewage sludge with manure showed the best results both in terms of a stable digestion and markedly enhanced gas production rates (Kayhanian & Rich 1995).

Small-scale biogas utilization

There are three options for (small-scale) biogas utilization: (1) direct end-use; (2) electricity generation; or (3) indirect end-use (Strachan *et al*. 2006). The most cost-efficient process for biogas use is direct use for cooking/heating, light or even refrigeration rather than converting it to electricity (Stegman 1996, Harris 2006, Strachan *et al*. 2006), since the change of biogas to electricity loses significant energy potential and complicates the process. Direct end-use requires an end user within 2–3 km from the biogas generation site, preferably with a continuous demand and also preferably with a process that can use 'dirty', low calorific value gas.

Anaerobic digestion technology and biogas production in South Africa

Are the Asian examples relevant to South Africa?

When considering the introduction of the anaerobic digestion technology for energy production in South Africa, the environmental, social and economic aspects of the various areas in South Africa need to be considered. The rural areas of South Africa may be comparable with those in China, which, like other Asian countries (e.g. India, Nepal, Vietnam, Bangladesh), apply this technology to generate energy from organic waste for lighting and cooking in rural areas (Van Nes 2006). China's Ministry of Agriculture introduced new technologies to rural areas of the country, of which a domestic biogas plant forms the base, combined with other transformations that are dependent on local conditions, such as pig farming and the construction of solar-heated greenhouses (Van Nes 2006). The director of the Energy Ecology Division (Chinese Ministry of Agriculture) stated that 15 million households in China were using biogas by the end of 2004, and this is predicted to increase to 27 million households by 2010. Livestock and poultry farm waste as well as household waste are the feed sources for the digesters. Not only are the benefits of the biogas recognized in these countries, but also the benefits of the valuable fertilizer created, which supplies nutrients and organics for the soil. The biogas plants are mainly situated in farming communities where they serve a dual need: the reduction in organic waste and the supply of biogas as an energy source in areas where no energy was available previously. Potentially, the South African Department of Agriculture can apply this example from rural China for the sustenance of farming communities in mainly rural areas, provided that the required governance environment is in place.

Case study in China (Van Nes 2006)

More than 90% of the 227 family units in Shipai Village in Jianshi County of the Hubei province in China operate a 10 m^3 anaerobic digester, providing 1.0–1.2 m^3 biogas day^{-1}, the equivalent of enough energy for cooking purposes and providing 1–1.5 h of light per day. With the provision of renewable energy from waste degradation, the costs of coal and the purchase of electricity were saved. Other related benefits were measured in the form of fertilizer, and further social benefits, such as improvement of health, employment and increased participation in social work by women, were achieved.

Anaerobic digestion and biogas generation in other Asian countries

The potential for domestic biogas production in Vietnam is large, since the country's farming industry is large, comprising mainly small subsistence family farms. The rural population is educated and wants to assist in realizing the potential of biogas from waste. Similar encouraging signs have been received from Nepal, where in 2004–2005 almost 20 000 domestic biogas plants had been installed (Van Nes 2006). These examples from rural settings in Asia indicate that waste is considered a resource in these countries. This can also be observed from the information on biogas digesters originating from India, where 3.7 million biogas units were installed by the end of 2004 (Van Nes 2006). This initiative is driven by the Ministry of Non-conventional Energy Sources to implement the National Biogas and Manure Management Programme. In India, biogas production is realized in combination with sanitation, where biogas units are incorporated with public toilets in small towns to supplement the inadequate delivery of cooking gas and where 'high-tech' wastewater treatment facilities are unaffordable (Van Nes 2006). This inventive technology shows that two needs (sanitation and shortage of energy) were combined to a 'win–win' situation, which can serve as an example to South African communities with similar needs.

Anaerobic digestion and biogas generation in South Africa

Often no electricity is supplied to informal settlements in South Africa or the poverty levels are such that households cannot afford electricity (HSRC 2006). The percentage of households living in informal dwellings increased from 12.7% in 2002 to 15.4% in 2007, according to the General Household Survey (Statistics SA 2007b). The number of households connected to electricity was reported to be 81.5% in 2007. Provinces with the lowest levels of electrification are the Eastern Cape (70%) and KwaZulu-Natal (76.1%). During the winter months, gas, paraffin, wood, coal and other products are burned for heating and cooking purposes. The burning of these fuels generates gases and particulates, which can result in lung and other respiratory diseases, especially in the young, elderly or immuno-comprised individuals. A need therefore exists for inexpensive, safe, alternative energy sources in communities presently without an electricity supply. In situations where the OFMSW can be separated at the source and co-digested with manure in an anaerobic digester, the biogas produced could be used to supply heat and light to these communities.

Present applications in South African

The Asian example has been implemented in South African by the AGAMA Energy group. This group has acknowledged that biogas and thus energy can be generated when treating wastewater, manure and organic waste and is implementing the necessary technology. Its main core business is the provision of green energy services and solutions in South Africa and the group has built a small number of biogas applications in this country. They advocate that biodigester systems relieve the environment since energy generated reduces the energy from carbon fuel-emitting power plants. A systematic extension of biogas technology is a manner to strengthen decentralization, create jobs and generally improve the quality of life with the highest benefit in the rural areas.

The company has conducted many feasibility studies and opportunity assessments for biogas utilization in different sectors and for several applications for implementation of anaerobic digestion of organic waste, in both the private sector and for the South African government. They mainly focus on three different applications.

1. Household energy plants, as can be observed from Case studies 1 and 2.

   Case Study 1: Stanford household digester (Agama Energy 2008)

   A 6 m^3 digester has been constructed to treat the household sewage and food waste. The biogas is used for cooking in this household.

   Case Study 2: Stanford Valley Farm Conference centre (Agama Energy 2008)

   In this situation a 13 m^3 digester is fed with the household sewage of 30 people, combined with restaurant food waste and some manure. The biogas generated is used for cooking in the restaurant.

2. Wastewater/sanitation treatment plants.

   Agama has acknowledged that in South Africa, especially in the rural and peri-urban areas, schools, orphanages and clinics are lacking sanitation. It is suggested that the generation of biogas could be used for sanitation and for sterilization of equipment in the clinics. Presently biogas generating projects are being implemented in the Kingdom of Lesotho, which borders South Africa (www.agama.co.za).

3. Small- to medium-scale agricultural plants in South Africa have the potential to generate biogas, as is the case in Europe and the USA. One such implementation is discussed in the following case study.

   Case Study 3: eThekweni small holding (Agama Energy 2008)

   The anaerobic digester is fed with household sewage and manure from three cows. In an agricultural environmentt the biogas emitted from animal manure and other organic waste provides sufficient energy to supply cooked food for a family of eight people (www.agama.co.za).

From the above case studies it can be concluded that waste-to-energy has been realized on a very small scale in South Africa by a private company. In order to take the concept of waste-to-energy further, waste companies, municipalities, non-governmental organozations and similar organizations have to 'buy-in' to this model. It has been estimated that more than 300 000 rural South African households could benefit from the waste-to-energy production to meet their cooking needs, thus eliminating long travels to collect five wood used for cooking (Agama Energy 2008). Often the women have to travel long distances to obtain enough wood to meet their cooking needs. With the introduction of a digester, these women could be actively tending to agricultural activities, which would improve the standard of living and could also contribute positively to the economy and food security. The feed stock for the digesters can be generated in the yard in the form of manure from farm animals, from human and kitchen waste as well as from agricultural waste.

Landfill gas utilization in South Africa

Landfill gas is a general term to describe the gas produced during the microbial degradation of organic waste in a landfill. As already indicated, landfills where MSW is disposed of, are among the biggest producers of methane, a gas which is 21 times worse than carbon dioxide in terms of its so-called greenhouse effect (Strachan *et al*. 2006). Biogas energy is renewable energy, which can contribute to the South African government's 10-year goal of 10 000 GWh of cumulative renewable energy contribution to final energy consumption by 2013 (Austin *et al.* 2006).

The first utilization of landfill gas in South Africa was in Johannesburg, through the Robinson Deep landfill gas scheme in the 1980s. More recently, gas extraction wells have been installed at the Marianhill, La Mercy and Bisasar Road landfill sites, in the eThekwini area to capture the methane for electricity generation, which will be sold to the municipal electricity department, eThekwini Electricity (Strachan *et al*. 2007). Applying this technology reduced the emission of greenhouse gases (GHG), for which carbon credits were earned. Gas turbines can generate electricity when more than 2500 $m^3\ h^{-1}$ gas is produced. Couth (2000) indicated that generally 670 $m^3\ h^{-1}$ landfill gas (at 45% CH_4) can produce 1 MW of electricity, although this ratio may have improved due to more efficient engines (Strachan *et al.* 2007).

The studies conducted by Themelis & Ulloa (2006) showed that in 2001 there were 1000 landfills collecting landfill gas worldwide. Approximately 2.6 million tonnes of methane are generated from landfill gas annually in the USA, of which 70% is used to generate heat and electricity. From this it can be deduced that it is very beneficial to collect the biogas produced from landfills, not only from a renewable energy point of view, but also because of the effect on global warming. A survey undertaken in 2004 by the South African Department of Minerals and Energy (DME 2004) analysed a total of 57 sites throughout South Africa to determine the potential for landfill gas extraction for electricity generation. The survey concluded that the majority of the power generation opportunities were associated with the larger landfills, located in metropolitan municipal areas. It was concluded that all 57 landfill sites included in the survey had potential for conversion of landfill gas to electricity. This prospective addition to the national electricity grid can thus contribute significantly to the country's renewable energy targets. Furthermore, a large consortium of interested parties (among which: South Africa's Central Energy Fund, the waste management firm 'Waste Rite' and Likusasa Energy Africa) is planning to generate electricity from the Johannesburg City Council's landfill sites under the '*Clean Development Mechanism of the Kyoto Protocol*' (pepei.pennnet.com/.../330209/17/ARTCL/none/none/1/Producing-power-from-landfill-in-South-Africa-is-a-gas/) (accessed July, 2008). Although the use of biogas from landfills to produce electricity is a good alternative to methane emissions into the environment, it should not be used to advocate landfilling as the best waste treatment option, since the present-day trend is towards waste minimization rather than towards waste disposal.

Biogas as vehicle fuel

Biogas (biomethane) can be used in the same vehicles that use natural gas. In several European cities, Stockholm, for example, buses are driven on bio-methane gas. This is also beneficial for the GHG emissions, since CO_2 emissions are reduced by more than 95% (Wellinger 2007). With the escalating cost of fuel in South Africa, the introduction of biogas as a vehicle fuel can possibly be an attractive alternative locally, where biogas has not been earmarked for this purpose before.

Fuel prices in South Africa almost doubled between January 2007 and July 2008 (Department of Minerals and Energy 2008), and even more price increases are expected in the forseeable future.

Economics of anaerobic digestion technology

Investment and maintenance costs

The economy of an anaerobic digestion plant is characterized by high initial investment costs, followed by ongoing operation and maintenance costs and the income from the sale of biogas or electricity. The input materials (e.g. feed) are often free of charge, unless transportation costs form part of the equation. Looking at various economic indicators allows the combined effect of the various costs and revenues to be considered. Typical economic indicators to consider include capital cost, operating cost, electricity price, heat price, digestate sales income and tipping fee income (Higham 1998). Although the rate of treatment of organic material in a digester will depend on several factors, such as the nature of the material, the digester temperature and digester mixing, the size of the digester tank can be taken as a proxy for treatment rate. Therefore the capital cost per unit volume of digester gives an indication of the cost for the treatment of a given amount of organic material (Higham 1998). In comparing data for farm scale and centralized anaerobic digestion plants, Higham (1998) concluded that there was no clear difference in cost m^{-3} between these scales. There was, however, a clear difference between commercially supplied equipment and plants where farmers took a large role in plant construction.

Capital cost per unit volume provides a measure of cost from a material treatment point of view. If energy is however a main driver, capital cost per unit energy recovered is a better measure. Capital cost per kW electrical export capacity gives an indication of the technology's effectiveness as a renewable energy source. In this instance attention should be paid to the optimization of gas yields and minimizing gas leakages (Higham 1998). If anaerobic digestion technology is introduced in South Africa by one of the larger municipalities, the initial capital costs could be eliminated or reduced significantly when using existing digesters at sewage plants. Many sewage sludge digesters in South Africa are presently under- or not utilized (Snyman *et al*. 2006). For example, of the 11 anaerobic digesters at the East Rand Water Treatment Works, only one was in operation for a research study conducted by the nearby University of Pretoria (personal communication, Erwat, 2007).

A study by Amigun & Von Blotnittz (2007) concluded that fixed capital investment per unit of capacity increased with increasing plant capacity. Doubling the size of a plant increased the capital cost by 130% and tripling the plant increased its cost by about 270%. On the positive side though, the payback period decreased exponentially as the capacity of the biogas plant increased (Singh & Sooch 2004).

Non-measurable environmental costs

In common with many types of projects with environmental implications, the analysis available does not account for all of the costs and benefits. For example, the environmental and nuisance costs resulting from conventional treatment and disposal methods are not given monetary value by the market economy. The benefits and environmental values are not realized as cash flows but through reduced complaints, better local relations and improved environmental conditions. A comprehensive economic analysis should include any avoided costs of disposal or avoided environmental costs (Higham 1998).

Costs savings when OFMSW is used to produce biogas

Utilizing the OFMSW for biogas production applying the anaerobic digestion technology will lead to cost saving; for example, reduced landfill management due to a reduction of up to 40% in the waste stream to be disposed of at the landfill. Furthermore the landfill lifespan can be extended over a longer period, thereby saving on the cost of acquiring new land for future landfill space. Additional cost savings will be achieved as less leachate needs to be treated and managed, thus increasing landfill stability. Finally, fewer or cheaper odour control measures will be required as a direct consequences of reduced organic waste disposed of at landfill.

Biogas used as electricity

Using biogas as an energy/electricity source will save environmental costs associated with conventional energy sources and electricity generation; however, it is difficult to quantify the cost savings in this regard. Basically, the value of biogas depends on the replacement of the conventional energy source. The production of 750 m^3 biogas day^{-1} to power a 60 kW generator, produces electricity at approximately R 0.50 kWh^{-1} (Agama Energy 2008). At present (July 2008) the average electricity price in Tshwane municipality is R 0.56 KWh^{-1}, which implies that the price of the renewable energy from waste is currently cheaper than the electricity as supplied by Eskom. The real incentive for using the anaerobic digestion technology to digest organic waste and generate energy will no doubt arise with the present and future predicted increases of electricity costs as well as with the increase of the world oil/energy prices and more importantly, due to the forecast shortage of electricity supplied by Eskom, the national electricity supplier.

Agama Energy (2008) calculated that in July 2008 the costs associated with the production of biogas to power a generator were slightly cheaper than the average electricity price as charged in Tshwane municipality. This finding implies that the price of the renewable energy from waste is currently cheaper than the electricity as supplied by Eskom.

Technology transfer

Although composting of organic waste is being practised in South Africa, the application of anaerobic digestion for the treatment of OFMSW is not widely implemented, except by Agama. Composting of organic, especially garden waste, is a feasible alternative to disposal at landfill, since garden waste, due to its high lignin content, is less biodegradable. At a local South African waste management company, considerable volumes of organic waste, such as paper and pulp waste, which is not suitable for composting, are used in a brick-making project. Interestingly, the results of laboratory studies conducted in the CSIR laboratories (South Africa) showed that co-digestion of pulp and paper waste with kitchen waste as well as pulp and paper waste on its own, resulted in high volumes of biogas. These empirical findings will be presented at local conferences in South Africa with the aim of eliciting the interest of private and public sector waste companies to transfer the developed anaerobic digestion technology into the market place (Greben *et al.* 2008). A study undertaken in England (Kramadibrate & Smith 2006) indicated that energy recovery through anaerobic digestion technology is the best practicable option for municipal solid waste. The findings of that study were based on comparing the environmental impacts as well as the health, technical, economic and social aspects of: recycling, composting, anaerobic digestion, mechanical biological treatment, incineration, pyrolysis, gasification and landfill among other factors. The other outcome of that study indicated that landfill was identified as the management option with the least benefits.

Discussion

This study clearly indicated that OFMSW is a valuable resource for energy production. In Europe the biological treatment of organic waste was boosted by the introduction of waste separation at source before collection (De Baere 2006), which may be one of the constraints for the implementation of anaerobic digestion using OFMSW in the urban areas of South Africa, where presently very limited waste separation at source occurs. This, however, does not apply to the rural areas, where waste is seldom collected. The South African Environment Outlook Report (DEAT 2006) identified waste stream separation in the near future as an opportunity in waste management. Source separation of waste in South Africa will benefit not only anaerobic digestion but all recycling efforts by providing cleaner materials for recycling and reuse as well as increasing the value of waste as a resource. Although waste minimization, such as composting and recycling, is applied in South Africa, the anaerobic digestion technology is not yet in the same league. Only small-scale anaerobic digestion operations have been reported, as discussed.

Local authorities in South Africa are responsible for solid waste management as well as sewage disposal systems (Republic of South Africa 1996). An assessment by the Department of Environmental Affairs and Tourism of the status of waste management in local authorities revealed that 87% of municipalities do not have the capacity or infrastructure to pursue waste minimization (DEAT 2007). In addition, it is reported that in excess of 80% of the municipalities are initiating recycling activities in some form or another but these projects are struggling to gain momentum due to lack of capacity. Serious problems are also reported with the management of sewage sludge at sewage treatment facilities in South Africa (Snyman *et al*. 2006) while many treatment plants indeed have anaerobic digestion reactors on site to assist with sludge stabilization.

Conclusions

Whether the resource potential of organic waste will be unlocked in South Africa, is largely dependent on an enabling governance environment, including national legislation, and on the priorities of both the environmental and energy sectors in South Africa. The obstacles that are preventing local municipalities from providing sustainable waste and sanitation service are numerous. They range from budget restrictions to illegal dumping, service backlogs, lack of effective bylaws and insufficient skills development (Snyman *et al*. 2006, DEAT 2007). In order to provide a sustainable waste service that is based on waste minimization principles and addressing the obstacles being faced by local municipalities, a host of interventions could be implemented. It will, however, require more than just enforcement of legislation and policies. An innovative approach to utilizing the available resources and capacity (human and infrastructure) at local authorities will be required.

To this effect, anaerobic digestion in a co-digestion scenario between sewage sludge and the OFMSW in an existing digester at the sewage treatment plant may provide opportunities for municipalities to not only improve waste management but also unlock the energy potential of organic waste (including sewage sludge). The generated biogas could then be used as energy to drive, for example, the pumps at the sewage plant, where the digester is in operation or to generate electricity to be added to the national grid. Generating energy at sewage works will reduce the vulnerability of sewage treatment plants to interruptions in electricity supply, which will increase in frequency while the electricity demand is higher than the supply, as is the current situation in South Africa.

Landfill management will become less problematic due to a reduction in leachate production and less CH_4 and CO_2 emissions from the reduced organic waste load and as an added bonus, an extended landfill lifespan. By combining OFMSW and sewage sludge in the anaerobic digestion reactors at sewage plants the anaerobic digestion treatment process and biogas generation will be improved, resulting in more biogas for utilization and improved sludge quality.

The current obstacles hindering the sustainable delivery of services (waste and sewage treatment services) by municipalities will have to be removed in order to exploit the full resource potential of organic waste that is going to be realized in South Africa,

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