Municipal Solid Waste Utilisation for Green Energy in Gauteng Province-South Africa: A Review

Tsietsi J. Pilusa, and Edison Muzenda

***Abstract*—**This short paper discusses the potential of utilizing various municipal solids waste streams as feed stock for green energy production. These waste streams includes but not limited to mixed combustible waste, rubber and plastic waste, health care risk waste, organic biodegradable waste, biomass and sewage sludge. Technologies such as anaerobic digestion, gasification and pyrolysis have been reviewed relative to the location and waste stream quantities in the selected sample area. It was discovered that there are environmental, social and economic benefits in waste to energy approach for the waste streams reviewed. The feasibility of implementing such technologies is mainly dependent on the initial capital investment and operational cost of the facility. Other factors include the size of the waste stream, product price and demand.

***Keywords*—**Biogas, Fuel, Gasification, Renewable, Gasification.

I. Introduction

MUNICIPAL Solid Waste (MSW) is continuously being generated. Thermo-chemical conversion of MSW for material and energy recovery continue to attract research interest [1]. Gasification of refuse-derived fuel (RDF) is a very efficient route to generate heat and electricity. Fossil fuels such as crude oil and coal are not only non-renewable; their rising consumption has been reported to be the principal cause of climate changes worldwide [2].

Sustainable energy sources are potential alternatives to the fossil fuel-dominated energy industry. Biomass is uniquely a renewable energy source that is not location-dependent. Secured, affordable and clean energy sources are critical for economic growth and development [3]. Over 70% of MSW is composed of combustible materials ideal for energy production. Gasification of the MSW via the refuse derived fuel (RDF) route will generate heat for power generation and synthesis gas rich in hydrogen as feed to fuel cell in a combined heat and power (CHP) systems [4].

There are various technologies available for energy generation from MSW, these includes incineration, gasification, generation of biogas and utilization in a combined heat and power (CHP) plant, generation of biogas and conversion to fuel [5].

Typically the residual component of MSW (non-recyclable, non-organic) is incinerated producing electricity at an efficiency of about 20% and thermal product at an efficiency of about 55%. Gasification produces electricity at an efficiency of about 34%. Thus, gasification of the residual component of MSW is more advantageous than incineration where a market for thermal product does not exist. Gasification of MSW (a non-homogenous fuel) is, however, not proven at commercial scale [6].

Biogas may be generated by digesting the organic fraction of MSW (OFMSW). The produced biogas may be utilized for CHP production or for transport fuel production as methane (CH_4)-enriched biogas. When used to produce transport fuel some of the biogas is used in a small CHP unit to meet electricity demand on site. This generates a surplus thermal product [7].

Both biogas technologies require significantly less investment costs than the thermal conversion technologies (incineration and gasification) [8]. A shortfall of the transport fuel production technology is that only 50% of biogas is available for scrubbing to CH_4-enriched biogas [9].

This review discusses MSW treatment and conversion systems integrated for green energy generation and material recovery, thereby eliminating the environmental footprints of the conventional MSW management processes in South Africa.

II. Technology Discussion

A. Builders Rubble Processing

This process involves crushing and screening of builder's rubble so that it can be re-used for backfilling or in road construction. The plants are generally fully mechanised operations and can also be designed as mobile or fixed plants.

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The material aggregate produced by these plants are either used on site or transported to a particular market. There are a number of these plants in operation in South Africa, mainly by private contractors for processing at demolition sites to save on transportation and material costs.

B. Materials Recovery Facility (MRF)

Waste is taken to a MRF where all, or selected quality and quantities of recyclable materials are removed from the waste stream, with the remaining residues going on to the landfill, or other process. The primary intent of a MRF is to move reclaimers from the landfill face to an enclosed building where loads of refuse that are judged to be high in recyclables (recyclable rich loads) are dumped on a covered tipping floor and then conveyed past the reclaimers in an orderly manner. The operations can be almost totally mechanised at a very high cost or be done on a highly labour intensive basis. There are a number of privately owned and operated labour intensive MRFs in South Africa

C. Mechanical Biological Treatment (MBT)

Residual waste is fed into a mechanized front-end to remove the metals, glass, plastics and contaminants. The mechanical processes maximize the diversion of recyclable and combustible materials, leaving a mainly organic fraction for the next stage of the process i.e. the biological process. Any anaerobic or aerobic biological process can be applied, including trommel separation, screen (static or vibrating) segregation, magnetic separation, eddy current segregation, hand picking and air classification. To date there are no MBT plants erected in South Africa due to high cost and it is an intermediate process in the waste processing process.

D. Gasification

A gasifier heats waste to a temperature in excess of 1000°C in an atmosphere starved of oxygen in order to have an incomplete combustion of the waste. This produces a gas, called a syngas, which can be used as a fuel [4]. The gas stream comprises mostly of carbon monoxide, hydrogen and methane. The precise composition of the gas is influenced by the temperature and the air and water content, which can be adjusted to yield the required gas composition [6]. There are no such plants in South Africa, but a few exist in the world.

E. Pyrolysis

The waste tyres, rubber and plastics are delivered by an approved waste tyre distributor to a permitted treatment facility where they are weighed. The tyres are offloaded, classified according to size, brand and quantities and stockpiled in accordance to the environmental permitting condition. This system allows the treatment facilities to have full record of all the tyres treated in terms of their class, size, manufacture and brand.

The tyre rings are trimmed and cut into pieces to extract the reinforcement high tensile steel using a mechanical steel extractor. The steel cords are baled and sold as a recyclable product. These trimmed tyres undergo mechanical shredding to approximately 10-15mm rubber chips. The chips are steam washed, dried and stockpiled before they are fed into a pyrolysis reactor vessel. The steam is generated using excess heat from the diesel generator set.

The reactor vessel is heated initially using gas or fuel burners in the absence of oxygen to temperatures of about 570°C until gasification occurs. The gasses are contained and condensed to form Crude Heavy Fuel Oil (CHFO) which can be further fractionated in a distillation column to form light diesel equivalent Tyre Derive Fuel (TDF) and Heavy Fuel Oil (HFO) [13].

The HFO fraction is blended with low sulphur commercial diesel fuel at 30:70 volume ratios to fuel a diesel generator-set that provides electrical power to all plant machinery. This approach is considered the most economical method for combusting high sulphur HFO since it allows exhaust emissions capture and chemical neutralization into value added products.

The emission from the generator set and reactor fuel burners is contained and chemically treated through a gas absorption column to produce valuable products such as gypsum and sodium sulphite depending on the type of the alki-solution used. The waste heat rejected by the generator set and reactor cooling is recovered though a heat exchanger for steam generation which is used in the plant [13].

Excess uncondensed gas from the process is recycled for process heating using gas burners and a portion of this is compressed and used as a fuel. At the end cycle, the reactor vessel is cooled, carbon black and steel remain as by-products.

The steel is baled and sold as a recyclable product whereas the crude carbon black is further processed in a supper micro mill using process water to wash and facilitate wet grinding. The milled slurry product is further classified and dewatered as a final product.

F. Anaerobic Digestion

Anaerobic digestion or bio gasification involves the biological decomposition of organic matter of biological origin (bio-waste) under anaerobic conditions producing methane and other secondary gases. The main process occurs in an enclosed and insulated steel or concrete digester. The process involves different micro-organisms at three distinct stages. As the process is anaerobic, no heat is produced directly and the temperature of the slurry must be maintained. The digestion typically destroys 40-70% of the volatile organic compounds in the waste [10]. The three main anaerobic treatment methods available are separate digestion (dry method), separate digestion (wet method) and co-digestion (wet method).

There are a large number of wet digestion plants at a number of sewage treatment plants in South Africa. A large proportion of these have been mothballed due to high cost of operation and the energy extraction benefit is very limited. Most of East Rand Water plants in Gauteng province, South Africa have sewage sludge digesters which are still fully functional.

In Europe, this technology is mainly used for food and putrescible waste.The process consists of a pre-treatment to prepare the organic residues for the anaerobic digestion, the digestion itself and a post-treatment of the digested solid fraction [8]. Auxiliary process steps deal with the air and water emissions before discharge. The pre-treatment usually consists of a dry and a wet step. The dry pre-treatment is a mechanical sorting. However, as some unwanted objects and materials are still present in the organic matter, a second wet pre-treatment is necessary to homogenize the material, adjust the water content and remove stones, sand, plastics etc. The product is now adjusted to the anaerobic reactor conditions. The mixture is pumped to the anaerobic digesters through heaters [6]. Heating is necessary to ensure optimal digestion at all times, independent of the weather and pre-treatment. The heat is supplied from biogas engines. The anaerobic treatment consists of the microbial conversion of substrate into mainly methane and some carbon dioxide and water. The degradation process requires strictly anaerobic conditions at an ideal temperature of between 30°C and 40°C. The degradation process encompasses several steps in which complex substrates (polymers) are hydrolyzed to monomers (e.g. amino acids, sugars) and further on to CH_4, CO_2 and H_2O. The reactor can be Continuous Stirred Tank Reactor that is completely closed and stirred using the produced biogas [10].

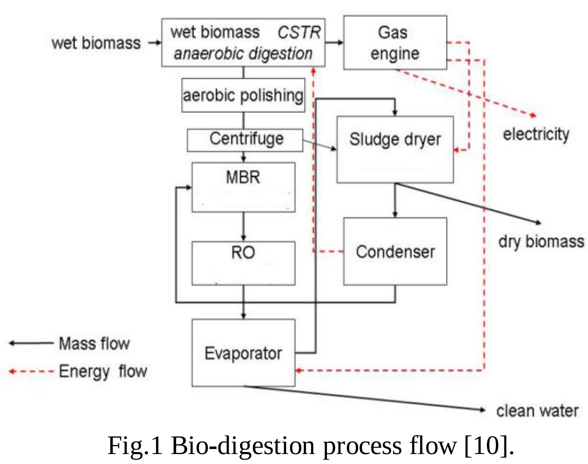

Fig.1 Bio-digestion process flow [10].

Valuable biogas (60%-80% methane) is collected in a gas chamber on top of the reactor system and is valorised in a cogeneration unit, producing electricity and heat. The biogas may require dewatering and desulphurization. The digested mixture is pumped out of the reactors and is first received in an intermediate buffer tank and then pumped to the dewatering presses to separate the liquor fraction from thickened fraction (25- 30% DS). The CSTR anaerobic digestion system has the following key features:

- Wet, mesophilic anaerobic digestion
- High biogas yield.
- High gas yield
- Higher quality of organic product
- Sufficiently long residence time.

III. WASTE TO ENERGY

A. Combustible Waste- Refuse Derived Fuel (RDF)

Production of Refuse Derived Fuel (RDF) is a thermal or mechanical pre-treatment method suitable for general waste. Pellets are produced which can then be used as fuel in approved facilities. Such processes produce higher quality fuel products with a higher calorific value than the initial waste and they are to easy to handle, transport and use. Pellets are normally sold, or distributed for free to industries. Although there are a number of RDF plants in the world, to date none has been erected in South Africa, and a market for the RDF will have to be investigated and developed first, as well as assessing environmental impact when the fuel is used in normal burners.

B. Biodegradable Waste

A bio-digester is a prefabricated vessel, into which various organic biodegradable waste can be added providing an integrated solid and liquid waste processing facility. It is designed specifically to meet the waste management need of households and farms while providing fuel gas. It is a multi-feedstock digester which insures high gas production. It enables anaerobic digestion of the biodegradable organic material. It is further designed in such a way that 50 percent of the nominal biogas produced can be stored in the digester. The gas outlet area allows easy and regular maintenance.

The digester is installed underground followed by complete process water, digestate and gas piping installation. A modular bio-digester vessel is shown in Fig.2.

Fig. 2 Pre-Fabricated 6000L bio-digester [11].

Feeding rate is dependent on the feedstock and temperature. A maximum of 1000 liters' of water can be added daily. Gas production is seasonal, hence loading in winter should be reduced due to slower biological activity. A daily loading of 30kg waste can produce up to 2000 litres of biogas. Biogas production is proportional to the amount of feedstock and operating temperature. Biogas contains approximately 60% methane, 39% carbon dioxide and 1% hydrogen sulphide. Each cubic meter of biogas has the heating value of approximately 0.43kg LP Gas. The nominal daily energy output is equivalent to approximately 0.8 kg LP Gas.

C. Health Care Risk Waste (HCRW)

The state of medical waste management in South Africa is alarmingly unacceptable. Recently, few cases of both general medical and health care risk waste dumped illegally in unauthorized sites have been reported. This practice poses a significant threat to human beings and the environment at large. In the wake of these cases and their detrimental effect, government has prioritised this problem and looking for coordinated efforts with the private sector and all stakeholders to find a sustainable solution. This means that the cost of medical waste management will have to increase to ensure proper destruction.

TABLE I
ESTIMATE HCRW IN SOUTH AFRICA

	Gauteng Province – South Africa	KWA Zulu Natal-South Africa	Eastern Cape Province-South Africa	Western Cape Province-South Africa
Public Health Care(t/m)	970	1231	830	212
Private(t/m)	432	101	83	177
Total(t/yr)	16,824	15,984	10,956	4,668

Table I shows HCRW quantities in metric tons per month or per year for major provinces in South Africa. These waste quantities were estimated using the number of registered patient beds in hospitals as reported in the Hospital and Nursing Year Book, 2013- Basis 1.8kg/patient –patient –bed-day at 62% occupancy. The waste quantities was estimated based on major health care facilities excluding day clinics, doctors consultation rooms and mobile clinics which are expected to feed their wastes into the nearest major health care centers. According to the data presented in Table 1, there is over 48,432 tons of HCRW generated in South Africa per year. This waste can be potentially be transformed in to an inert high calorific value refuse derived fuel via a non-burn treatment technology described herein. The resulting product can be used as a feedstock for gasification and co-generation stream.

i. HCRW Treatment Solution

The envisaged solution was desired to be onsite (within the waste generator's premises) to avoid the transportation of medical waste with its associated challenges, some of them being container management and tracking. It was also important for the solution to be non-thermal and well proven with minimum operating personnel contact with the waste.

This solution criterion of a decentralized, mobile onsite treatment solution was satisfied by the mechanical shredders supplied by three technology suppliers. All these technologies make use of mechanical energy to shred the waste into fluff with a high calorific value. In the second phase, disinfection occurs either by a chemical application or heat depending on the technology. The resulting product is an inert fluff with sufficient caloric value to be used as refuse derived fuel (RDF).

The shredders are mounted on trailers for mobility. This makes possible the objectives to treat onsite and avoid transporting of HCRW. They are also be equipped with loading and weighing mechanisms for billing onsite. This prevents the possibility of operator contact with the infectious waste and eliminates onerous tracking.

All these technologies have been tested and proven in their countries of origin however but none has been used in South Africa yet. These technologies are OMPECO H-25, PIWS-3000 and MedicShred.

ii. Challenges Relating to Current Medical Waste Treatment

- Thermal Incineration treatment, autoclaving and illegal dumping.
- Lack of permitted treatment facilities.
- Limited treatment capacities for permitted treatment facilities.
- Theft of reusable container due to intrinsic value.
- Handling of HCRW and associated risks.
- Cost of washing containers and generation of effluent.
- Non viable pricing, resulting in illegal dumping of HCRW.
- Transportation of HCRW treatment facilities enabling possibilities for illegal dumping.
- Thermal treatment of HCRW in facilities without air emission licenses.
- Autoclave facilities installed
- Relatively high Capex for centralized facilities (ZAR30-40mil/ facility) vs. (ZAR 3-4mil/mobile facility)

iii. Sustainable Approach to HCRW treatment

- Non-burn, chemical/wet-heat sterilization treatment technology with zero emissions.
- All technologies to go through technology approval process followed by a mobile full EIA.
- Focuses on the private sector.
- Hospital specific pricing is used.
- Use of sacrificial containers to provide total destruction on site.

- Viable pricing, including treatment, containers, power and logistics.
- Zero transportation/ handling of infections HCRW.

iv. Alternate Treatment Technologies

In this section alternative technologies that are available are considered.

- Hydroclave
- Autoclave
- Microwave treatment
- Incineration (with air emission licence)

D. Sewage Sludge Treatment

Sewage sludge is the unwanted by-product of the wastewater treatment process. It consists of a concentrated mix of solids in liquid which is biologically unstable and thus needs further treatment before it can be used as product or be disposed off. There are various options for treatment, such as incineration or stabilization, however, thermal drying is preferred as it leaves many sustainable disposal options open such as solid fuel and compost and can also be integrated technically and economically in large wastewater treatment plants [10].

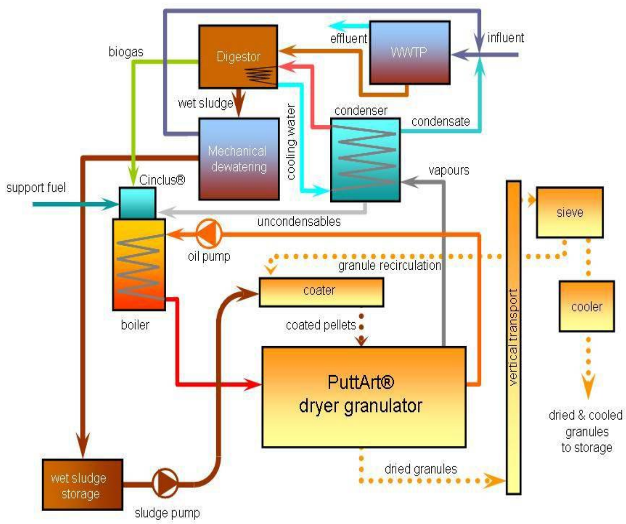

Fig. 3: Biological sludge dryer and Granulator [10].

The benefits of thermal drying are numerous: an 80% volume reduction and a more than 90% weight reduction dramatically decreases the transport and disposal cost. In contrast to the wet sludge, the final product is dry, sanitized, and odorless and can be stored for an indefinite time. The dry product is used as soil conditioner or fertilizer in agriculture

IV. Conclusions

Generating of alternative green energy from Municipal Solid Waste in South Africa is of a great interest. Recycling of material such as builder's rubble, metal, glass and clean plastics is active; however more attention is required in assessing the feasibility of implementing waste to energy facilities in South Africa. Economical use of fuels obtained from these processes may positively influence the environment while boosting the Economy by creating sustainable jobs and alternative low cost cleaner fuels from waste material.

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