In view of that, urban settlement in the country and most especially Sekondi-Takoradi metropolitan area which is the prime focus for this study is inundated with so much filth which proves to be very difficult and seemingly impossible to control, manage, or solve and thus threatens public health and the environment. The deplorable state of municipal solid waste (MSW) situation within Sekondi-Takoradi metropolis is reflected in the titles of most newspapers and online articles: “Sanitation worsens in Sekondi-Takoradi Metropolis”; “Sanitation problem in Takoradi is out of control”; “Filth engulfs Sekondi-Takoradi as landfill site chokes”; “STMA losing battle against filth”; “Sekondi-Takoradiś sanitation dilemma, Metro set to re-assign contract”.

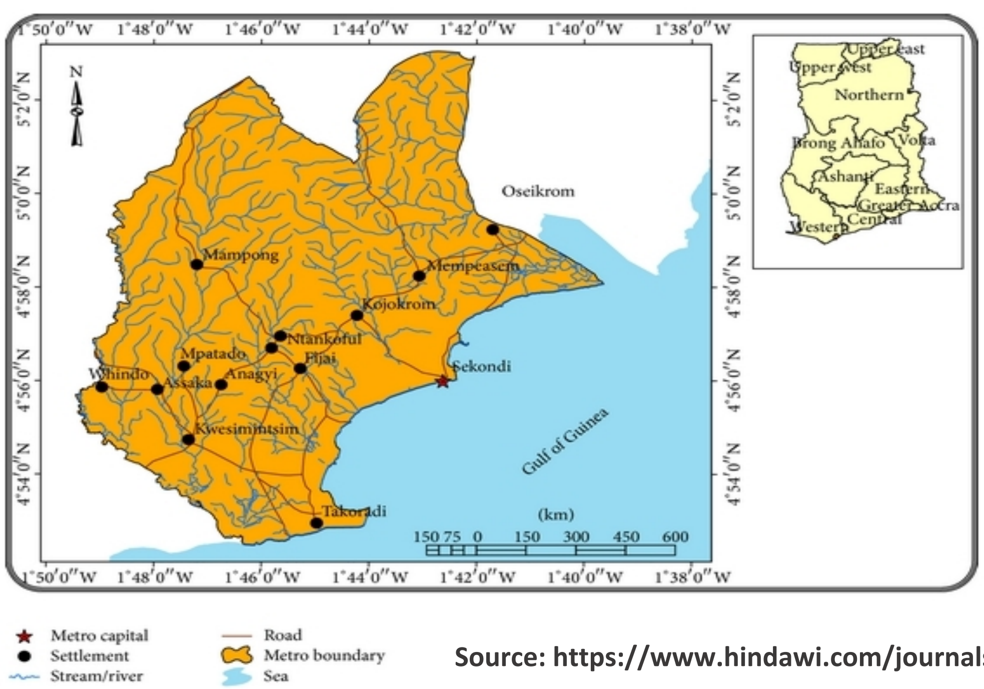
The main objective of the study was to examine the factors affecting effective solid waste management in the Sekondi-Takoradi Metropolis so as to get a better understanding of what the problems of solid waste management are and provide proper strategies to tackle the problem.

2. Methodology

2.1. Description of the Study Area

2.1.1. Location and Size

Sekondi-Takoradi metropolitan area is located between latitudes 4°52′30′′ N and 5°04′00′′ N and longitudes 1°37′00′′ W and 1°52′30′′ W. Bounded to the North of the metropolis is the Mpohor-Wassa District, to the south by the Gulf of Guinea, to the west by the Ahanta West District, and to the east by Shama District. The metropolis happens to be the smallest district in the region with a land area of 385 km2. However, it is the most populated district. The metropolis is strategically located in the south-western part of the country, about 242 km to the west of Accra the capital city and approximately 280 km from the La Côte dIvoire in the west. Figure below is a map of the study area.



Source: https://www.hindawi.com/journals/jwm/2014/823752/

3. Results and Discussion
3.1. Existing Solid Waste Management Practices
3.1.1. Waste Generation and Storage

The per capita waste output in the city according to the Waste Department of Sekondi-Takoradi is estimated at 0.6 kg with the total daily waste generation output based on a current 2010 population census figure 559,548 being 335,728.8 kg.

Waste generated at source within the metropolis just like most communities in Ghana is stored in all manner of containers such as plastic bags, paper boxes, baskets, unused buckets, or any container considered appropriate for such purpose. However households in the high and some middle class income areas within the metropolis have been supplied with dustbins with proper covering at no cost by the private waste collection company operating within those areas. Separation at source is not practiced but whatever waste that is generated in the various households regardless of their nature is put together in the same container for disposal.

Figure below depicts how the various sampled households store their waste before disposal. Data gathered from the sampled households revealed that 48.6% store their waste in closed containers with majority of such respondents hailing from the high class zone and about 30.4% ascribed to the use of open containers for waste storage whilst 21% use polythene bags/sacks for storing waste. This method of waste storage was very common in the low class zone and adds to the waste management problems as wind and animals scatter the content, thereby making the area unsightly. However, there wasnt any other form of waste storage apart from the three mentioned earlier.

State of a waste collection truck leaving the final waste disposal site at Sekondi-Takoradi Landfill.

3.1.2. Waste Collection and Transportation

Sekondi-Takoradi Metropolis - Solid waste collection system employed within the metropolis is of two main types and is either on a franchise or contract basis. The major cities and towns within the municipality have been zoned into units with each private waste collection company assigned the responsibility of collecting and transporting solid waste from the various zones to the final disposal site. The two main methods of solid waste collection within the metropolis are the door to door collection and the communal waste container system. The door to door collection which is usually done on franchise basis is carried out by private waste collection firms in high and in some middle class income areas at a fixed cost. Those that do not enjoy this service and who are usually from the deprived or low class income areas deposit their waste in central containers placed at designated points to be emptied at specific intervals at a very small fee. According to the Waste Management Department of the assembly, the high income zone within the city pays a monthly levy of GH 5 (USD $ 1.46) with the middle class zone paying GH 4 (USD $ 1.17) for the waste collection service that they receive. However, the low class income areas pay a very small amount, GH 0.20 (USD $ 0.06), for using the skip.

Those that use the communal container system are in the majority representing 49.3% whilst those who enjoy the curbside system make up 32.6%. However, 18.1% of households without the benefit of having the curbside and communal container system and which are usually from the low class zone and newly developed areas resort to the use of waste dumps and other crude means of waste disposal.

Massive patronage of the communal container system by majority of the residents coupled with erratic schedules of waste collection by the waste collection companies has put pressure on the limited number of skips available for waste deposition, thereby resulting in a huge number of spillages and mushrooming of illegal dumpsites often seen at most middle and low class zones where central container system is employed at no cost. This has led to serious spillages as well as the mushrooming of illegal dumpsites. These spillages were very evident with the skip monitoring study conducted in the metropolis as shown in Table 3.

Table 3: Frequency of skips filling and evacuation in selected areas of study. Sekondi-Takoradi Landfil

Residential area/section	Number of days taken for skip to get full	Frequency of evacuation
Effia	2	4 days
Sabon Zongo	3	4 days
Essipon town	5	3 days
Kojokrom	2	6 days
New Takoradi (upper)	3	5 days
Amanful East	2	Over 7 days
Nkontompo	3	6 days
Kweikuma Zongo	4	Over 7 days

All wastes collected within the metropolis are disposed of at a municipal dump site near the newly constructed landfill site yet to be operational at Sofokrom, a suburb of Essipon in the Sekondi-Takoradi Metropolis. The municipal dumpsite is a poorly managed area where authorities manning the area are engaged in open burning of waste at the site. This procedure is often adopted to reduce the volume of waste but it releases toxins and carcinogens especially from plastic materials. However, the best option to reduce waste volume and extend life of existing disposal site would be to improve waste recovery through recycling and composting programs. Even though there exist a municipal dumpsite for solid waste disposal, not all generated solid waste lands up at the dump site. The accumulation of waste as a result of the erratic schedule of skip evacuation poses a potential adverse impact on public health and environmental quality due to its attraction of rodents and vector insects for which it provides food and shelter.

Waste collection trucks that cart waste from the point of generation to the dumpsite are not covered and in some cases are covered with thin net that could barely keep it intact. As a result, the waste that was supposed to be conveyed to the municipal dump site gets littered all over the road. However, information gathered from Waste Management Department of the assembly indicates that operations of public and private waste management institutions cover 72% of the metropolis leaving 28% unattended to. The private waste collection firms take a greater chunk of percentage of waste collection within the metropolis whilst that of the assembly takes only 23% out of which most are evacuation activities. Within the coverage areas where solid waste collection is done, current statistics show that 69% of solid waste is collected and disposed of leaving 31% of the waste uncollected.

3.1.3. Waste Treatment and Recovery

In the city, there is no waste treatment or recovery facilities established by either the assembly or private companies. However, there exist some informal recycling facilities within the city that accept major recyclable items such as metals, glass, plastics, rubber, and papers.

Hence solid waste mostly disposed of in the metropolis does not go through processing or treatment. This is simply because wastes generated at the various households or points of generation are bundled together without undergoing any form of separation. This practice of handling waste at source without any form of waste separation has been a serious obstacle to any form of processing or treatment that relies on recycling or recovery programs. Due to nonavailability of any proper or formal legislation to ensure waste separation at source, potentially harmful or dangerous waste such as cadmium batteries, paint containers, pesticides containers, and other materials are found mostly in our household waste. In some cases medical and clinical waste are treated by incineration in open pits with no environmental control. However, the only form of recovery and reuse activities is by scavengers who search through waste in temporary storage areas and at final disposal site for items considered to be of economic value. These scavengers mostly use their bare hands and at times stick for separation and picking of the items which are dictated mostly by type, market value, and demand. The operational activities of these scavengers tend to be very dangerous and unhealthy since most of them go about their scavenging activity without any protective equipment. In some cases, hazardous waste from the industrial setting is buried at designated portions of the dumpsite without any prior treatment.

Sekondi-Takoradi Landfill - for more details of the World Bank funded & waste study performed - Study details - https://www.hindawi.com/journals/jwm/2014/823752/

New Vehicles required to transport waste to Bioreactor Landfill sites and in two years time to take the waste to the New Energy Plants.

One of the current waste vehicles in Ghana above

ZoomLion have similar trucks in ACCRA

New compactor waste vehicles required

Better waste vehicles required - increase tonnage

Waste Skip vehicle

The collection of waste and its transportation distance to either a Landfill site or Energy plant is an important factor.

The longer the distance there are both time and environmental costs.

Vehicles, Trucks & Machinery	Price EA.	QTY	Total
Saloon	25,000	2	50,000
MSW Frontend Mobile Equip	N/A	9+	2,000,000
4x4	25,000	2	50,000
Compactor Trucks	225,000	3	675,000
Mini Crew Bus	80,000	1	80,000
Dump Truck (20 m3)	120,000	1	120,000
Pickup Trucks (2)	25,000	2	50,000
		TOTAL	3,025,000

Waste Treatment processes

Waste Pre-treatment

Pre-treatment of the waste by shredding and mixing the shredded remains would have the following advantages:

- ❑ material of more uniform permeability is produced, with fewer preferential pathways;
- ❑ biodegradable material would be more uniformly distributed creating more uniform methanogenesis and consequent settlement;
- ❑ the addition of other materials such as sewage sludge might be facilitated, if desired.

Settlement of placed waste can be separated into three stages. The first stage consists of a rapid settlement in response to applied load as further waste and capping materials are placed above. Once the waste has been placed, there follows further settlement as the waste rearranges itself. The third and most prolonged phase arises from mass transfer, through biodegradation and the removal of gas and leachate.

Increasing the rate of degradation and stabilisation will require water to be added to bring the waste up to field capacity. This could be achieved at an early stage as part of the shredding and mixing process (wet shredding) or by irrigation (by bowsering or spraying) onto the working face. Inclusion of effluents or sludges such as sewage sludge at this stage may assist as a source of water. Since several bed volumes of water will be required to flush the elevated levels of dissolved salts out of the waste, wherever possible low grade water should be used. During the early stages of the site's life, recirculation of leachate should be used to ensure that all waste is sufficiently wetted and to act as a means of seeding the waste with bacteria. Recirculating acetogenic leachate from fresh waste will have the double benefit of promoting further degradation and converting the high levels of degradable organic carbon in the leachate into microbial biomass and landfill gas. After the onset of full methanogenesis and the production of a fully methanogenic leachate, this practice is of less value. To promote flushing of contaminants from the waste, a further low grade water source will be required. Treated sewage effluent might be suitable as it contains relatively low levels of salts such as ammoniacal nitrogen and chloride which are found at elevated concentrations in leachate.

The recirculation of leachate or treated leachate alone will not lead to removal of contaminants that are not susceptible to degradation, such as chloride, as they will not be removed from the site, but will concentrate in the leachate.

Liners & Caps

If flushing bioreactors are operated with thick saturated zones, then double composite liners may be required. This should however be based on a site-specific risk assessment.

A simple mineral cap is unlikely to be sufficiently flexible to cope with the rapidly sinking surface of the waste below and still provide gas control.

Depth of Landfill

Since the waste will settle and compact under its own weight, irrespective of any compaction technique used, there is a maximum depth to which the landfill or cell can be constructed and still maintain adequate permeabilities. For unsaturated shredded wastes, this may be between 20 to 30 metres pre-settlement.

Degree of Saturation

Maintaining the wastes in the site at field capacity will promote accelerated degradation. As discussed there is also a number of potential advantages, especially with regard to flushing, to operating the site with a saturated zone. The ability to operate the site with a saturated zone will probably require a secure hydrogeological location and enhanced engineering measures. The depth of the saturated zone within the site would be controlled through the leachate recirculation and drainage systems. Saturated conditions could be developed during landfilling by the introduction of water through the leachate collection system, thereby removing the need for intermediate injection systems.

Leachate Drainage System

In view of the large volumes of water involved, the most efficient collection system possible should be used. This will involve a full drainage blanket, which should be constructed from large stone rather than small particle sizes as resistance to clogging increases with particle size. Division of the drainage blanket if possible into a number of discrete zones will also provide more flexibility over how to flush the site.

The efficiency of the liquid reintroduction system under the cap will be related to the number of points at which the reintroduction is carried out. Section 5.6 notes the very close spacing which would be required if trenches are used, and suggests the use of a layer of drainage medium.

Depending on the depth and permeability of the waste, more than one leachate recirculation layer may be required for each cell.

Gas Control

Low permeability mineral caps are subject to cracking, and uncontrolled gas emissions may occur where insufficient suction is applied by the gas abstraction system. If the rate of waste degradation is accelerated, then it follows that the rate of gas generation will also increase. This is likely to exacerbate any leakage problems leading to landfill gas emissions and odour problems. One means of reducing the risk of landfill gas emissions is to include a flexible membrane.

For a landfill to be considered sustainable, any economic volumes of landfill gas must be collected and utilised locally for energy or for power generation. To allow large amounts of gas energy to be wasted cannot be considered to be sustainable. Residual quantities of gas must be flared or passively oxidised, e.g. in aerobic capping layers.

The question of the ideal period over which gas is to be generated must be carefully considered since production over too short a period might lead to inefficient and less economic utilisation.

Effect of settlement on liquid and gas control systems

In order to protect against the impacts of settlement, leachate extraction/collection infrastructure should be constructed on the foundations of the landfill rather than on the waste. Design might therefore involve sidewall risers on the lining system, and ringmain collection around the perimeter outside of any waste deposit. This configuration is already regularly adopted in site design of MSW landfills.

Leachate recirculation equipment presents more of a problem, as it is more likely that some of the infrastructure will have to be suspended on or within the waste mass.

In order to protect against the impacts of settlement, leachate extraction/collection infrastructure should be constructed on the foundations of the landfill rather than on the waste. Design might therefore involve sidewall risers on the lining system, and ringmain collection around the perimeter outside of any waste deposit. This configuration is already regularly adopted in site design of MSW landfills.

Leachate recirculation equipment presents more of a problem, as it is more likely that some of the infrastructure will have to be suspended on or within the waste mass.

Gas extraction systems have a combination of elements constructed on stable ground and elements constructed on the landfill. The design will need to allow for these differences and include flexible components and degrees of tolerance whilst not compromising the integrity of the system. At the same time, it is unlikely that the capability to withstand 40 per cent settlement can be easily engineered,

be commenced at a much earlier stage without the risk of leachate seepages around the margins of smaller operational cells.

The current benefit of increasing compaction by concentrating vehicle movements into small cells will in future be a disadvantage as discussed The absence of bunds should help to reduce differential settlement across the surface of the landfill.

Leachate Treatment

All of the water being recirculated will eventually have to be treated as leachate. The treatment may be carried out on-site or off-site but in both cases the residual components must be discharged off-site. If this is not done and the treated leachate continues to be recirculated, then components of the leachate such as chlorides will remain in elevated concentrations. These compounds may be polluting if they were to be released suddenly into the environment at such concentrations and thus the landfill would continue to present a threat to the environment. A strategy that consists only of recirculation of leachate, therefore, is not sustainable.

The volume of leachate and certainly the concentration of contaminants in that leachate will vary as the site ages. Of the components of leachate which will require treatment, the ammoniacal nitrogen content is usually the most expensive to deal with. As the refuse in the landfill is flushed, the concentrations of components such as ammoniacal nitrogen will fall. Ammoniacal nitrogen concentrations may initially be in excess of 2,000mg/l and have to be reduced to less than 20mg/l. As the nitrogen is leached from the site, supplying a constant daily load of ammoniacal nitrogen to a treatment plant would require the daily volume treated to increase as the leachate becomes more dilute. As the degradation progresses the permeability may fall making the passage of the necessary volumes of water more difficult. When the volume of leachate that can be supplied to the treatment plant is restricted by site hydraulics, then the daily load which it must treat will fall over time. This means that the cost-effective design and the sizing of treatment works is problematic and many operators, if the opportunity exists, may prefer to export leachate for treatment elsewhere rather than build an on-site treatment facility.

The degradable materials, ammoniacal nitrogen and the degradable organic compounds measured as BOD, can be successfully reduced in a treatment plant to an acceptable level for recirculation or for discharge to the environment. Poorly degradable organic compounds and inorganic salts will be residual components that may prove problematical for discharge under some circumstances.

If the discharge is to a relatively small surface water course then the size of the treatment plant may be limited by the amounts of chloride and non-degradable Chemical Oxygen Demand (COD) which may be discharged. Any limits on the discharge of non-degradable components may have obvious implications for the size of landfill that can be operated in a sustainable manner in a given location.

If the discharge of leachate is to sewer, then chlorides will pass through the sewage works untreated apart from dilution. Poorly degradable organic compounds will also pass through the sewage treatment works apart from a small degree of treatment and possibly some adsorption onto the sludge. The receiving works' own discharge limits may restrict the volume or load of leachate that can be accepted to sewer, and hence restrict the opportunities for flushing.

Treatment of the necessary large amounts of leachate, either in a purpose-built plant or in a sewage treatment works will obviously entail higher rates of expenditure than are usually allocated currently at UK landfills. However, present practices lead to the same pollution load being produced, treated and discharged, entailing similar total costs, but simply over longer timescales. The difference is therefore mainly a function of how accounting practices treat short-term and long-term expenditure.

Since the elevated levels of contaminants such as chloride have to be discharged to the wider environment (ultimately the sea) and the rate of release is constrained by the ability of the local environment (watercourses) to accept the burden of treated leachate, this has implications for site location. A low grade water supply for flushing purposes will be required. Location close to a large sewage treatment works or the sea is likely to be an advantage.

Restoration and aftercare

As well as the need for possibly larger structures for power generation and leachate treatment than currently utilised, planning authorities will need to appreciate that the landfill is not going to 'appear' complete until it is ready to achieve a certificate of completion, i.e. the waste is stabilised. If the site is operated to achieve this state within 30 to 50 years, then throughout much of this time there will be activity on the site extracting gas and leachate and maintaining equipment. This is in stark contrast to current sites which may 'appear' complete and restored within a much shorter timescale. Despite that appearance, in reality the period over which those current sites will be disturbed is likely to be longer than for flushing bioreactors although the disturbance will not be so intensive.

The placement of waste at a low initial density, followed by settlement of perhaps 40 per cent means that:

- waste planning authorities must accept pre-settlement contours which provide for such settlement; or
- a number of phases will be required to reach final contours, following the model set out in Section 6.8.2 below; or
- total waste input will be less than is achieved with present practices.

As described in the above sections, if a landfill site containing degradable materials is to be operated in a sustainable manner, it is likely to have a composite cap with a membrane barrier and underlying liquid reabsorption system as well as the usual gas collection system. It is likely to be shallow and the waste in it will be shredded and mixed. The waste will be wet and producing landfill gas very rapidly. At the base of the site will be a drainage system overlying a high specification liner system.

Possible Landfill scenarios

As described in the above sections, if a landfill site containing degradable materials is to be operated in a sustainable manner, it is likely to have a composite cap with a membrane barrier and underlying liquid reabsorption system as well as the usual gas collection system. It is likely to be shallow and the waste in it will be shredded and mixed. The waste will be wet and producing landfill gas very rapidly. At the base of the site will be a drainage system overlying a high specification liner system.

The following scenarios can be used if the need arises in the future in Ghana for more sanitised Landfill sites.

Scenario 1: Shallow landfill <15-20m pre-settlement

If the site of a proposed landfill is shallow, i.e. less than 20 metres at its deepest, then with the provision of an efficient drainage system, a composite cap and leachate recirculation system, it might be operated according to the principles above. Shredding and mixing equipment, leachate treatment and disposal, and gas control and utilisation would also of course be required.

Fig 8

FIGURE 6.1: Scenario 1 – Shallow landfill <15-20 metres deep pre-settlement

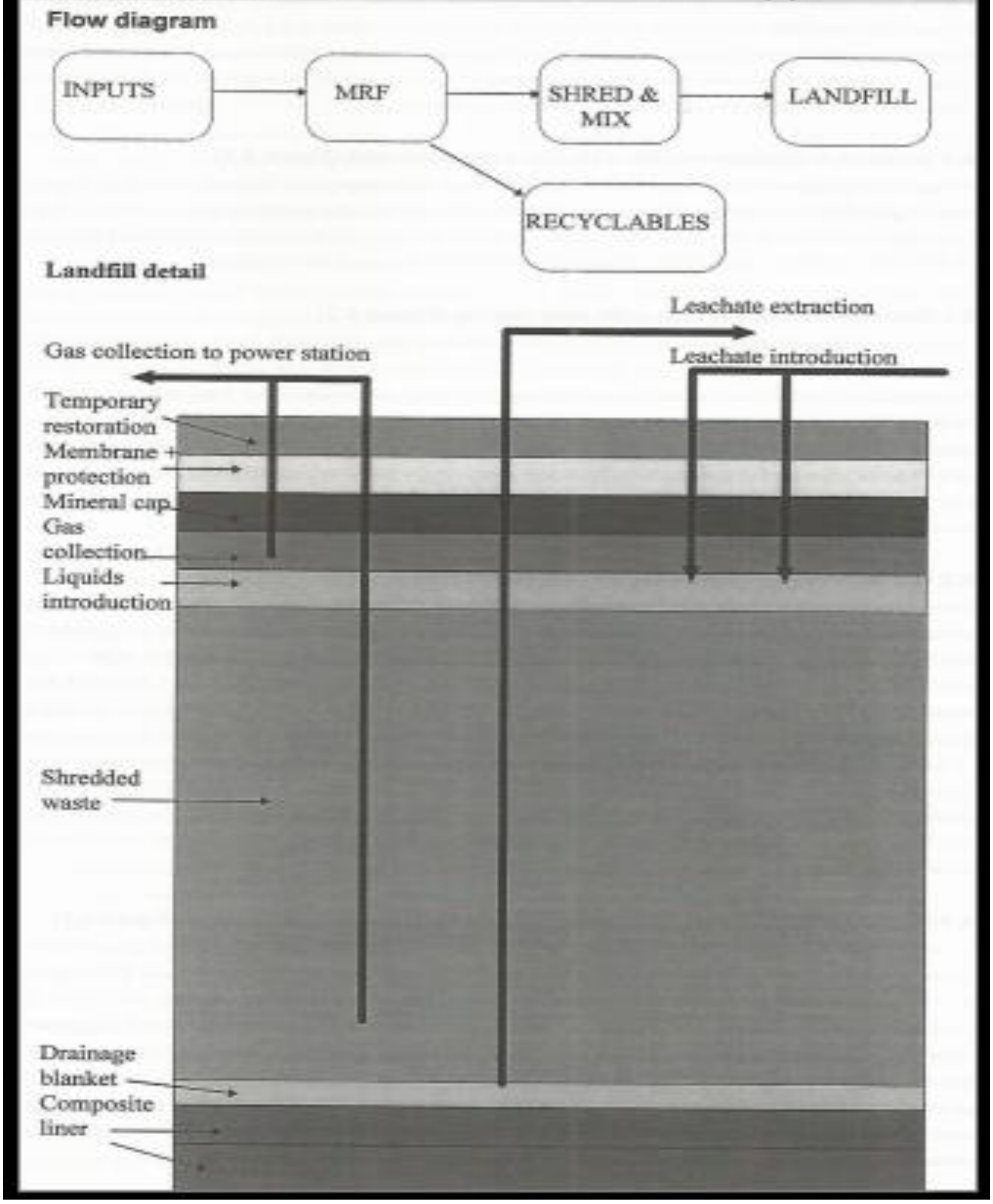


Fig 9.

Scenario 2: Shallow cells with over-tipping

A deeper landfill site might be subdivided into shallow cells, each cell being shallow enough to allow the passage of water through the waste, and equipped with gas and leachate control. The cells would be capped with a flexible membrane to enable gas control and leachate and other liquids would be recirculated at a rapid rate to allow substantial stabilisation before the filling sequence required the cell to be over-tipped. Some limited flushing could still continue after over-tipping but at a lower rate due to the compaction from the overlying waste leading to lower permeability. The initial recirculation rate would need to be very high for this type of operation due to the likely timescales for over-tipping.

FIGURE 6.2: Scenario 2 – Shallow cells with over-tipping

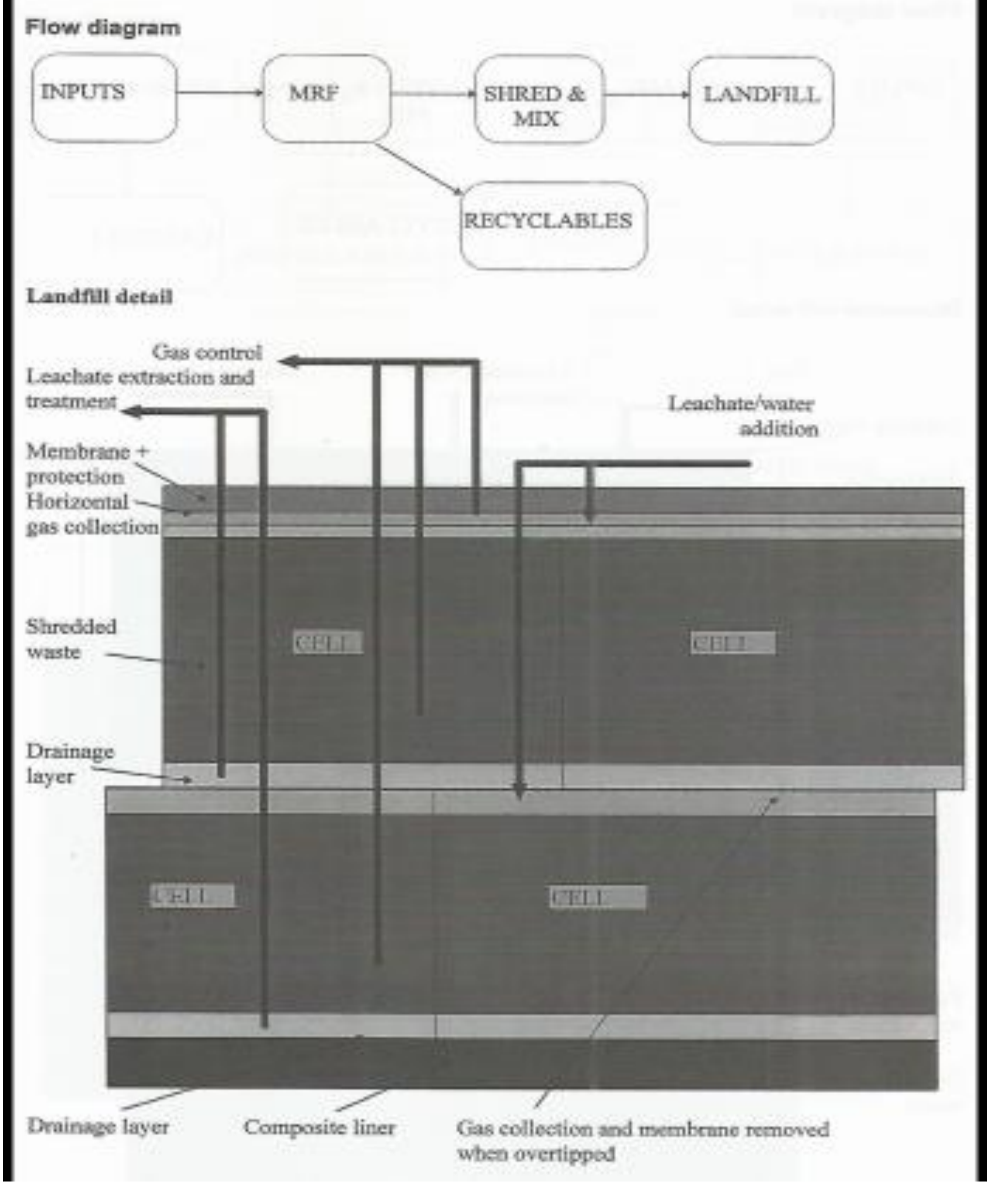


Fig 10.

Scenario 3: External digestion cell

Due to the difficulties of this very fast recirculation in landfills, an option worthy of further consideration may be to carry out the degradation in specially designed re-usable bioreactor cells and landfill the waste only after degradation. This concept formed the basis of the Landfill 2000 test cell study (Blakey et al., 1996; Knox, 1997). This might also be compatible with the Proposal for a Council Directive on the landfill of waste since this could be seen as a pre-treatment and no degradable carbon would be landfilled. The cells where the degradation took place might be engineered in a permanent manner, e.g. with a concrete base as part of the environmental protection. Such a design has been proposed in the output of a DTi/ETSU Research Contract (ETSU, 1993). This reusable cell could be engineered to a very high standard. The landfill receiving the treated waste might only require minimal engineering because the pollution potential of the waste would largely have been removed.

FIGURE 6.3: Scenario 3 – External digestion cell

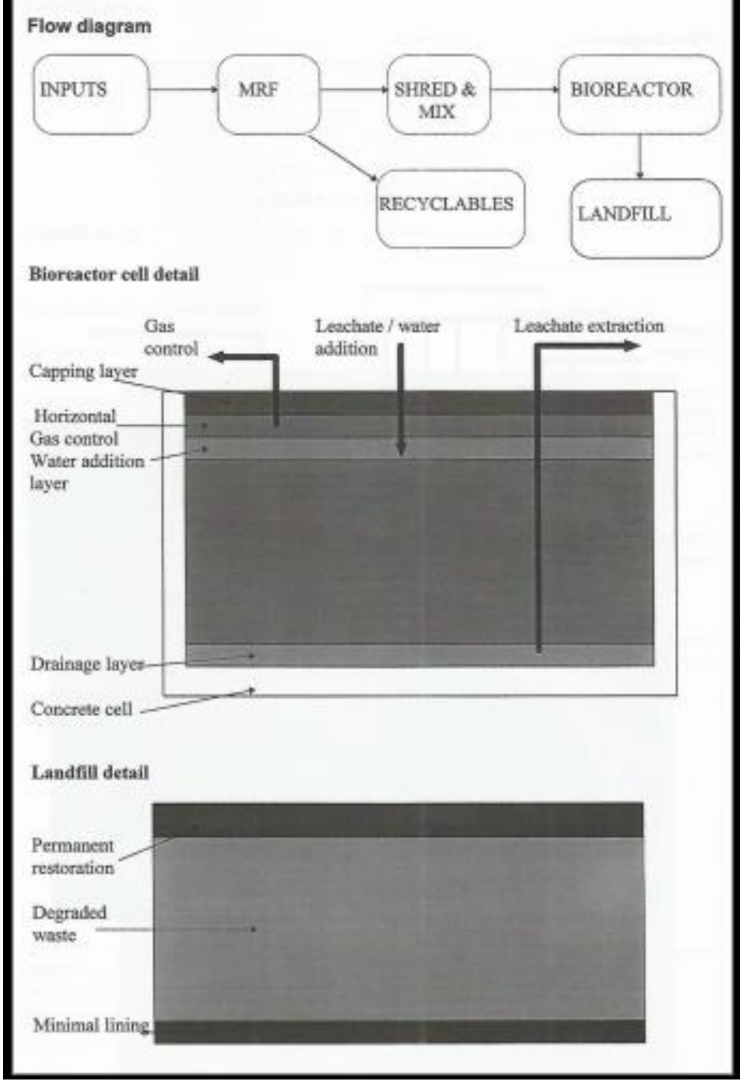
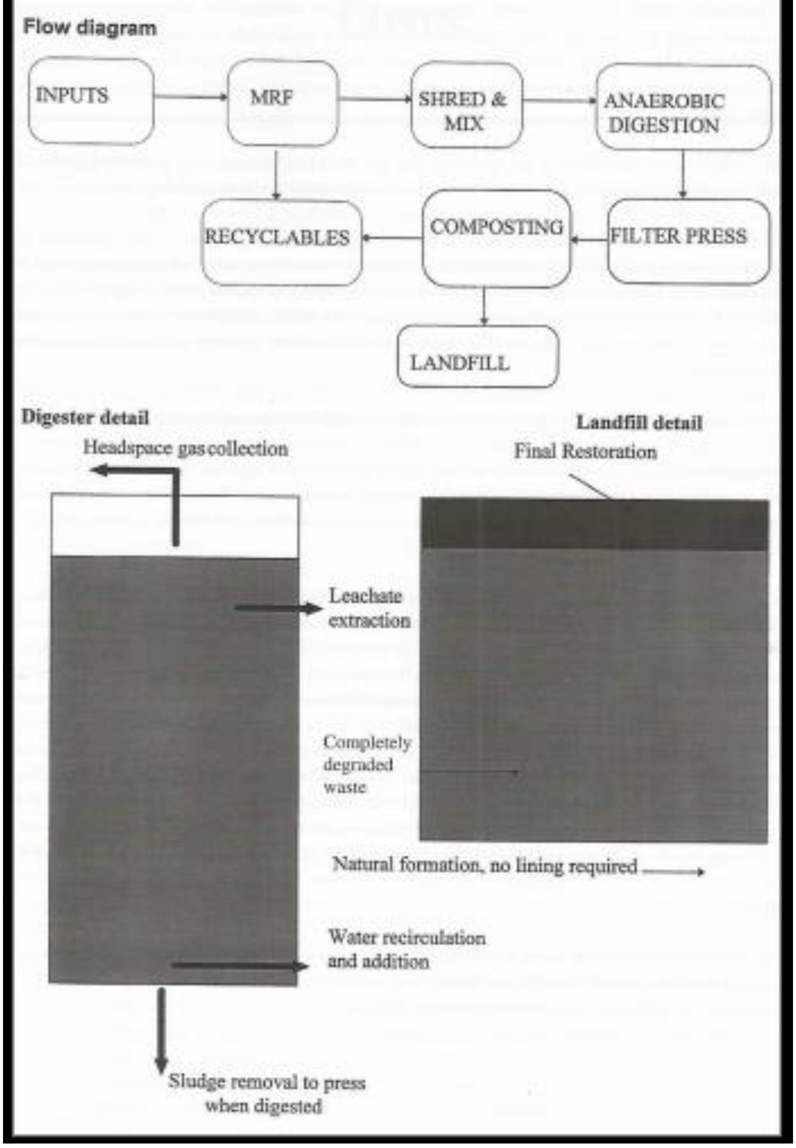


Fig 11.

Scenario 4: Anaerobic digester and other extensive pre-treatment

The anaerobic degradation stage could be carried out in a digester instead of a cell that mimics a landfill design. Operating in this way would be likely to minimise the timescales that the degradation would take and so the area required for this stage of the process. It may also have the advantage of more efficient gas capture during the early period of high reaction rates. If required or desired, a composting stage could be incorporated. This composting stage would further degrade some material (such as some of the wood and paper) that is not degradable anaerobically. The composting phase might replace anaerobic digestion if the energy value of the waste was not required. Some of the composted material might be recovered and used, either as landfill site restoration material or commercially.

FIGURE 6.4: Scenario 4 – Anaerobic digester and other extensive pre-treatment



As described in the above sections, if a landfill site containing degradable materials is to be operated in a sustainable manner, it is likely to have a composite cap with a membrane barrier and underlying liquid reabsorption system as well as the usual gas collection system. It is likely to be shallow and the waste in it will be shredded and mixed. The waste will be wet and producing landfill gas very rapidly. At the base of the site will be a drainage system overlying a high specification liner system.

None of the above scenarios is suggested as the definitive solution to the problem of how to design a sustainable landfill. They are simply examples of how the difficulties of degrading and flushing the waste might be overcome. The components of these systems might be used in combination or omitted depending on the composition of the waste as received. This in itself is dependent upon the markets for recycled materials from the on-site waste recycling facility or indeed earlier in the waste chain.

The proposed trial described in the Appendix will test the practical aspects of Scenario 1, and provide valuable information for use should the other scenarios be implemented in practice.

4. Medium to Long- Term - New Energy Plants

Zero Waste to Landfill – Energy Plants initially for Kumasi & ACCRA

PENNGATE recommend one New Bioreactor landfill site for ACCRA, close Oblogo Landfill site BUT also to utilise the MSW waste from Ghana in New Energy plants. The first plant is proposed for ACCRA and sited at the existing Landfill site. After the Energy plant is operational over the next two years the waste deposited in landfill sites can then also be utilised in the Energy Plant. Once Ghana is underway with their Sustainable Waste Strategy then Material Recovery Facilities may also be constructed to recover and reuse waste for manufactured goods in the future.

Short Term - Landfill

to

Ghana - ACCRA - New Energy Centre CAPEX Build cost $ $315,391,250. Cost comparable with other Renewable energy BUT we deal with the MSW at the same time.

Medium Term - Energy Plants

Medium to Long Term – Energy Plants & MRF's - funding available

We propose an Energy Plant of 35MWh - generating 840 MWh per day or 380,190.72 MWh year of electricity.

The collection of waste from Homes and Commercial outlets should be done on a daily / weekly basis and then sent to the Transfer Stations for processing and sorting and RDF production. RDF will then be fed into the Gasification process and Energy will be produced and sold to ECG for $185 per MWh.

There are no dedicated facilities for industrial solid waste management or hazardous waste management other than fairly basic oil water separation, our Energy Plants can process this waste. Industrial solid wastes are generally disposed of in municipal dumps with or without any form of pre-treatment. There is also believed to be widespread illegal dumping. This waste could be processed by the Energy Plant producing electricity with Zero Emissions and Zero waste to Landfill.

New Energy Plants will help provide funding towards Ghana's Waste Strategy objectives over the next twenty years. Kumasi & ACCRA sites for New lined Bioreactors Landfill and then Sunyani, Wa, Bolgatanga and Konoridua

Table 4. Cost breakdown of the New Integrated Waste Management Energy Plants

For these calculations we assume that a plant takes in 620 MT/day of MSW to produce the required 500 MT/day of RDF we remove the Metal, Glass, Stone and excess moisture if any from the incoming waste to produce the required 500 MT/day of RDF. This 500 MT/day with an average calorific value of 4,000 Kcal/kg will produce circa 32 Mwh per hour or 768 Mwh per day, also the average value for the metal, glass and stone will be after processing and commission paying in the region of US$ 20/- per ton sold at the gate. The 25 MT of Basalt type sand or gravel has no specific value so is set at US$ 5/- per ton at the gate. Carbon credits and methane credits have not been considered in this matrix.

Whilst we require a rate of US$ 185/- per plant for single or double plants, we require a slightly lower figure for multiple plants,

No.	Element and weight	Calculations	Contribution to PPA in US$
1	Metal, Stone and Glass	Here we assume that in any 620 MT/per day of MSW we get approximately 100 MT per day of Metal Glass and Stone 100 x 20 / 768 =	2.60
2	RDF	500 MT per day, 95% Organic, produced 32 Mwh per hour or 768 Mwh per day	85.36
3	Basalt type sand or Gravel	Production of average 25 MT/day at US$ 5/- = US$ 125/- per day	0.17
4	MSW not going to Landfill	620 MT/day of MSW not going to landfill at US$ 120/Mt US$ 74,400/- per day, this is an average world figure calculated for the proper construction of sanitized landfills to the accepted international standards with operation and monitoring costs of the landfill for its 30 year life. But is does not include End Of Life disposal Costs, because as of not this has not been considered but it will be high.	96.87
		Combined total cost of PPA including Zero Landfill and Electric Cost	**185.00**

NOTE :- Even if Ghana could manage to construct proper Sanitized Landfills at three quarters of the cost that it costs the rest of the world it would increase the Electric cost from US$ 85.36 per Mwh to US$ 109.58.10 per Mwh which lower than the Government is paying now for electricity, the only difference being is that our electricity is Green, Clean fully sustainable does not pollute the atmosphere and gains both Methane credits and Carbon Credits.

David J, Burton 29th November 2017

Ghana - ACCRA - New Energy Centre CAPEX Build cost $$315,391,250 (funding available)

Table 5. CAPEX of an Energy Plant

Capital Costs		
Plant & Equipment		284,375,000
Contract, Legal, EIA Etc		5,000,000
Working Capital		6,000,000
SubTotal		295,375,000
Placement Fee	1%	2,953,750
Sales	6%	17,062,500
Sub Total Other costs		31,016,250
Total CAPEX		315,391,250
Capital Structure		
Equity amount	0%	0
Debt amount	100%	315,391,250

OHEAD/Yr	15,764,101		OHEAD %
OHEAD/Project 18mths	23,646,151	284,375,000	8.32%

Vehicles, Trucks & Machinery	Price EA.	QTY	Total
Saloon	25,000	2	50,000
MSW Frontend Mobile Equip	N/A	9+	2,000,000
4x4	25,000	2	50,000
Compactor Trucks	225,000	3	675,000
Mini Crew Bus	80,000	1	80,000
Dump Truck (20 m3)	120,000	1	120,000
Pickup Trucks (2)	25,000	2	50,000
		TOTAL	3,025,000

JCB	QTY
Front end Grabs	2
Hydraulic gripper	1
Fork lifts	2
3 tonne front end loader	2
Ground Scrapper	1
High pressure washers	3

Short to Medium Term

Energy Plants for all waste types and with some separation of wastes such as glass and metals - this is a Sustainable approach for ACCRA

ACCRA generates over 2,000 metric tonnes of MSW a day or 730,000 tonnes per annum (tpa) - all of ACCRA's waste can be treated in one Energy Plant and one Bioreactor landfill site

Zero to Landfill

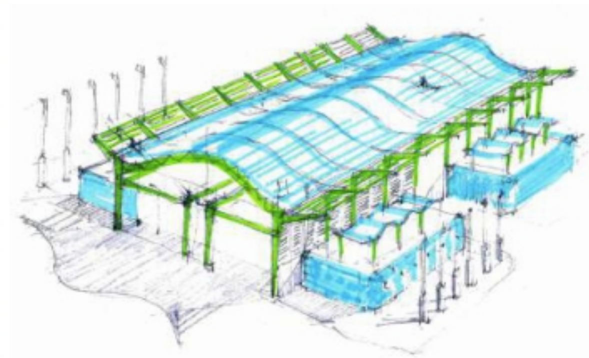
Zero Emissions,
Ultra High Temperature Hydrolysis (Gasification),
Waste and Biomass Energy Recovery System

JAN 2017

Ghana - Kumasi / ACCRA - New Energy Centre CAPEX Build cost $$315.391 million. Cost comparable with other Renewable energy BUT we deal with the MSW at the same time

There is a fundamental assumption that the WTE Plants will be site at or on the existing landfill sites. In this way the WTE Plant has no major planning or environmental impact negatives. The WTE Plant will only reduce the social impact of the existing problem waste areas.

The conscious management of town planning is necessary to avoid unnecessary conflict and unnecessary duplication of infrastructure services within the nominated existing landfill site locations where the individual WTE plants will be sited and operated.



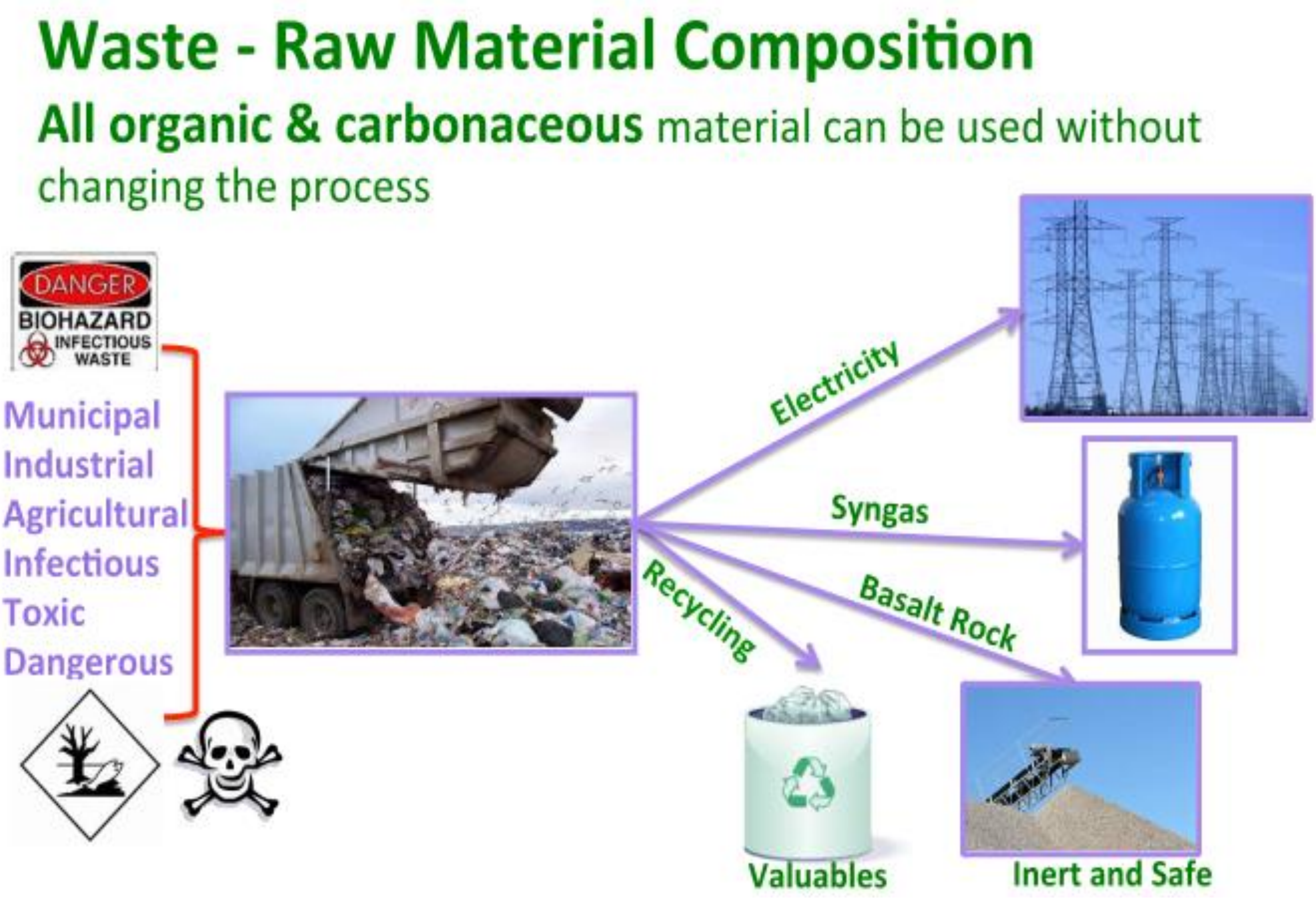
Once identified, optimum solutions will need to be identified to synergise with the existing area's infrastructure, to consider sharing existing facilities and services, and or building new common infrastructure services and facilities to operate the plant.

Type of Benefit	Description	Value – 25 Years $M
No Landfill	**MSW Dumping Fee Savings** The average cost of sanitised landfill and its long-term management can be proved to equate to around $120 per MT lifetime cost. This means that by avoiding landfill the municipal authorities will save this money. This therefore equates to approximately 750MT of non landfill per day $120 x 365 days x 25 years	**821**
Power Output	**Usage** The power from the plant will help sustain urban conurbations or businesses and industries in the community. This figure as an output from the plant is ~ net 30,000 KW per hour. This means that around 60,000 people can be serviced by this power or around 500 Small/medium sixed enterprises can be developed which will be capable of employing around 3,000 jobs in the community. This is worth around $3M per year x 25 years	**75**
Feed Material	**Saved Feed Material Cost of other Source of Electricity** Powering the grid using the municipal waste avoids being dependent on other raw materials, avoids transporting them on the roads and avoids being held to ransom over fluctuating market prices. This can equate to the cost of Coal or Oil per Metric Tonne and conservatively is estimated at $30/MT. This would be therefore (at twice the Kcal value of MSW) $30 x 250 MT x 365 x 25 years	**68**
Health Savings	The health saving from reduced toxicity, no leachates and eradication of toxins in the community area and ground water supplies plus reduced health hazards of no landfill and no fly-tipping and reduced burning of waste in the community, can be equated to the catchment area of around 1.5M people At $10 per year this equates to $10 x 1.5M people x 25 years	**375**
Community & Social	A CSR programme associated with Plant profits is likely to support the disadvantaged	**50**

General Overview

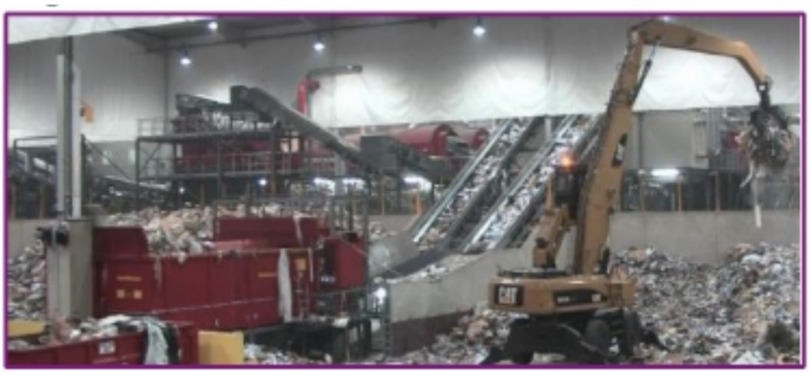
- Patented highly efficient Waste to Energy Technology
- Processes ALL TYPES of Municipal & Industrial Waste & Biomass
- Waste/MSW is converted to Syngas & Inert (Non Toxic, Non Leachable) Basalt type Sand/Gravel
- NO EMISSIONS – Completely Clean, Ecological & Economic
- Full DIOXIN & Persistent Organic Pollutants (POPs) ERADICATION
- NO SEGREGATION of waste needed – all done at plant.
- Syngas is used to produce Electricity.
- Complies with and Exceeds all international Emission Control Regulations, Standards and Directives

Energy Plants for all waste types, ZERO Emissions, ZERO to Landfill, Electricity production and some seperation of glass and metals - this is a Sustainable approach for Ghana.



Receipt and conversion of MSW to RDF requires only the removal of the inert non-carbonaceous materials such as bricks/stone, glass and metal (both ferrous and non-ferrous). These items are sent for normal recycling activities.

These amounts if coming from usual MSW collection places total around 10% of the MWS weight.



The average water/moisture content (depending on season) is also expected to be around 10% greater than desired for the MSW to RDF shredding process therefore we dry the MSW by this % amount.

The total weight of MSW is therefore reduced by an average of ~ 25%

Table 6. Energy content (Kcal) of Vaious Waste Types

Waste Types – Kcal Values

ENERGY MATERIAL	APPROXIMATE Kcal / kg	ENERGY MATERIAL	APPROXIMATE Kcal / kg
Bamboo	3'800	Paper sludge	3'910
Braun coal	4'500	Paper coated	6'390
Cacao shrub	3'300	Paper adhesive coated	4'200
Cardboard	3'800	Newspaper	3'910
Cardboard corrugated	3'910	Tar paper	6'390
Citrus peels	4'500	Paraffin	10'340
China grass	4'030	Polyethan foam	9'770
Car Tyres	8'300	Polyethylene	10'990
Coconut shell	3'800	Polypropylene	11'030
Coffee bean shells	6'000	Polystyrol EPS	9'800
Compost	4'200	Polystyrol carbon reinforced	10'840
Cork	6'300	Rice pods	2'900
Corn	4'400	Rubber	5'600
Cotton seeds	3'300	Sewage sludge (dried)	3'300
Hay	3'200	Sunflower residue	4'200
Household Waste (pulverized)	3'500 – 4'500	Straw	4'000
Hospital waste	6'780	Tobacco powder	3'000
Leather	4'020	Tar & Refinery residues	9'200
Manure (dried)	3'760	Tar acid	5'600
Neoprene	7'100	Textiles	4'000
Nylon	7'570	Treated wood	4'500
Oil sludge	8'800	Untreated wood	4'200
Paper	4'400	Plywood	4'500

Toxic Dioxin Problem

- Dioxin and Furan leaching is a growing worry and risk to health and the environment
  - Classed as one of the persistent organic pollutants, POPs, also known as PBTs (Persistent, Bio-accumulative and Toxic) or TOMPs (Toxic Organic Micro Pollutants.)
  - A small set of toxic chemicals that remain intact in the environment for long periods and accumulate in the fatty tissues of humans and animals.
  - Dioxins are known human carcinogens and they are the most potent synthetic carcinogen ever tested in laboratory animals, they are extremely toxic and cause all manner of illnesses and cancer.
- The National Institute of Standards and Technology said in
  - cancer causing potential of a dioxin is over 10,000 times more potent than the next highest chemical (diethanol amine), 500,000 times more than arsenic and a 1,000,000+ times greater than all others.
- The World Health Organization said
  - "Once dioxins have entered the environment or body, they are there to stay due to their uncanny ability to dissolve in fats and due to their rock-solid chemical stability."
  - POP/Dioxin releases are the real killers from plastics in the environment because they so easily get in the food chain.
  - It is even worse when the plastics are incinerated or burnt, or catch fire on the dumpsites due to methane gas release, then self-ignition/flashing off etc.
  - Living within three miles of a rubbish tip could be damaging to health and raises chance of developing fatal lung cancer by 34 per cent and increases the risk of hospital admissions by five per cent.
- The cost of landfill and the risk to health and environment can be significantly reduced by eradicating the MSW problem

Unlocking the Dioxin Energy Value

- Allowing a dioxin to form or scrubbing out the dioxin reduces the energy potential for conversion to a Syngas and costs money.
- The Hydrogen, Carbon and Oxygen elements are lost.

- **UHTH technology unlocks and destroys the dioxin input material problem and stops reformation;**
- **keeping the the key energy elements in the Syngas.**

Typical Sanitised Waste Dump Site Costs

- Prepare Ground Pit with Gradient
- Lined with Special Liner
- Sump and Pump System - to collect toxic water
- Waste Layering – protect lining
- Capping, Gas Venting & Toxic Liquid Treatment
- 30 Year Monitoring - after capping

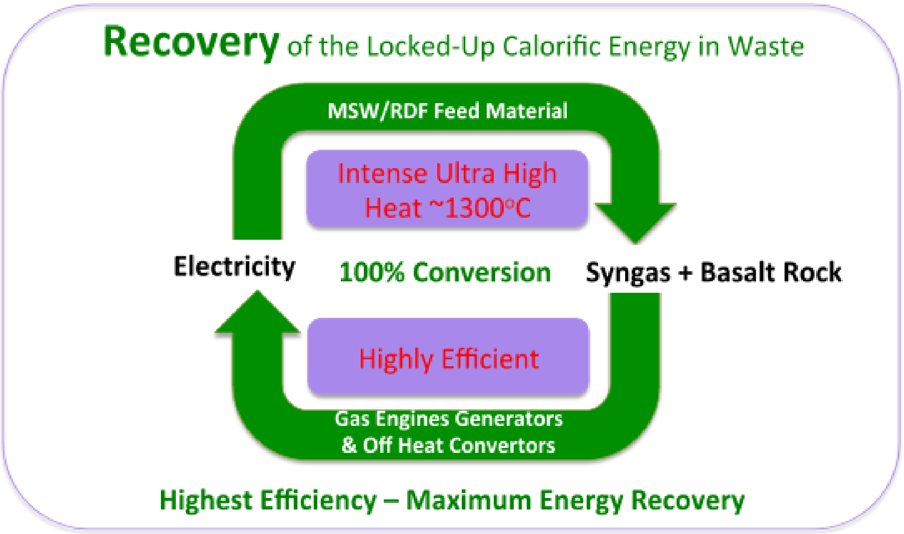
UAE proven cost analysis – Equivalent to $129 per Metric Ton – lifetime cost

Ultra High Temperature Hydrolysis Technology
Saves
Dumping fees and avoids problem land usage

Landfill just pushes the problem away 25-30 years – Not even one lifetime

No Need for Landfill sites

What is The UHTH Process



- ✓ A WASTE MANAGEMENT SYSTEM
- ✓ AN ENERGY RECOVERY & RECYCLING PROCESS
- ✓ A POWER PROVIDER

Process – Example Output

MSW → Waste Segregation and Shredding → RDF → UHTH → SYNGAS → Power Generation → ELECTRICITY

MSW RECEIVING
MT/DAY
750

RDF BUFFER
MT/DAY
525.00
Kcal VALUE/Kg
3,700

UHTH PROCESSING / DAY		
MT/Unit/Day	% Syn/MT	Vol. Syn M3
25	30.00%	582,750.00
UHTH UNIT QTY		
21.00		

LHV			
- CO %	35	30.18	3.95
- H2 %	51	25.76	
- CH4 %	12	85.78	

ELECTRIFICATION	
Vol/Unit/Hr	UNIT KW/Hr
1140	1970
UNIT QTY	Off-Heat
19.12	157.6
LHV	
3.95	

ELECTRIC REVENUE
Produced MW/Hr
40.69
Produced MW/Day
976.56
Produced MW/Yr
356,445.63

RECLAIMED MT/DAY				BASALT SAND/GRAVEL MT/DAY
Glass	Metal	Stone	Moisture	
45	22.5	90	67.5	26.25
225.00				

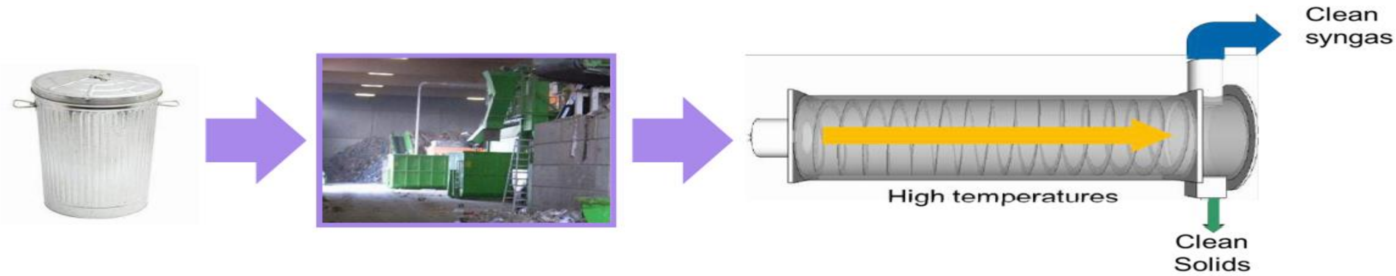
Process Details

Cracking of the organic material into a low molecular combustible gas, using high temperatures in an oxygen-free environment:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$
$$C + H_2O \rightarrow CO + H_2$$
$$C_nH_m \rightarrow CH_4 + H_2 + C$$
$$C + CO_2 \rightarrow 2\,CO$$

Cracking of organic material with added Steam Shift technology.

$$C + H_2O \rightarrow CO + H_2$$
$$CH_2 + H_2O \rightarrow CO + 2H_2$$
$$CO + H_2O \rightarrow CO_2 + H_2$$
$$CH_4 + H_2O \rightarrow CO + 3H_2$$



Gas Composition Comparison

Element			Natural Gas	UHTG Syngas
Methane	CH_4	Vol. %	80 – 88	>4
Ethan	C_2H_6	Vol. %	2 – 6	>6
Propane	C_3H_8	Vol. %	0.5 – 2	-
Nitrogen	N_2	Vol. %	2 – 14	>5
Carbon Monoxide	CO	Vol. %	0.5 – 1	40 – 60
Carbon Dioxide	CO_2	Vol. %	-	>2
Hydrogen	H_2	Vol. %	-	40 - 60
Low Heating Value	LHV	NJ/MN3 Kcal/NM3	30 – 35 7,200 – 8,400	13 3,100

Table 7. UHTH Volume Syngas Analysis for the Energy Plant

UHTH Volume Syngas Analysis (sample)

Pos.	Waste Type	Abfalltyp	Calorific Va Kalorienwert	Humid Feuchtgkeit	Gas Volu Theoretsiches Gasvolumen	Gas Composition in Vol % Gaszusammensetzung				Tota Summe	Other Gases Andere Gase
			kcal	in %	m3	CO	CO2	CH4	H2	Vol. %	Traces / Spuren
1	Tobacco Husks	Tabackpflanzen		32		30.43	14.87	2.42	26.99	74.71	NH3, H2SO3
2	Coal Fines	Kohlestaub	3600	9	1080	45.51	20.02	1.72	28.12	95.37	
3	Coal Fines	Kohlestaub		16		22.78	19.80	2.82	30.44	75.84	
4	Chicken Droppings	Hühnermist	3300	20	990	30.34	14.31	15.84	30.49	90.98	H2SO3, C2H2
5	ASR	Autoshredderrückstände		37		19.00	9.50	9.80	31.90	70.20	
6	Recycling Residue Pellets	Recyklingabfall pelletiert	7600			24.27	5.83	11.72	35.69	77.51	
7	Platic Wood Mix	Plastik-Holz Mix	3900	23	1170	45.33	8.87	2.50	43.19	99.89	
9	MSW	Haushaltsabfall	4900	18	1470	22.04	4.62	22.11	45.66	94.43	H2SO3, C2H2
10	Animal Farine	Tiermehl	4700	60	1410	41.50	3.75	3.00	46.00	94.25	N2, CH2H2, CH2H4
11	Wood Pellets	Holzpellets		11		40.19	4.85	1.64	48.00	94.68	
12	MSW	Haushaltsabfall	5200	20	1560	23.50	0.95	11.46	48.74	84.65	H2SO3
13	Automobile Waste (ASR)	Autoshredderrückstände	6500	15	1950	26.76	2.21	0.73	49.67	79.37	NH3, H2SO3, NO2, C2H2
14	ASR - Low Grade	Autoshredderrückstände	2900	18	870	28.28	4.91	16.25	49.88	99.32	NH3, H2SO3, C2H2
15	Extruder Waste (PET)	Extrudermaterial (PET)	6000	20	1800	35.05	3.77	5.67	52.54	97.03	H2SO3, C2H2
16	Tires	Altreifen		2		14.11	1.90	2.60	52.71	71.32	NH3, H2SO3, NO2, C2H2
17	Cotton Shrub Pellets	Baumwollstauden pelletiert		16		34.34	6.14	2.48	56.54	99.50	
18	Filter Cake	Filterkuchen		17		29.87	2.63	1.79	62.96	97.25	
19	Tires	Altreifen		2		13.46	1.40	4.46	65.35	84.67	
20	Plastic Granulate	Plastikgranulat	7600	14	2280	10.94	0.74	2.89	66.90	81.47	H2SO3

Typical Mass Balance Examples

Municipal Solid Waste (MSW)
550 – 1,000 MT/day

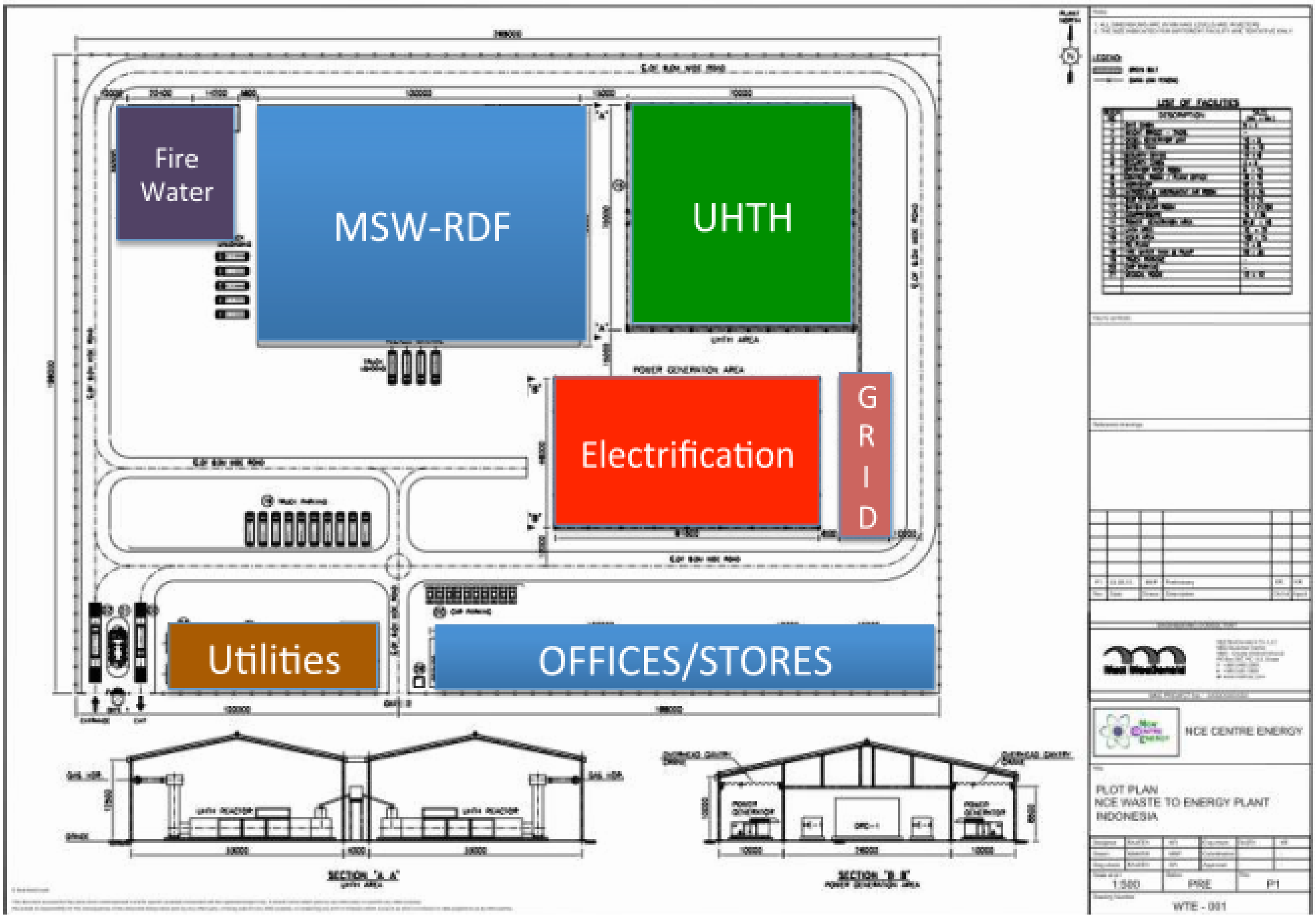
Removed/Recycled
Glass, Stone, Metal
(& Moisture)

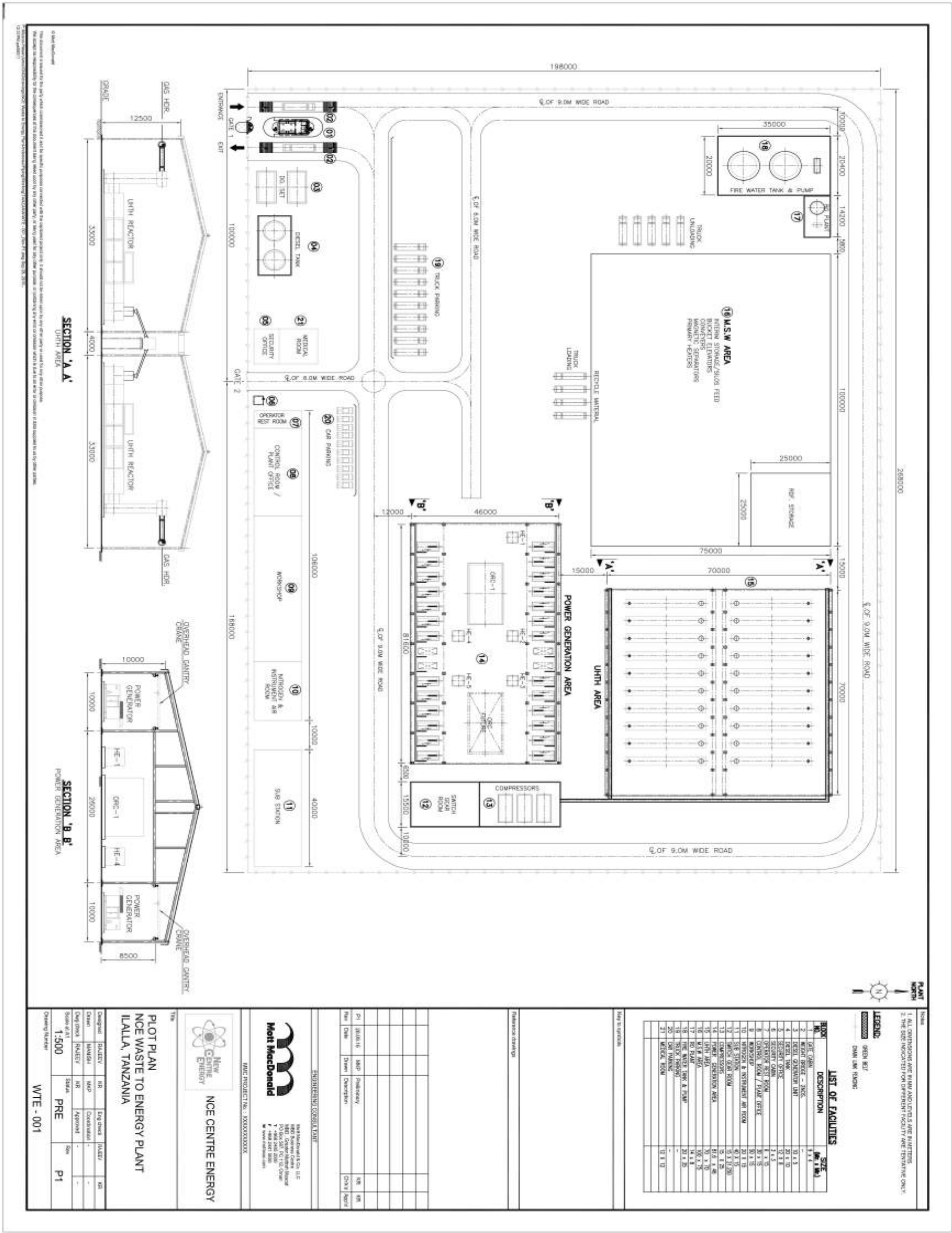
Refuse Derived Fuel (RDF)
500 MT / Day

Calorific Value of RDF Kcal/KG	Syngas Produced M³	Electricity Produced MWh /Day	Electricity Produced Mw/Hr
3,500	547,000	1,040	43.3
4,000	625,000	1,189	49.5
4,500	703,000	1,337	55.7
5,000	780,000	1,486	61.9

Basalt Sand / Gravel
25 MT / Day

Plant Block Diagram – Example




PLOT PLAN
NCE WASTE TO ENERGY PLANT
ILALLA, TANZANIA
NCE CENTRE ENERGY
Mott MacDonald
ENGINEERING CONSULTANT
WTE - 001
1:500
PRE
P1
LIST OF FACILITIES
LEGEND:
PLANT NORTH
SECTION 'A A'
UHTH AREA
SECTION 'B B'
POWER GENERATION AREA
UHTH REACTOR
POWER GENERATOR
OVERHEAD GANTRY CRANE
GAS HDR.
GRADE
M.S.W AREA
INTERIM STORAGE/SILOS FEED
BUCKET ELEVATORS
CONVEYERS
MAGNETIC SEPARATORS
PRIMARY HEATERS
FIRE WATER TANK & PUMP
RO PLANT
RDF STORAGE
TRUCK UNLOADING
TRUCK LOADING
RECYCLE MATERIAL
TRUCK PARKING
CAR PARKING
DIESEL TANK
DG SET
MEDICAL ROOM
SECURITY OFFICE
OPERATOR REST ROOM
CONTROL ROOM / PLANT OFFICE
WORKSHOP
NITROGEN & INSTRUMENT AIR ROOM
SUB STATION
SWITCH GEAR ROOM
COMPRESSORS
ENTRANCE
EXIT
GATE 1
GATE 2
℄ OF 9.0M WIDE ROAD
℄ OF 8.0M WIDE ROAD
198000
268000
168000

Plant Staffing - Jobs

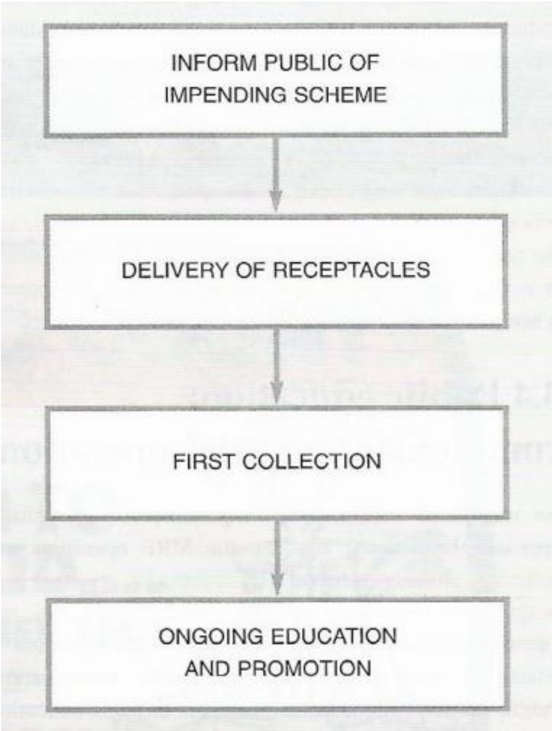
Position	Shifts/ Day	Number /Day Shift	Number/ Night Shift	Number Of Teams	Emplyd
Plant Directors					
GM Manager - NCE	1	1	0	1	1
Subtotal		**1**	**0**	**0**	**1**
MSW Treatment Plant Operations (2 x12hr)					
Plant Shift Manager	2	1	1	2	2
Senior Shift Operator	2	2	2	3	6
Shift Operator	2	3	3	3	9
Weighbridge Operator	2	1	1	3	3
Shift Assistant	2	10	10	3	30
Plant Shift Driver	2	4	4	3	12
Subtotal		**21**	**21**	**18**	**63**
UHTH and Gas Treatment Plant Operations					
Plant Shift Manager	2	1	1	3	3
Senior Operator	2	2	2	3	6
Operator	2	2	3	3	6
Assistant	2	2	2	3	6
Plant Driver	2	1	1	3	3
Chemical Engineer	1	1	1	1	1
Laboratory Assistant	1	1	1	1	1
Subtotal		**10**	**11**	**17**	**26**
Power Generation & ORC Plant Operations					
Plant Shift Manager	2	1	1	3	3
Senior Operator	2	2	2	3	6
Operator	2	2	2	3	6
Assistant	2	2	2	3	6
Subtotal		**7**	**7**	**12**	**21**
Plant Maintenance					
Maintenance Manager	1	1	0	2	1
Mechanical Maintenance Team Leader	2	1	0	2	1
Mechanical Engineer	2	2	1	2	3
Mechanichal Technician	2	1	1	2	2
Mechanical Fitter/Welder	2	1	0	2	1
Electrical Maintenance Team Leader	2	1	0	2	1
Electrical Engineer	2	1	1	2	2
Electrical Technician	2	1	1	2	2
Instrument Maintenance Team Leader	2	1	0	2	1
Instrument Engineer	2	1	1	2	2
Instrument Technician	2	1	1	2	2
Control and Automation Maintenance Team Leader	2	1	0	2	1
Control and Automation Engineer	2	1	1	2	2
Control and Automation Technician	2	1	1	2	2
Maintenance Assistant	2	1	1	2	2
Warehouse Manager	1	1	0	2	1
Warehouseman	2	1	1	2	2
Subtotal		**18**	**10**		**28**
Finance Department					
Finance/Sub Contract Manager	1	1	0	1	1
Senior Accountant	1	1	0	1	1
Accountant	1	1	0	1	1
Clerical Assistant	1	1	0	1	1
Subtotal		**4**	**0**		**4**
HSE & Security					
HSE & Security Manager	1	1	0	1	1
HSE/PTW Team Lead	1	1	1	1	2
HSE/PTW Engineer	1	1	1	1	2
Security Team Leader	2	1	1	1	2
Security Staff	2	4	4	1	8
Doctor	1	1	0	1	1
Nurse	2	1	1	1	2
Subtotal		**10**	**8**		**18**
Administration					
Administration Manager	1	1	0	1	1
Administration Clerical Staff	1	1	0	1	1
Human Resources Manager	1	1	0	1	1
Human Resources Clerical Staff	1	1	0	1	1
Public Relations and Community Services Manager	1	1	0	1	1
Systems IT Manager	1	1	0	1	1
System IT Engineer	2	1	0	1	1
Cooks	2	3	3	3	9
Kitchen Staff	2	7	7	3	21
Subtotal		**17**	**10**		**37**
					198

The Companies Technology Timeline

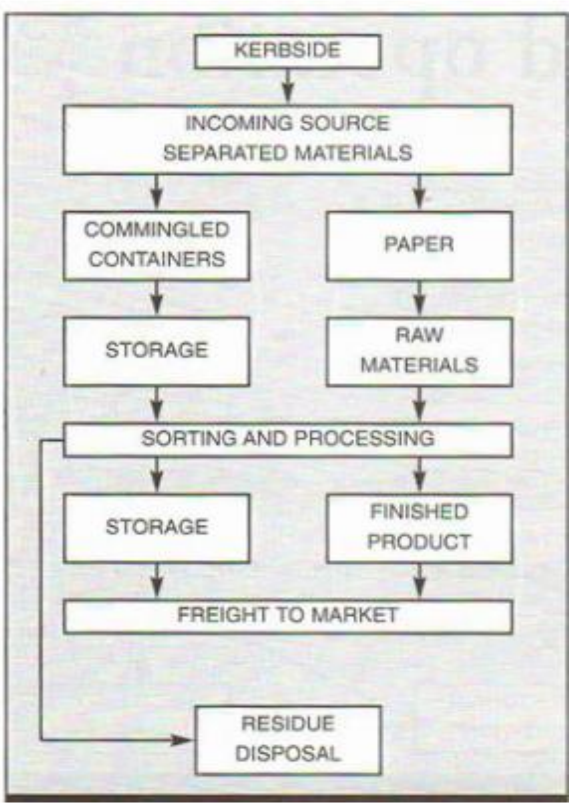
- **1989** Development of waste neutralization and solidification system
- **1992** First demonstration plant operational in Switzerland
- **1993** Development of Pyrolysis technology
- **1995** Development of UHT Gasification with induction electricity
- **1996** Demonstration plant in England
- **1999** Development of industrial plant in Germany
- **2000** Operation of industrial plant Emmerich
- **2003** Operation of industrial plant Neustadt
- **2007** Construction of the commercial, plant Munich
- **2008** Operation of Munich
- **2010** Full approvals and Environmental Clearances
- **2012** Completion of the commercial, plant Munich
- **2015** Client Demonstration Unit – Zug Switzerland

5. *Long term – Material Recovery Facilities (MRF's)*

Fig 12. Basic flow of MSW through an MRF.



Operational Phases for Kerbside Collection



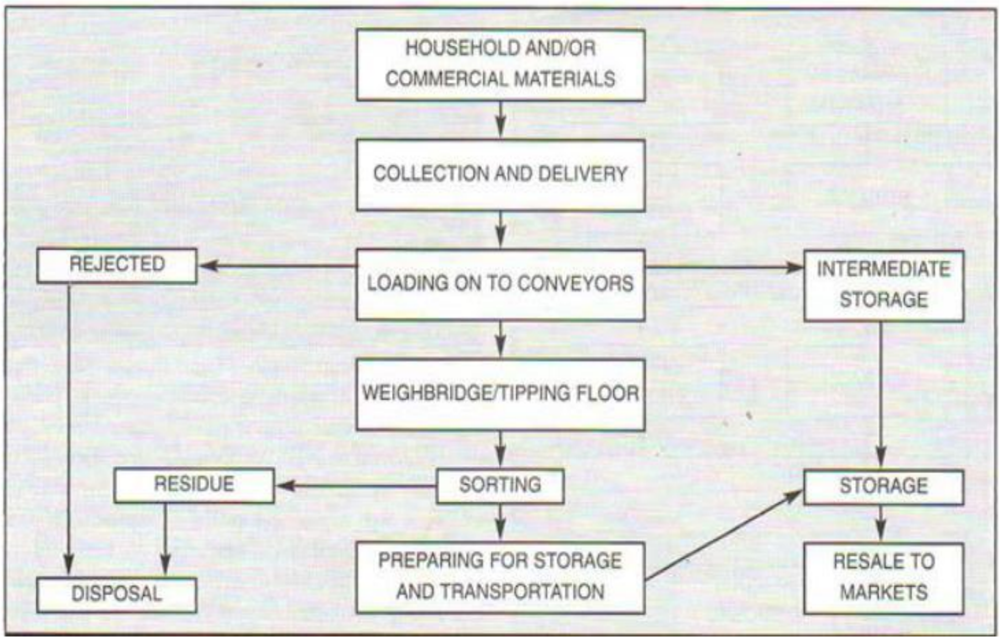
source: Basic flow of waste through a MRF - Institute of Wastes Management – December 2000 – Vol - Materials Recovery Facilities (from USA EPA – 1991, and Aspinwall & Co. 1993 ISBN: 0 902944 57 6

Collections systems

In this Long-Term strategy, two generic collection approaches have been developed for Ghana in order to collect materials for recycling, namely "Drop Off" (or bring) and Kerbside collection programmes throughout Ghana.

The Drop Off systems involve householders taking selected materials to designated collection points, where Fee Standing containers are provided for separate materials such as plastic, glass, metals etc. Kerbside programmes normally involve collections from the household of the individual recyclables such as glass, plastic and metals placed in separate boxes at the home. A vehicle then collects the boxes along with the normal household waste such as organic – care taken not to mix the waste in the vehicles – separate compartments. Manufacturing of secondary goods can now occur.

Fig 13. Flow diagram of MSW through an MRF



Source: Materials Recovery Facilities (MRF's) Chartered Institute of Wastes Management – IWM Business Services Ltd December 2000.

MRF – Material Recovery Facility

The collection of such waste and recyclables now requires the support of the Material Recovery Facility, which also has an Energy Plant attached. Manufactured goods can then be made, and new items sold with revenue gain and enhanced environmental protection occurs due to material being recycled – (Life Cycle Analysis or LCA explains this).

The source for the information in this section was copied directly from: Materials Recovery Facilities (MRF's) Chartered Institute of Wastes Management – IWM Business Services Ltd December 2000.

Principles of waste separation

In theory, the separation of waste in a MRF is relatively straightforward. Recyclables are collected and taken to a treatment centre (the MRF) for separation and preparation for secondary markets.

Collections systems vary from place to place. Some organisations collect the recyclables in plastic bags, others in boxes or wheeled bins. The method of collection can have a considerable impact upon the design of the MRF. For example, if recyclables are bagged, consideration has to be given to how the bags will be opened and their contents emptied out.

A system that allows collection crews to quickly inspect the recyclables before they are emptied into the vehicle will normally help reduce the amount of 'contrary' contaminated material arriving at the MRF. Thus MRFs with 'a box' collection system will tend to have a lower contamination rate of the supplied recyclables than a MRF relying on a bag or wheeled bin collection system.

The nature of the incoming material itself can bring difficulties. In ideal conditions, the majority of incoming materials will be suitable for recycling. Source-separated recyclables commonly consists of newspapers, other paper, small cardboard, (e.g. cereal packets), aluminium cans, steel cans, glass and plastics. However, local conditions can result in the materials being far from ideal for recycling. For whatever reason, house-holders will place mixed waste in the bags or containers that are intended for only recyclables. In extreme cases, the presence of large proportions of non-recyclable waste in the recycling stream can overwhelm segregation activities, manual and mechanical. Often this situation can occur at the start of a recycling campaign where the public has not received or assimilated instructions on source separation.

In the MRF process itself, each recyclable element is segregated and prepared for the market. Traditionally, segregation has been done by manual means and this method still accounts for the great majority of the segregation that takes place today. However, mechanised sorting is beginning to make an appearance and is expected to increase considerably in the future.

General MRF design

There are potentially many conceptual designs and combinations designed and implemented as a MRF (US EPA 1991, Aspinwall & Co. 1993). The type of facility constructed in any given area will rely on many factors, including the economics of the design and operation of the facility, and other impacts such as collection, transportation, processing and shipping, which are dependent on the siting of the facility. Lund (1993) states that a well-conceived design should optimise many of the following variables:

- collection cost;
- shipping cost of the processed material;
- capital cost;
- operating and maintenance costs (processing);
- sufficient material storage space;
- public and employee safety;
- public education;
- product quality;
- maintain flexibility; and
- efficient layout.

The general flow of materials throughout a MRF is taken as a starting point This type of flow diagram can be applied to both high and low-tech MRFs, as it follows a general flow of materials exclusive of sorting methods.

MRFs range from large, single-site, purpose built facilities

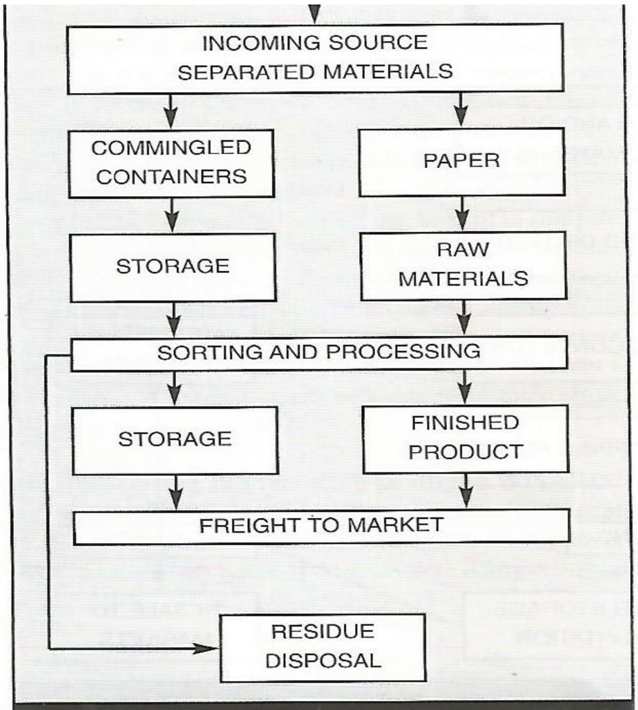


Figure 4.2 A Flow Chart for a Basic MRF (from US EPA 1991, and Aspinwall & Co. 1993)

dealing with over 30 different materials (such as in Milton Keynes) to smaller facilities, housed in existing buildings dealing with six or more different materials (as in Hampshire and Sheffield). These can also be divided into 'high-tech' and 'low-tech' MRFs. If a MRF is using an integrated separation system, it is classified as 'high-tech', described by Aspinwall & Co. (1993) as having a high capacity (able to accept a large amount of materials, i.e. at least 100 tonnes per day), being relatively complex, mechanically-intensive, with high capital and maintenance costs. If the equipment consists of a conveyor with or without a magnetic separator, or if there is simply floor sorting of materials, it is classified as 'low-tech', described by Aspinwall & Co. (1993) as being of a low capacity, relatively simple, intensive labour and with minimum equipment. Two thirds (65%) of MRFs in the USA fall in the low-tech category, although planned MRFs appear to rely on a higher degree of mechanised separation (Berenyi 1995). Few such figures are available in the UK for either

Separation and processing boxes shown in Figure 4.2 are the areas which determine whether the MRF is a low or high-tech facility. According to Waite (1995), the three basic approaches to the separation of material are:

- manual sorting;
- combined manual and automated sorting; and
- automated sorting.

MRFs typically use both mechanical means and labour intensive manual sorting to separate the various fractions of recyclables (Aspinwall & Co 1993). Often there is a trade-off between high capital cost versus high operating cost (US EPA 1991). Manual separation is the most labour intensive and common method found in many processing systems. Manual separation entails operatives placed along-side conveyor belts at picking stations manually sorting different materials into their various components as they pass by. Manual separation is generally able to achieve a high degree and quality of separation with a relatively low capital investment.

Low-tech MRFs tend to rely heavily on labour intensive sorting, although most will combine this with some automated sorting. Although some processing equipment is sophisticated, and for some materials automatic sorting methods may become both quicker and more cost-effective, there will always be machines that are limited in their ability to separate materials and even the most technologically advanced MRFs often need the precision and accuracy provided by manual sorting to guarantee clean separation of recyclables (Aspinwall & Co. 1993). Manual sorting is also much more flexible, as new materials can be incorporated at no extra capital cost.

Designing for the material mix

It is important to ascertain at the planning stage the mix of recyclables the MRF is to process over its operational life. It is usually too late once the MRF is constructed, since the designed number of picking stations permanently limits the variety of recyclables that can be sorted. A view may have to be taken about the available markets for recyclables over the operational life of both the MRF and collection infrastructure. This view may have to be

Standard recyclable streams for different types of MRF

MRF Type	Standard Materials	Additional Materials
Municipal Solid Waste (MSW)	Paper, cardboard, plastic bottles, steel and aluminium cans.	Glass, textiles, wood, other plastic containers and film, scrap metals, chemicals, batteries.
Industrial / Commercial	Paper, cardboard, plastics, metal depending on application.	Glass, textiles, wood, batteries depending on application.
Single Stream	Such as paper product split into different grades.	Any single stream that needs to be split into sub-sections.
Construction and Demolition (C & D)	Small and large aggregate, soil, metal.	Wood, insulation products, electric cable, glass, plastic.

extended to encompass the impact of proposed legislation on the mix. The following table indicates 'standard' recyclable streams for different types of MRF although the additional materials can be used to supplement or replace a 'standard' item

Obviously, if there is a market or a requirement to separate a specified component from the waste stream, a suitable collection and MRF can be designed to achieve this purpose. The important factor is to ensure the collection and MRF integrate with each other to form a seamless flow of correctly specified recyclables from source to reprocessor or end user.

Throughput

Perhaps the most important input factor is the throughput (i.e. tonnes per hour) of material to be processed. The throughput will determine the size of the plant.

The designer must know the make-up of the incoming materials with a percentage breakdown by weight for each element. The information provided is not always accurate and some designers will add a nominal percentage to take account of under-estimates and future expansion. If the incoming material is in bags, the designer has to determine how the contents will be liberated so that the subsequent sorting processes may reach it. Sometimes, a MRF opera-

Location

The second most important factor is probably the proposed building and site. The designer may already have an idea of the required building size from the given throughput. Often, however, the building already exists and the designer has no option but to design, or shoehorn, the MRF into the building and the surrounding site.

Basic questions a designer will ask include: Is there adequate headroom? Does the site lend itself to a suitable traffic flow? Could the MRF be expanded in the future? (please also refer to the section entitled Building Design.

Outgoing materials

The designer also needs to know what materials are to be segregated and the manner in which they are to leave the plant (e.g. loose or baled). This information tells the designer how many sorting stations have to be provided and whether a baler is to be included.

High-tech vs.. low-tech

Recently, sophisticated automatic sorting machinery has made an appearance on the market and a commercial decision has to be made by the operator between a high-tech MRF and a low-tech MRF. As mentioned previously, a high-tech MRF is highly-mechanised whereas the low-tech MRF is minimally-mechanised but labour intensive. The high-tech MRF has higher capital costs but lower running costs while the inverse is true for a low-tech MRF.

The designer has to know at the outset which route the future operator wishes to follow because the two types of MRF have very different design philosophies. The automatic sorting machinery found in a high-tech MRF will be discussed later.

Personnel and shift patterns

The designer will need to know the number of personnel the MRF operator is prepared to engage for the MRF process, especially for sorting. From experience, it has

Table 4.2 MRF Productivity

Material	Weight (g)	per hour per picker (kg)	Recovery (%) >160 mm	80–160 mm
Newspaper [1]	250	600	85–95	60
Magazines	500	1200	85–90	60
Other Paper [2]	50(+/–)	125	80	50
Card Packaging	300–500	600	80	50
Mixed Paper/OCC		400–800	80	50
Plastic Bottles	5–150	100–150		
Plastic Film		50–100		
Mixed Plastics		100	50	25
Ferrous cans [3]	50	200	50	90
Al. UBCs [4]		40		80
Aluminium foil [4]				50

[1] 'Individual' newspaper items. The Sunday Times as a whole may weigh 1.5/2kg.
Other published data suggests a picking rate of up to 4550 kg/hour/picker for newspapers and also corrugated cardboard;
[2] Other paper includes envelopes, junk mail, note-paper, tissue;
[3] Based on over-band magnet separation;
[4] based on eddy current separation (Coggins 2000).

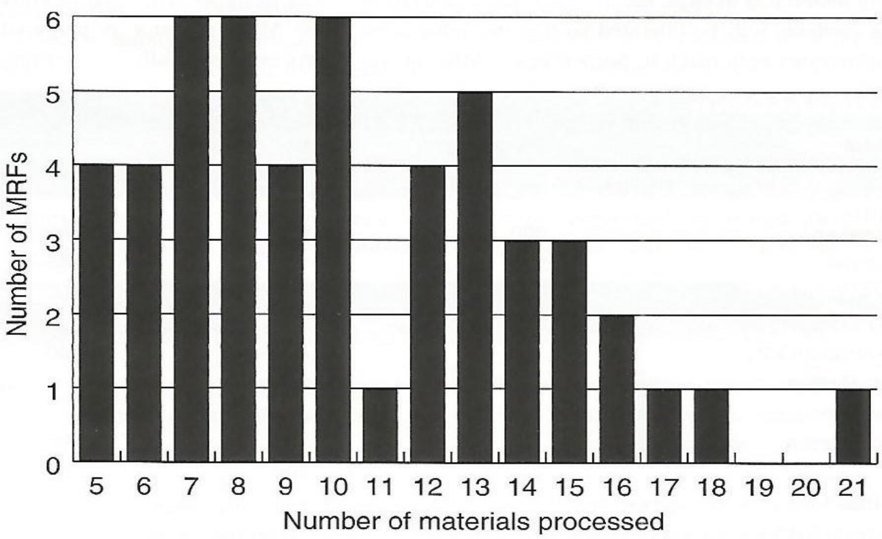
Data for the 'average MRF' in Ontario		
MRF parameters	**Range**	**Average**
Hours per day	8—24	11.1
Days per year	104—268	249
Hours per year	832—6,000	2,778
Tonnes per hour	0.12—13.5	3.97
Tonnes per day	0.8—220	46.02
Total daily staff	1—49	11
Tonnes per worker per day	0.21—14.23	4.43
Building size (m^2)	93—6,503	1,785

The available data shows that the 'average MRF' in Ontario operates about 11 hours per day, 249 days per year in a building 1785m2. Eleven staff each day process about 3.97 tonnes per hour, or an average of 46 tonnes per day. Of the 11 staff, 9 are operating personnel and 2 are dedicated to administration. No correlation was found between the building size and either the annual throughput, or the extent of recyclables commingling. Thirty-eight of the facilities operated on a single shift (8-12 hours), ten on a double shift and only 3 on a three shift basis. Worker productivity (tonnes/worker/day) for the MRF classification adopted are outlined below.

Worker productivty data related to MRF type and number of waste streams		
MRF classification	**Number of streams**	**Tonnes per worker per day**
Commingled	1—4	4.08
Partially commingled	4	4.93
Segregated	4—7	2.13
Average		**3.97**

In the Ontario MRFs productivity rose from the commingled to partially commingled group as sorting requirements presumably decreased. However, it fell dramatically in the segregated group, this may be attributed to the need to still perform contaminant and some material sorting on some of the streams, or because many of the segregated operations are low throughput facilities and not as efficient by nature.

These results were compared to a survey of MRFs in the United States that processed commingled recyclables as of May 1992, reported that on average processing productivity was 3.80 tonnes/worker/day (Glenn 1992). The US survey also found that worker productivity at privately operated facilities was reported to be 53% higher than that at publicly operated facilities.



The distribution of the number of recyclable materials processed at each of the 51 MRFs is show above. Although some facilities rely on minimal sorting and processing of segregated materials, there are others that receive a fully commingled stream, and rely heavily on both mechanical and manual separation of the recyclables.