The entity that enters a system designed for managing wastes is known as ‘refuse’. The system must not only handle these refuse but ideally must have infrastructure to use the refuse again or recycle it. The system should have facility wherein the refuse can be composted or incinerated. A system comprising of all these components is termed as ideal system for management of wastes. The refuse that enters the system comprise of trash, unused metals, effluents from domestic and industry sources to name a few (T. Janakiram 2010). Effective management of these refuse is essential as it can cause severe impairments to human health and environment if left undisposed. Looking at this need the technologies developed during present studies were designed to manage domestic wastes of municipality and industry wastes especially fly ash wastes. The point of origin for refuse that is domestic in nature is mainly residencies. Industry refuse comprise of effluents from mines and mills and may also comprise of agri and food refuse, ash and other sludges. Generally, all these refuse is due to the use of solid entities as once they are used it needs to disposed off as refuse. The refuse that is domestic are small sized but generated in larger quantities. Thus, any approach to manage these wastes must take into consideration the quantity of wastes that needs to be handled. This is so as the volume of refuse that needs to be handled determines the required infrastructure. A standard unit of expression must be taken to estimate the quantity of these refuse for instance cubic meters and/or metric tons. The measurement of weight is also strategic as it ensures smooth calculations and record keeping. When we measure these refuse by weight the main benefit is that it will remain constant as compared to volume that can change frequently. When we wish to compare refuse from various parts the quantity must be measured as pounds/capita/day that is abbreviated as pcd. The refuse estimations should be done by the following equation:

\[
\text{pcd} = \frac{2000T}{365P}
\]

Where, pcd = pounds/capita/day,

\[T = \text{Generated waste (tons)/annum,}\]
\[P = \text{Area population where waste is generated.}\]

The management of refuse is strategic as it results in microorganism multiplication, attracts other predators, can cause epidemics, create foul smell and pollutes environment. The most common technology to handle these refuse currently is sanitory land-filling. But the harsh fact is once the land is utilized for such a purpose it will be unable for us to re-cultivate that land.
These systems generate foul smell due to the decomposition of wastes and even if the refuse is covered by dirt in a landfill still it will generate bad odors. Transportation of wastes to and fro of landfill sites also pollutes environment. Therefore it is recommended that sanitry land-filling should be integrated with incineration facility wherein all those entities that are suspected to create foul smell can be burnt. Another approach is to process this waste into compost that will ultimately eliminate foul smell. The processing facility must be designed optimally so as to it generate minimum smell. Apart from all this solutions there persists the problem of Leachate generation during sanitry land-filling that requires careful attention. Leachate is the liquid percolated from wastes to the bottom of the land-fill that is highly toxic and if leaked to outside soils can damage surface water as well as contaminate ground water. Thus, there must be effective standard protocols to manage this refuse and to seek benefit from them. Programs must be designed to recycle this refuse, process them into compost, energy generation from them, recovering gas generated from landfills etc. The basic parameter that affects all the aforementioned approach is the components present as refuse. It is important to know the component of wastes before selecting the management system for it. The following table lists few category wise general components present in the municipal solid waste (MSW) (Table 8).

**Table 8: Category wise general components in Municipal solid wastes**

<table>
<thead>
<tr>
<th>Category</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organics</td>
<td>Kraft, newspaper, corrugated and paper of high grade, magazines and other household residues</td>
</tr>
<tr>
<td>Wastes from yard</td>
<td>Clippings of grass, other wastes from yard</td>
</tr>
<tr>
<td>Food based waste</td>
<td>Leftovers from foodstuffs</td>
</tr>
<tr>
<td>Wastes of plastics</td>
<td>Bottles of Polyethylene Terephthalate (PET), High-density polyethylene (HDPE), Other plastic, Polystyrene, Bottles of Polyvinyl chloride (PVC), Bags of Polyethylene and film</td>
</tr>
<tr>
<td>Other organics</td>
<td>Wood, diapers, fines, rubber tyres, rubber wastes and other organic waste materials</td>
</tr>
<tr>
<td>Inorganics/Non-combustibles</td>
<td>Metals – Cans of aluminum, bimetal cans and tins, ferrous metal. Glass – Containers of beverages and food, other glass, batteries and other inorganics</td>
</tr>
</tbody>
</table>
Characterizing the solid wastes

The characterization of solid wastes is essential parameter affecting solid management systems. It is required to characterize the solid wastes due to the following main reasons:

1. It determines capacity, size, and design of facilities that will manage them.
2. It determines whether the waste can be reused or can be composted.
3. Effectiveness of waste management programs depends on waste characterization.
4. Tracking of entities that cause pollution is possible.
5. It is essential as per operations point of view at management facility for solid wastes.

Thus, the designing of waste management facility has the basis of characterization of wastes that have to be handled therein. It is recommended that the wastes should be characterized on the basis of its density, compaction potential and quantity when the intention is to landfill them. Their chemical composition is not that much required for this purpose. Only if one wishes to incinerate them than other parameters like combustible components levels, heat value needs to be assessed along with the quantity of waste. Furthermore, exact studies of elemental composition is required if the intention is to reuse or process the wastes into compost. This is so as it will help to isolate certain components at its source, compliance can be monitored, target based recovery can be done and helps the identification of waste constituents.

Selection of samples from solid wastes

The appropriate method to select a sample is to choose individual trucks well in advance that represent specific areas from where wastes were collected. The selection of trucks must be based on regular duration and sources of these wastes. The suggested regular duration sampling is to choose every $x^{th}$ truck for each $x^{th}$ ton of wastes and every $x^{th}$ cubic yard of wastes plus truck every $x$ minutes. The ‘$x$’ here represents any set of numbers. Sometimes there can be over representation of samples when every $x^{th}$ truck is sampled as the wastes in small trucks and half filled trucks are also sampled. Thus, wastes should be collected from every $x^{th}$ ton of wastes. Even this can be problematic as truck weight cannot be determined merely just by observation. The solution to this problem is sampling from each $x^{th}$ cubic yard of wastes because the capacity in terms of volume of each trucks can be estimated by visualization. This can also led to the issue of over-representation as discussed above. Thus it seems sampling from each truck at $x$ minutes is feasible as far as manpower is concerned but this too may led to over-representation. The wastes can also be under-represented during peak working hours. Thus, it is advisable that
handler must sample wastes as much as he/she can so that they can have fair amounts of data regardless of the sampling procedure adopted. Next approach is random selection of trucks based on generation of a random number that can assist the handler by providing random intervals that correspond to all predetermined intervals. The classical instance is when a facility has inflow of 100 trucks per day, than a generation of 10 random numbers in range from one to hundred, can be used for sampling or each tenth truck can be sampled in accordance to this approach. The same principle can be applied for knowing intervals for volume of wastes to be handled, tons of wastes and calculating duration for handling a particular quantity of wastes. However, this approach has certain limitation like as mentioned below:

1. This approach may result in few handlers to remain free for some time.
2. This approach may result in few handlers to remain at site for overtime.
3. This approach may result in few trucks to be skipped as the sampled trucks may arrive at short time duration.

The remedy to these issues is to sample the wastes at source as this can facilitate sampling from particular waste locations, residencies, commercial locations etc. This approach is advisable when the quantity of wastes from each source is known. This can be done by weighing the amount of wastes to be handled at the source itself. The only thing that needs to be installed is a scale at the source sight that can record weight of each lot of wastes to be handled. Record keeping for wastes type, weight, vehicle type, origin etc. must be practiced. However, if scales are not available then approach should be based on design of sampling plan. The thing that needs to be differentiated at this point is levels of wastes that are compacted and those wastes that are un-compacted. McCamic et. al. (1985) had provided information on the said approaches.

**Collection of samples from solid wastes**

It is a common parlance that wastes from trucks be disposed at defined location for sample collection and is also convenient to handlers. But the surface on which the samples are to be disposed must be free of dirt. Thereafter a sample must be collected from only filtered trucks and care must be taken when more than one sample needs to be collected than it should be taken from different location of the same truck. A variety of sizes can be collected starting from 50 lb to almost whole lot. Generally, the samples that are large are beneficial due to certain reasons as mentioned below:
1. The standard deviation is less when samples are collected from large lots as only few samples need to be collected and precision can also be achieved.
2. The sample sorting results will resemble normal distribution like a bell-shaped curve.
3. Other benefits include easy decision making by handler to include heavy entities as by this approach boundary area between the sample and remaining lot is smaller in proportion to the sample volume.

The samples that are small have an added benefit of short sorting and collection duration. The standard size of sample must be in the range of two hundred to three hundred lb in accordance to the developed consensus (SCS Engineers 1979, Klee and Carruth 1970, Britton 1971). The area of boundary around sample is high when its size is lower than two hundred lb. in this circumstances handler should decide to add this boundary items. The ideal approach to get samples in this range is to assemble a composite sample from pre-decided locations in the lot. Grab sample collection is another alternative. Moreover it can also be collected manually. There are many variants available of these standard protocols. But the major limitation of samples that are composite is the same as that for samples that are small and that which includes large boundary area because it pressurizes the handler to take more decisions regarding inclusion of wastes items in the sample. Thus, it can be envisaged that low levels of accuracy can be attained in collection of samples that are composite. Furthermore, these samples require larger collection duration and variation is possible as each sample needs to be collected from each lot. Thus, it is a type of approach that is time-consuming.

Another approach is mixing a large volume of wastes for uniformity and then arranging it onto a rounded heap that is termed as ‘coning’ and then selecting a sample of quarter randomly from it is termed as ‘quartering’. This approach can be beneficial as sorting can be easy and only a small amount of sample is required. A part or whole lot can be used for sampling for once or numerous times. However, these approaches have few limitations like high time required for sampling, larger space requirements, requirement of front-end loader for larger duration. Moreover, moisture from samples can be lost and waste stratification can be a problem. The sorting accuracy can be compromised and also its duration can be more. There can be chances of refuse bags breakage that will lead to more difficulty in handling the wastes. The major benefit of this approach is that it lessens the standard deviation and so low amounts of samples are needed during sorting. The samples collected by this approach will have characteristics that
represent the entire lot thus increasing the precision levels of the approach. During this approach sample number to be selected is proportional to standard deviation square and thus only few samples are needed to be samples that will save time.

The next approach uses front-end loader for sampling purpose and this approach is termed as ‘Grab sampling’. The approach is fast and can be easily done by handler without interfering normal operations of the facility. This approach eliminates human errors that are rampant during sampling manually. However, it can promote shovel sampling as the loader will prefer small cum dense entities over large cum light entities. The latter entities can be withdrawn from the loader during sampling. Penetration of loader into wastes may break refuse bags resulting in under-representation of these samples. The sampling by loader from ground may result in sampling of wastes that does not have actual in place wastes as they are just the fallen off wastes from the top. These samples can even contain pollutants like dirt. All these factors need to be controlled by proper sampling procedures and training of the handlers. For instance training must be provided to handler to collect samples from different lots from different sampling loci to facilitate proper sample representation. The variation in sampling locations is possible by random patterns. The major limitation of these sampling approaches is exact determination of sample weight. Thus, simple approach is to collect a sample manually from any loci from lot surface and extending it from bottom to top of lot. This approach has low operations and maintenance costs and sample representation is also good and requires less time for sampling. The precision can be achieved by handler during sampling in this manner. The major limitation of this approach is that sampling of wastes located in sides of lots is tuff as it is compacted and there can be chances of under-representation of samples.

**Sample weighing and sorting from solid wastes**

The measurement of samples should be in terms of ounces and not in milligrams/grams for accuracy. Whenever one targets more accuracy in sampling than sorting can be affected and there can be reduction in the samples collected and ultimately it will reduce the precision. Thus, there must be provision of area for sorting i.e., 1000 square feet and 16 feet width at the starting of the facility. This should have easy access to trucks and needs to be saved from extreme weather conditions. They must be kept isolated from parts where heavy equipments are in operations. The general approach of sorting after sample collection that needs to be performed by the handler at the facility is as mentioned below:
1. Choose the truck and transfer sample from loci of sampling to area of sorting.
2. Put sample on surface of area for sorting.
3. Separate bulky entities from sample and weigh it bypassing the box for sorting.
4. Put remaining samples gradually into box for sorting.
5. The samples are sorted around the sorting box into the containers.
6. Weigh these containers into the scale and check for accuracy.
7. Measure the container and waste’s gross weight.
8. Now these wastes must be sub-sampled for any analysis.
9. A location must be designated for these container dumping.
10. Take care that wastes are not mixed between samples.

The process by which efficiency of handler can be increased is by installation of a sorting box that is a type of counter-height. This can have 4 feet width, length of 6 feet and depth of 1 foot. It must be open at the top. Now the sorting process must target initially to allot common loci for all waste type around sorting container and then all handlers can be allotted a category group so that handlers can place wastes into their assigned containers. The sample weighing can be done by a scale installation that has capacity of ninety kgs and 0.045 kgs of precision. These containers are dumped in the area designated for sorting at landfill sites. At locations where energy recovery is targeted from these wastes the said containers needs to be dumped at tipping floor edge. Thereafter when results needs to be processed weight of sorted samples and gross weight is recorded and also type of container must be recorded in a data form. The net weights must be calculated for all and should be recorded in the data form.

**Sampling from solid wastes for laboratory analysis**

There are varieties of entities present in a typical municipal solid waste. Also, the size of these entities is large. This makes it difficult to sample these wastes for laboratory analysis. It is a common rule that when there is a small heap of entities it is easy to pick a sample that represents it, but if the heap if large then it is difficult to pick a sample that represents the entire heap. Another problem is the levels of moisture present that hinders sampling process and also the protocols for sampling are not consistent. The initial dilemma is to decide whether to analyze individual sample or to analyze a mixed sample. If the intention is to know wastes stream characteristics the choice of source must be mixed samples. This can be adopted in those streams where there is consistent composition. Another approach is preferable when the intention is to
analyze individual components in the wastes stream. This approach is suitable to assess the success of composting process, level to which wastes has been recycled and ensures quality control because as compared to mixed samples mistakes can be easily identified from individual samples. The protocol followed for collection of mixed samples for the purpose of sorting is also applicable for mixed sample collection. Individual samples are mostly categorized into ‘composite samples’ that are collected to know composition. These samples are usually subsamples collected after the process of sorting is done and they represent each sample that is sorted and hence it is termed as subsamples.

**Material collection for laboratory subsamples**

After the process of sorting is done there are mainly three approaches for collection of laboratory subsamples from these containers. The approach includes blind grab sampling, tearing pieces from entities that are large and selection of entire entity to include in sampling process. When there are major entities in smaller forms then the blind grab sampling should be adopted. The tearing method is preferable for larger entities that have varied characteristics. The method of selecting entire entity is advisable when wastes contain a limited variation in its component types. The next important step to analyze all the results obtained after the laboratory analysis no matter whatsoever mistakes had happened during sampling. In this manner the characteristics of combustion can be easily estimated. However it is difficult to identify any errors for results obtained for toxins and metals. But the chemical types of various wastes like of foods, fines, combustibles, rubber and textiles etc., allow calculations of combustion properties on dry matter basis inspite of their variability and that is a benefit from this approach. The care that must be taken is to ensure results obtained for C is six times that of H and the O\textsubscript{2} results should not be greater than fifty percent. If the wastes are plant or food based than O\textsubscript{2} results must not be less than thirty percent. The ash values of papers must be more than ten percent. The levels of nitrogen must be less than one percent and also that of chlorine should be less than one percent. Moreover, the levels of sulfur should also be less than one percent. If this is not obtained than the tests must be performed again. After these estimations the testing of samples for individual components needs to be done on the basis of dry matter. In this case elemental composition and levels of moisture show high variation. The solution is to test composition first and than their subsamples can be used to assess levels of moisture. Thereafter comparing it with standard values overall combustion characteristics can be studied.
Implications for managing of solid wastes

The major limitation of solid wastes are they cause foul smell, generated in large amounts and are not having any aesthetic values. They result in micro-organisms multiplication and attract other pathogens, predators and have many toxins therein. They may have risks of explosion and can cause epidemics. Thus, as it can be fatal to human health and pollute environment effective system for handling and managing these wastes is required that are highly reliable and robust. The approach of Reduce, Recycle and Reuse are strategic for effective solid waste management systems. For instance composting of solid wastes can be done for which the individual components needs to be identified in wastes as to which subsamples therein can be recycled, which can be composted and which that are combustible. The table 9 shows the compostable, combustible, and recyclable fractions of typical solid wastes that must be identified initially prior to its further processing for different purposes. Thereafter, waste components that are compostable needs to be isolated and processed to form compost. The ration of carbon to nitrogen determines composting potential of entities. This ratio must be optimum to enhance rate of composting and reducing foul smell. If the ration is high than it limits rate of composting and if the ration is low than it generates foul smell.

Table 9: Components of solid wastes: combustible, compostable and recyclable

<table>
<thead>
<tr>
<th>Category of wastes</th>
<th>Wastes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustible, compostable and recyclable</td>
<td>Magazines, papers, cardboard and kraft paper</td>
</tr>
<tr>
<td>Recyclable/combustible and uncompostable</td>
<td>Bottles of HDPE, PET and films of Polyethylene, bags of refuse</td>
</tr>
<tr>
<td>Recyclable and uncompostable cum combustible</td>
<td>Cans of beverages, aluminum, tin and metals</td>
</tr>
<tr>
<td>Compostable and combustible and unrecyclable</td>
<td>Wastes from yards, paper, foods, fines and diapers</td>
</tr>
<tr>
<td>Combustible and uncompostable cum recyclable</td>
<td>Wastes of wood, plastic, rubber and other organics</td>
</tr>
<tr>
<td>Uncombustible cum compostable or recyclable</td>
<td>Wastes of metals, aluminium, batteries and other inorganics</td>
</tr>
</tbody>
</table>
One of the limitations of compost processing is that in results in bioaccumulation of metals in lands as it is repeatedly exposed to compost application. This is so as the compost contains minute amounts of metals therein and repeated application of the same result in accumulation of these metals in soils. The result is reduction in the fertility of soil. Research has indicated that such metals are present in constituents of solid wastes that are mainly unable to compost (Camp Dresser 1991, Rugg 1992). A contradictory research has also indicated that the same are present in solid wastes that can be composted (Rigo, Chandler and Sawell 1993). The classical example includes rubber, wood, textiles, wool fabrics category as shown in Table 9.

**Municipal waste composting strategies**

In the recent times most of the management systems for solid wastes are opposed by people as it affects health and environment. Majority of localities that dwell nearby a facility managing solid wastes oppose it and complain regarding foul smells. The facility renders the land as unproductive. There can be no plantation of agriculture on and nearby these facilities. Another problem can be due to Leachate. There are chances of nearby soil contamination. Moreover, the landfill system needs to be carefully engineered that has provision of a Leachate collection system that again is a costly affair. Other technologies like incineration can cause environment pollution. All types of wastes cannot be incinerated. Larger spaces at isolated location are required. The ultimate management of solid wastes turns out to be costly by this approach. Thus, a cost effective solution that is also a clean energy approach and that satisfies the principle of 3 R’s i.e., Reduce, Recycle and Reuse is the need of the day. Therefore, processing these wastes into compost can be handy, safe and option to incineration or sanitory landfilling (Hyatt 1991). These systems need less space, are easy to operate and require less maintenance. The approach is a clean energy solution that is environment friendly. There is less generation of foul smells and less skills and expertise is required. This is the reason why solid waste management systems in integrated forms give prime importance to composting technology. However, care must be taken that operations, planning and management of these places is well executed. The main basis for composting of solid wastes includes:

1. Recovering and preparing the wastes that are compostable.
2. Processing wastes to compost and refinement.
3. Planting neighbour in appropriate manner.
4. Controlling noise, litter, runoff and dust by appropriate means.
Figure 9: Generalized flow diagram for the composting process. (Source: G. Tchobanogluos 1993)
Prior art search: Solid waste management practices

Since long, worldwide attempts have been made to understand the aspects of effective management of solid wastes. In the year 2000, Yilmaz Gursel G. had studied how understanding the aspects of waste management at source helps to reduce the quantities of wastes that needs to be landfilled and thus had recommended that managing wastes at source is important. These wastes can be segregated as dry and/or organic at source and than can be collected, separated, treated, processed and recovered by appropriate equipments and can be transported to the plant where it can be recycled. This system reduces amount of organic wastes that is untreated and less daily cover is required to landfill. This in turn helps to generate less leachate and so it reduces risks of ground and air pollution. Also, Zoltan orosz-Istvan fazekas (2008) had highlighted on the main hurdle faced in Hungary regarding smaller capacity of sanitation landfilling and lack of facilities that can effectively collect and process wastes into compost. The next year, S.P. Gautam (2009) had indicated that solid wastes of urban origin can be effectively processed into compost and this can be applied as soil conditioner to improve soil fertility and attain sustainable agriculture. During the year 2010, Ishumael Sango of Chinhoyi had carried out studies on wastes that were left open and having high health risks and pollution threat to environment. They had indicated that for managing wastes in environment friendly manner the system must be designed in integrated manner that is cost effective and readily adaptable in the society. Also, Ayo Babalola (2010) of Nigeria had suggested that the main challenge in managing solid wastes is lack of facilities and the required monetary assistance. Thus, composting can be strategic technology that can be adopted and the processed compost can be applied as manure in fields. Another thing important for the success of these systems is involvement of the society and their awareness. During the same year, Luis F. Marmolejo (2010) had carried out studies on ideal practices for handling wastes entities. They had pin pointed that if the standard operating procedures for handling solid wastes at source is not proper than it can adversely affect the recovery of materials that are useful from solid wastes. There is a need to proper storage of wastes and segregation at source for effective management of these solid wastes. Also, Norbu (2010) of Bhutan had processed solid wastes into compost and used it on soils to improve its fertility. They had indicated that other wastes left after the composting process can be recycled. They had suggested that ideal management system for solid wastes must comprise of components that include facilities wherein the wastes can be stored, collected, transported,
treated and recovered and finally where they can be disposed. Another group of researchers T. Janakiram et. al. (2010) had indicated that wastes of *Jatropha* can be composted aerobically when mixed with cow dung in appropriate levels. Their results were quite promising as levels of N, P, K, Na, Ca and Mg had increased after every 24 hours and also the capacity to hold water, levels of moisture and electrical conductivity had improved. Simultaneously, there was a decrease in carbon to nitrogen ratio and pH. Moreover, Zaini Sakawi (2010) of Malaysia had indicated that effective management of solid wastes is mainly affected by consensus of parties interested for it as collection of data and planning can be adversely affected if properly trained men are not available. They had emphasized on to bridge the gap between industry and academia and to have an industry oriented curriculum in universities that will give highly skilled manpower that are trained as per industrial needs and so they can easily plan and implement management systems for solid wastes.

Recently, I.R. Ilaboya (2011) at community of Igbinedion University had designed a model of managing solid wastes in integrated manner. The important points to remember were the need of community awareness, their active participation and knowing the waste constituents at source and characterizing them. Thereafter the wastes must be properly collected, reduce, the toxins therein must be removed and then it needs to be landfilled or incinerated. The final important factor is all the above mentioned control points must be optimized so that cost can be reduced and adverse effects on environment can be eliminated. During the same year, S. K. Maity (2011) had suggested a model of effectively landfilling the solid wastes and had recommended that wastes needs to be segregated at source so that final volume of wastes that needs to be landfilled can be reduced. Other important factors include properly collecting the wastes, transporting them, use of appropriate modes of transport and adequate operations of landfills. Also, C.K. Amenyah et. al. (2011) had done two works at Accra metropolitan assembly involving waste disposal at total three currently available landfill facilities and disposing the wastes at newly designed site with composting facility. They had proved superior results with the later and showed reduction is overall cost of operations. Also, monetary gains were possible due to compost and amounts of wastes that need to be landfilled can be reduced. Thus, they had recommended that in metros managing solid wastes in an integrated manner can be more effective than the conventional approaches. The model suggested by them was also cost effective and resulted in reduction of levels of pollution in environment.
The subsequent year Aysun Ozkan (2011) in Turkey designed Electre approach for managing solid wastes in an integrated manner. They had recommended that ideal management system for solid wastes must integrate 10-20% provision to recycle wastes, 70-75% provision to process wastes into compost and 5-10% wastes to landfill. The next year, Sohrab Hossain (2012) had carried out experiments in which they had tested medical wastes treatment by adoption of autoclaving by steam. They had used the approach as alternative to conventional incineration. They had obtained positive results however bacterial grew after two days of treatment even after they were inactivated. Therefore, they had indicated that this approach cannot be used as a replacement to incineration. Thus, as per the prior art search done, there is a need of further research on effective solid waste management strategies and that has triggered the present study to investigate it using environment friendly techniques. During the present studies, firstly composting technology was evaluated for effective solid waste management strategy.

**Composting process: At a glance**

The approach to process solid wastes into compost is based on microbial degradation of wastes in appropriate environment (Gray 1971a, Golouke 1991). The wastes discarded by municipal corporations and agri-food industries are ideal to process as they are organic in nature. The processing results to form a high quality soil conditioner (Haug 1993, Koivula 2000, Paredes 2000, Parkinson 2004). The processing is facilitated by the microbial community that can resist high temperature and grow from raw wastes. Their subsequent growth and multiplication finally degrades the organic components of wastes and forms compost. Several parameters like pH, O₂, levels of H₂O and temperature affect the process. The main advantage of the process is it is highly adaptable under many varied environment (Gray 1971a, Poincelot 1974).

**Abiotic factors affecting composting process**

The main principle behind processing wastes to compost is formation of a minute film of liquid around the solid entities wherein microbial community does the degradation action and water provides the necessary medium that facilitates metabolic and nutrient transportation (Rynk 1992). The threshold of water levels for optimum activity of microorganisms is thirty to fourty percentage (Gray 1971b). Once the levels of water decreases beyond the said limits than the microbial community will be adversely affected (Ryckeboer 2001). If levels rise beyond this limit than the end result is hypoxic environment (Gray 1971b). The degree of composting depends on the nature of the organic wastes. The wastes capacity to absorb and whether it is
porous or not decides how much levels of water is required. Many wastes for instance straws contain wood and high fiber and thus can tolerate high water levels (Golouke 1991). Researchers have also indicated that as compared to windrows that are static where aeration is passive more levels of water will be present in systems that have mechanical agitators (Gray 1971b). Another important parameter for effective microbial activity is how much oxygen is available. Ideally 4-6% levels of oxygen must be there in the space between pores of compost (Rynk 1992). The stage wherein large levels of oxygen is used include thermophillic step. If the level of oxygen is scarce than it can be maintained by churning and mixing over compost or forcefully introducing air therein (Gray 1971b, Fernandez 1997) that will ultimately eliminate excess heat and carbon dioxide in the waste materials that are organic as depicted in figure 10. Moreover, once the level of oxygen decrease beyond its threshold than the microbial activity can be ceased and may form hydrogen sulphide or other acids (Rynk 1992). However, if the levels of oxygen increase beyond a threshold than also microbial activity is adversely affected as due to low temperature levels of water will be decreased (Gray 1971b).

In order to process solid wastes to compost minimum adjustments need to be done as far as pH is concerned because the microbial community can sustain a varied range of pH with optimum as 6 to 7.5 for bacterias and for fungi the range is from 5.5 to 8 (Golouke 1991). Once the pH increases or decreases from the said threshold it will adversely affect the degradation process. However, generally pH is maintained in neutral range (Haug 1993). The main source of energy for the microbial community is provided by C that is utilized to synthesize new cells and nutrients like K, P, and N required by them to reproduce and grow. Ideally, depending upon the waste type a carbon to nitrogen ratio of 25 to 40 is required by microorganisms (Gray1971b, Finstein 1975). If levels of carbon is low as compared to nitrogen than ratio of carbon to nitrogen remains high. If the levels of carbon is higher as compared to nitrogen than bio-activity of microorganisms will tend to slow down (Golouke 1991) and if levels of N are high than it is released as NO₃ leaching and ammonia gases from the composts (Parkinson 2004). Gray (1971b) had recommended that in order to obtain end compost of high quality optimizing the levels of P present in the organics can be handy as it will result in fast degradation rates. Thus, maintaining appropriate levels of P during composting can be beneficial. This will process the raw materials effectively into compost. The obtained compost can be used as a soil amendment and can be applied as organic manure on the lands that have suffered from chemical deterioration.
Figure 10: Schematic diagram of the composting process
Microbial succession during composting process

The process of composting involves gradual changes in microorganisms when optimum conditions are maintained and that is termed as microbial succession. The main factors that affect this succession are variation in the abiotic parameters, constituents present in organics, raw materials present therein and microbial interactions (Golouke 1991). The processing of wastes to compost has four phases due to microbial succession that include:

1. Mesophilic step (Temperature range: 20 to 40°C): Generally lasts from few hours to several days.
2. Thermophilic step (Temperature ≥ 40°C): Generally lasts from few days to few months.
3. The cooling step: In this step temperatures decreases to ambient air temperature as the activity of microorganisms lowers in this step.
4. Maturation step: Generally lasts from several months or even years (Crawford 1983).

During the process of composting when the above mentioned steps are in progress a wide range of microorganisms function and the variation is more if the wastes are having high heterogeneity (Golouke 1991). According to Crawford (1983) the compost has about 10^8 dominant bacteria when 10^5-10^8 actinomycetes are excluded and 10^4-10^6 of fungi/gm dry compost. Also certain other large organisms may occur during last stages of composting like algae, protozoa, viruses, spiders worms to name a few (Finstein 1975). As compared to fungi during the composting process the bacteria acts with high efficacy as they have inherent characteristics of low time for generation and can produce a variety of enzymes capable of degrading a wide range of organics even if they have a high surface to volume ratios and that facilitate substrates to be utilized rapidly (Ryckeboer 2003). As there is increase in temperature above 40°C, the mesophilic organisms tends to lower their activity and only temperature resistant strains and thermophilic bacteria act wisely. Finstein (1975) had suggested that 42-56°C is the optimum range of temperature wherein the thermophilic fungi acts and 50-55°C is the optimum range of temperature wherein the actinomycetes acts. When the temperature rises above 60°C than only spore forming bacterias that are thermophilic in nature can survive and hence there is a decrease in the degradation rates (Gray 1971b, Ryckeboer 2003). These microorganisms can regrow only when the temptraure is low during the last step or can grow from the spores that are resistant to heat (Gray 1971a). Their activity is high when medium N levels persist and so degradation of organics that are complex will occur (Ryckeboer 2003).
Prior art search: Composting technology practices

Since long worldwide attempt have been done to optimize effective composting technology for solid waste management. Hiraki Yoshiharu (2002) had developed a organic waste composting method including chopping the organic wastes, adjusting water content of the chopped organic wastes to about 20%-40% by weight and then mixing an effective amount of EM-fermented feed with the chopped organic wastes such that the EM-fermented feed is substantially evenly distributed in the chopped organic wastes. Thereafter, the chopped organic wastes having the EM-fermented feed was stored in a closed container at suitable temperature at predetermined duration. These chopped organics thus composted in the closed container by fermentation. Shankar Hariharan S. (2005) had developed a process that convert organics to sold and fertilizer grade soil conditioners and had also reused water. They had adopted culture of *Pheretima elongate* for the process. During subsequent year, Nagavallemma K.P. (2006) had studied on vermi-composting as a tool for recycling wastes into valuable organic fertilizer. They had suggested that the utilization of vermi-compost can help society as it will lessen the costs of production and will enhance the productivity of soils. Moreover, it can provide additional source of income generation for landless people. As far as the industries is concerned vermi-composting can serve as cost-effective and pollution abatement approach. It can boost to rural economy and has a benefit of less wasteland formation.

In the year 2009, Hood Peter et. al. had developed technology to process organics wherein they are initially broken down to fine range of particles and than stored for sometime followed by subsequent breaking of particles to a defined size alongwith mixing in rotary drums. These treated wastes than come out from the outlet provision. The biological decomposition had occured under aerobic conditions in the aerated storage bay and the rotating drum. The method intended to produce a sustainable, alternative fuel product specifically using a bio-drying process to treat biodegradable entities of the organics. During same year, Boraste A. (2009) had developed a novel biofertilizer by the composting process for sustainable agriculture. The resulting biofertilizer was almost alkaline in nature and had a very good capacity to maintain moisture condition, to hold water, had less salt concentration, had high level of nutrients in the material with negligible heavy metals. Also, Abdoliman Amouei (2009) had done experiments to study processing of organic wastes to compost in Iran and had concluded that a sound quality compost can be produced when mixed raw materials are utilized that include organics from...
homes, cattle and agri-food industries. They had also recommended that rural solid wastes problem can be effectively tackled by the composting technology. The next year, T. Janakiram (2010), had studied on the aspects of solid waste management and had tried to dispose off *Jatropha* wastes by aerobic composting methods. They had used manure from cattle and mixed with the wastes at different levels and allowed to compost for thirty to sixty days and had indicated that as days passes the levels of nutrients present therein will rise and there will be a decrease in pH. The same year, I. Mahmud (2010) had studied the co-relation of Mycorhiza and organic farming and had concluded that technology of VAM is strategic to eliminate deforestation and composting systems can sustain Mycorhizas. Also, S. P. Gautam (2010) had studied on the designing facility for processing organics to compost and evaluation of its properties and had concluded that $E_d/E_6$ ratio can be adapted as appropriate parameter to determine stability of the compost.

In year 2012, Muhammad Ali Ramdhani had studied on the key success factors for organic farming development and concluded that organic farming can guarantee food security by sustainable farming as it improves the soil quality. It is advantageous in various aspects like it ensure stable and sound quality of product and is environment friendly. But for the success of organic farming there is a need for the stakeholders’ support, appropriate infrastructure and monetary assistance. Also, Manjula Gopinathan (2012) had conducted a study wherein they had used a combination of waste water from dairies and solid wastes from municipalities and allowed it to form compost. They had suggested that the co-composting of dairy waste water with municipal solid wastes produces compost that is more stable and homogenous and can be effectively used as soil conditioner. Moreover, Daniela Suteu (2012) had studied on the biohumus production by worms’ composting of some food wastes and had concluded that the biohumus produced by worms’ composting can be used as fertilizer for the soil, in agriculture or flower cropping. During the same year, A.E. Ghaly (2012) had developed anaerobic digester as well as compost formation system that can be best suited on average sized dairy farms. They had observed that their approach resulted in a saving of 6289 kg of fertilizer at a cost of $17,925 annually and additional saving of $20,547 on energy use.

Recently, Rajib Roy Chowdhury (2013) had studied on the aspects of agricultural productivity enhancement by farming in organic manner and had concluded that organic farming can be strategic and helps to attain sustainability in agriculture. Improper agriculture practices
have led to global climatic changes that have adversely affected environment and have resulted in erosion of soils and scarcity of water. The need of the day is farming in organic manner as it is superior as compared to conventional practices. S.V. Mahamuni (2013) had studied on the potential of fungi to process agriculture and industry wastes into high quality compost and had recommended that the quality of compost prepared from agro-industrial wastes such as PMC, molasses, dairy wastes, spent wash and bio-compost can be enhanced by the inoculation of consortium of phosphate solubilizing fungi. In the same year, Raja Ambethkar M. (2013) had suggested that proper collection to treatment model is the main factor required for effective management of solid wastes. Also, D. V. Wadkar (2013) had studied on the aerobic thermophilic composting and had recommended addition of bacterial cultures in it to accelerate composting process and had indicated that mainly the mesophilic bacteria are responsible to trigger the thermophilic bacteria at temperature around 40°C. The maturation period can be around 42 days. Moreover, aeration can be provided with the help of solar energy and that can increase the efficiency of process. All these can help to keep composting parameters within desired limits.

The compost obtained by such technology can be used for ornamental plants like azaleas, gardenias, camellias, etc. Another group of researchers, Tapas Dasgupta et. al. (2013) had worked on the aspects of managing solid wastes in Bhopal. They had suggested that biogas generation from wastes combined with a compost generation system can be effective in solving environment pollution issues. Also, Manju Rawat (2013) had conducted studies on the characterization compost from wastes from various metros in India and had recommended that there is need for periodic monitoring of heavy metals in MSWC so that quality could be insured and contamination could be prevented. Moreover, the quality of compost may be improved by adding cow-dung, bagasse, garden waste etc. Thus, utilization of MSWC would help in recycling of MSW and also increase the fertility of soil and decrease the volume of wastes. Finally, it was envisaged that there is a need to make compost popular among the farmers for its sustainable utilization. In the same, Yahaya O. (2013) had worked on the determination of bacteriological quality of animal and municipal solid waste using windrow and open pile composting techniques in Zaria, Nigeria and had recommended that a wide range of wastes can be composted using these techniques, but regulations must be framed and implemented in scientific basis. Moreover, the need to the day is awareness of the technology to localities and technology transfer to them. O. Yahaya (2013) had studied on the microbial quality of animal compost using the windrow and
open pile techniques and had suggested that composting of wastes could be the key in order to attain the desired reduced reliance on artificial fertilizer and cleaner urban environment. Sanonka Tchegueni (2013) had studied on physicochemical characterization for organics and had recommended that by composting, the value of organic matter can be improved in agriculture. They confirmed that shea-nut cake can be successfully composted and the mature compost obtained can contribute to the maintenance and increase of the organic matter stock of soils, thus bringing fertilizing elements to the plant. Thus, as per the prior art search done, there is a need of further research on composting technology development for effective solid waste management and that had resulted the present study to investigate it during the first phase. Furthermore, the second phase had focused on Biogas technology as a tool for effective solid waste management.

**Biogas technology: At a glance**

It is a well known fact now that the increasing need for energy has resulted in extensive variations in climate and exploitation of resources. Therefore, the next phase of present studies had focused on solid waste management and simultaneous energy generation utilizing the Biogas technology. Biogas mainly results as the oxygen less environment favors microbial growth that degrades the organics therein generating mainly gases like CO$_2$ and CH$_4$ and certain gases like H$_2$S in trace amounts (Hiremath R.B 2009, McKendry P. 2002). The important gas is CH$_4$ which has no color, blue flame and mainly used as source of energy (Itodo I.N. 2007). It is renewable source of energy that is clean and efficient to replace the conventional sources of energy (Yu, L. 2008). During the process of generation of biogas degradation of organics occur under zero O$_2$ conditions by microbes that ultimately generate the gases and the residues can be applied as soil amendments (NAS 1977, Singh, R.B. 1973, 1974, Sathianathan M.A. 1975, Meynell P.J. 1976, Santerre M.T. 1982). There are four different stages involved in methane formation during anaerobic digestion that includes conversion of polymers to monomers during first step followed by degradation of these monomers to acids of short chains in second step. The third step involves conversion of these acids to CO$_2$, acetate and H. The final step involves conversion of produced intermediates into CO$_2$ and CH$_4$ by methanogens (Deublein D. 2008).

**Biogas formation by anaerobic digestion: The responsible factors**

There are numerous factors that affect optimum performance of the biogas generation system that include forms of microbes present and the prevalent conditions, ration of carbon to nitrogen, amounts of hydrogen ions present, time of incubation to name a few. There must be
allowance of transition period for the microbes therein as they require at least 20-25 days adaptation duration whenever there are variations in the types of substrates used (Deublein D. 2008). There is a necessity of establishment of symbiotic relationship among the different microbes present during the biogas generation and pH in neutral range is required. Moreover, different microbes require different range of temperature and if not maintained can adversely affect the process (Deublein D. 2008). Also, the raw materials should be mixed properly for effective energy generation. If they are not mixed well that it can result in lower microbial activity and generate foam. As the doubling time for methanogens is slow proper incubation time must be given to them and also the ratio of carbon to other nutrients must be maintained appropriately. The levels of solids present therein must also vary however the size of particles is not that much significant (Deublein D. 2008, Gerardi M.H. 2003, Yadavika 2004).

Worldwide small anaerobic digesters for Biogas generation

Biogas production is different than other sources of energy as it is cost effective and easy to handle (Gijzen H.J. 2001, 2002). Biogas production can be facilitated by use of dung and that its residue can also be used as a soil amendment. Thus, it is environment friendly approach (Green J.M. 2002, Hall D.O. 1983). Large scale digesters require more maintainence and is costly hence cannot be adopted at rural scale. Thus, biogas generating digesters that are small in size can be used and affordable to individual farmers and is also their need (Georgakakis D. 2003). This approach has gained popularity mostly in China, India followed by Nepal and Bangladesh (Jiang X. 2011, Thien Thu 2012, Austin G. 2012). In China there has been a rapid and increased investment in biogas infrastructure and it is estimated that within the next decade most households will have such installations (NDRC China 2007). India had planned to implement one of the same at large scales that have prime strategy to promote biogas plants (Khoiyangbam R.S. 2011, Sarkar A.N. 1982). Many small scale biogas generation systems are also in operation in America, Canada and Europe. These digesters are also gaining popularity in Germany, Austria, Switzerland, United Kingdom and Denmark (EPA 2010, Wilkinson K.G. 2011, Raven R.P.J.M. 2007, Iea-biogas 2013). In many African countries there are installations of many small-scale biogas generation units however the approach has failed due to lack of quality infrastructure and knowledge for the same (Amigun B. 2009, Africa Biogas 2013, Parawira W. 2009). The demand for energy is very high in Africa and biogas generation technologies are just in their nascent stages (Parawira W. 2009, Omer A.M. 2012).
Different types of household anaerobic digesters for Biogas generation

Generally, there is no single remedy of biogas type for a single household as the types of digesters for different households will vary due to variation in loci, raw materials that are available and different climates. The classical example is popularity of underground digesters in most of the tropics as geothermal energy can be utilized maximum and digesters having low volume for gas in hilly areas can lessen the loss of gas (Bin C. 1989). However, China designed digesters having dome that is fixed and India designed digesters having drum that can float and both of these technologies have gained much popularity (Zhang D. 1989). Also, digesters having plug flow is widely accepted as it is highly portable and easy to operate.

Digesters having dome that is fixed for Biogas generation

The fixed dome digester as depicted in figure 11 was designed in China and is widely accepted throughout the world (Santerre M.T. 1982). The digesters have a provision for raw material intake and a top portion wherein produced biogas can be collected. The produced gas causes the residue to move to top portion and then is returned back to digester after release of gas. The gas is collected in top portion in a tank for storage (Sasse L. 1991). These digesters are ideally built underground (Santerre M.T. 1982). Mainly, their dimensions rely on the available raw materials and loci for instance in Nepal their dimensions are from 4-20 m$^3$ (Gautam R. 2009), between 1 and 150 m$^3$ in India (Tomar S.S. 1994), between 6 and 10 m$^3$ in China (Daxiong Q. 1990), and six m$^3$ in Nigeria (Adeoti O. 2000). Another option can be biogas systems based on cluster wherein a medium sized digester can be installed for a cluster of twenty to twenty five households instead of single households (Akinbami J.F.K. 2001).

Janata and Deenbandhu models are the types of fixed dome models developed in India. The former model was designed during 1978 and is represented in Figure 11a. The model has provision of dome at top and a chamber. The inflow, outflow valves and pipe for gas are on top of dome. However, only small amounts of gas can be generated in this model and residues that are not much digested can escape from top of the digesters (Anjan K.K. 1988). Thus, a modified Janata model was launched in 1984 by ‘The Action for Food Production’, abbreviated as AFPRO that is popularly known as Deenbandhu model as represented in Figure 11b. It has provision of a top sphere for storage of gas and a below sphere for fermentation and is cost effective. Several modifications are also made in this design like in China the digesters have a wall in the middle of the said design and is of hemispherical shape as represented on Figure 11a (Aburas R. 1995,
1996), and other models has modification like reduced arch diameter and lesser potential to hold gas as represented in Figure 11b (Kanwar S.S. 1994). If this modified design is used in hilly regions then there is less loss of biogas. Another group of researchers Jash T. et. al. in 1999 had used a cylinder of vertical type and a holder for gas that is having a shape like a bell with partitioning vessel to two using bricks. However even this design needed to be modified as few particles that were heavy were getting stuck so the inlet and outlet valves very redesigned and were made slightly curved as represented in Figure 11c. This design can be integrated with a drum of steel that has biomass so that no temperature can be lost (Mohammad N. 1991) or a plastic bag that can expand can be used to cover storage tank for gas with a roof of wood on top to increase the pressure of gas and also to protect the bag of plastic (Sasse L. 1991). As represented below Figure 11a depicts a typical design of Janata model having a dome that is fixed and its modifications, Figure 11b depicts a typical design for Deenbandhu model having a dome that is fixed and its modifications and figure 11c depicts a typical digester having a dome that is fixed straight and curved inlet and outlet valves.

![Diagram of Biogas Digester]

**Figure 11 a - A digester of Janata having dome that is fixed and its modifications**
Figure 11 b - A digester of Deenbandhu having a dome that is fixed and its modifications

Figure 11 c - A digester having a dome that is fixed with straight/curved inlet/outlet
Floating drum digesters for Biogas generation

This model was designed in the year 1962 (Figure 12) that is termed as Khadi and Village Industries Commission (KVIC) model. Although it is conventional practice still it has gained popularity in India even today. The model comprises of one chamber where the raw materials are fed and the other chamber is movable that forms the upper portion of the system. When the gas accumulates the floating chamber move upwards that depends on the amounts of gas generated. This in turn exerts pressure on the generated gas to flow through the outlet for use as energy resource. Thus a biogas that has variable volume and consistent pressure is generated (Green J.M. 2002). The chamber that is floating has the generated biogas therein that can be detected by its position. The outer portion of this chamber can be coated with paints in order to avoid rust. Care must be taken that no cloggy materials appear during the operation (Werner U. 1989). This model was redesigned in Thailand having around 1.2 m$^3$ of dimensions wherein jars were placed on either sides of this chamber (Gosling D. 1982). This system can be installed with dimensions around 5-15 m$^3$ for average sized farms (Werner U. 1989). Researchers have also redesigned this model into several types and compared them wherein each chamber used was of around 85 m$^3$ dimensions. The plant utilization factor (PUF) was found to be 0.36. The PUF is nothing but in accordance to the systems’ capacity levels of raw materials fed.

![Figure 12: Representation of digester having a drum that is floating](image-url)
Plug flow digesters for Biogas generation

The main limitation of earlier discussed designs is that after their installations they cannot be moved and thus portable designs that are movable were developed that is popularly known as digesters having plug flow as represented in Figure 13. They generate gas with consistent volume however the pressure varies (Green J.M. 2002). The size can vary between 2.5 to 7 m$^3$ and have a tank of medium length that has inlet and outlet valves in opposite directions. The rest of portion remains underground. There persists a system of dual phases within the model that is covered by a cover that protects the ingredients within the system (Ferrer I. 2011, Bouallagui H. 2003, Ferrer I. 2009, Garfí M. 2011, An B.X. 1997, Lansing S. 2008, Karagiannidis A. 2012). In recent days designs that have tubular structures are gaining popularity as it is cost effective (Ferrer I. 2011). They are robust and require less maintenance. It can be best suited in mountainous regions as the other two types of digesters require large pit to be dug for installation and this pit digging is difficult in such areas (Kalia A.K. 1998). Almost half of the digesters adopted by USEPA are these said digesters (USEPA 2007). They require incubation of twenty to thirty days and are ideal for manure and semi-continuous operations. The ingredients contain total solids of 10-15% and are risk free as maintenance is low (Lusk P.D. 1998, Cantrell K.B. 1998, Beddoes J.C. 2007). The design has gained popularity even in Philippines and is being adopted by the Bureau of Animal Industry (Moog F.A. 1997).

Figure 13: Representation of digester having a plug flow
During the present studies biogas generation from organic waste materials discarded from college canteen was also studied. Several other researchers from worldwide had also made attempts to generate biogas from wastes of foods. The ARTI organization had designed such types of digesters that can be adopted widely and were also provided with awards for this outstanding achievement. The main advantage of the designed model was that a variety of raw materials can be used in these types of digesters and the unit enables biogas generation (500 g methane) with just 2 kg of such feedstock within one day. As compared to the traditional approach the design is far more advantageous.

Prior art search: Biogas technology and practices

Since long worldwide research efforts have targeted to design and implement more effective Biogas technology for efficient solid waste management. It is well known fact that among renewable energy sources, waste is all the more attractive as its valorization enables us to both produce energy and dispose of waste streams. Globally, Biogas technology is a fast growing technology that transforms organic wastes into biogas through a biological fermentation. The technology splits organic substances into an oxidized form carbon dioxide and reduced form methane. In the year 1994, Soren Tafdrup had studied on the aspects of centralized biogas plants and had suggested that they have potential to generate energy as well as manage wastes. He had recommended that lowering temperature in later stages of the process can be handy. Thus, it is envisaged that these technologies can result in socio-economic development of society. In 2004, Brian Cox and Malcolm Souness had studied the Biogas opportunities and its potential in New Zealand and had indicated their usefulness as potential tool to treat dairy farms wastes. However, the feedstock collection and conditioning, feedstock availability can be issues and constraints for the technology advancement. Another group of researchers, S. Sedlacek et. al. (2010) had studied on generation of biogas from wastes of food materials and had shown sound results.

During the next year, Moinuddin Ghauri et. al. (2011) had designed a model for biogas generation and had suggested that the electricity generation using biogas by dry process can fulfill the energy demands of society. Reactor by-products can be used as a fertilizer and also for compost use and finally the excess CO$_2$ produced with CH$_4$ for the beverages industry and making of dry ice can be highly profitable. They had concluded that the electricity produced using biogas can fulfill the basic needs of the society. The same year, Abdeen Mustafa Omer (2011) had studied on the developments of Biomass and biogas for energy generation, its
perspectives and had suggested that development of the rural areas is mainly dependent on cost effective energy solutions like the technology of Biogas. Their review recommended Biogas technology as important tool for management of a wide variety of wastes. Also, Carlos Gonzalez et. al. (2011) had studied optimization of biogas generation process and had suggested that in spite of a heterogeneous composition of solid wastes, a majority of the solid wastes fractions was organic that generated a significant amount of biogas. Furthermore, the ANOVA procedure done gave highlights on influence of composition, biodegradability and time of confinement of solid wastes and methane production despite deficiencies in the final soil layer cover in those sites.

Recently, Sneha R. Vattamparambil (2012) had studied the anaerobic microbial hydrolysis of agriculture waste for biogas production and had suggested that the gas production will be enhanced by inoculating isolated hydrolytic microorganism to agriculture wastes with decrease in detention time and the pre-treatment of agriculture wastes with white rot fungus maximizes the accessibility of hydrolytic enzymes to its organic matter like hemi-cellulose and cellulose by lignin degradation. Also, Joaquin Perez Diaz et. al. (2012) had studied on Biogas production from kitchen wastes and concluded that food waste/refuse or peelings can serve as a significant energy resource and result in excellent residue that can retain the fertilizer value of the original waste products. Therefore, biogas technologies must be intensified so that ecological disasters like deforestation, desertification, and erosion can be arrested. During the same year, Daniel Pick et. al. (2012) utilized green wastes for processing it into Biogas and had suggested that a very high percentage of the theoretical residual biomass potential may be difficult to access as there can be various technical, legal, ecological or management (economic) constraints and only the municipal lawns and green spaces may provide suitable substrates. Moreover, Karthik Rajendran (2012) had done a review on household Biogas digesters and had indicated that the production of biogas relies on various parameters like ratio of carbon to nitrogen, levels of raw materials fed, its temperature and pH to name a few and that the technology is highly cost effective. Dr. Akhilesh Kumar (2012) had studied on the same pathway and had recommended that the design of model must be based on the socio-economic requirement of the locality wherein the technology needs to be installed. Another group of researchers, Usman M. A. et. al. (2012) had studied on processing wastes of domestic origin to Biogas and had concluded that the technology resulted in high energy generation and the said raw material can be ideal source for generation of Biogas. Moreover, the technology has potential to solve disposal problems of
wastes alongside energy generation. Also, Laxman Lama (2012) had studied on the production of biogas from kitchen wastes and had concluded that the average daily gas production per Kg of dry kitchen waste was 35 L, thus, by storing the 2-3 days’ gas it will be equivalent to consumption of 1 days LPG gas. They had recommended that the concept of kitchen wastes utilization using a modified ARTI compact plant can be handy.

During next year, Felix Chinedu Akubuenyi et al (2013) had worked on biogas production from domestic wastes and its purification with charcoal and had suggested that the charcoal can be used to upgrade biogas by reducing the CO\textsubscript{4} content and increasing the quantity of CO\textsubscript{4} thereby enhancing the caloric value of gas. Thus, as per the prior art search done, there is a need of further research on Biogas technology development for effective solid waste management and that had resulted the present study to investigate it during the second phase. Furthermore, the third phase had focused on Reed bed technology development that can serve dual purpose of solid waste management and wastewater treatment.

**Reed bed technology – Global scenario**

The interest in environmental biotechnologies is increasing in view of its clean energy solution and effective management of solid wastes. They have capability to treat a variety of effluents may it be from the industry of households. This is a type of Phytoremediation technique and had been previously studied on various aspects like the factors that are responsible for wastewater treatment, the microbial community that dwells therein and its coorelation with other external parameters. Implementation of Reed Bed technology requires social, environmental as well as economical factors to be considered. On a social level, there is a need to make sure that the locality is not adversely affected where such technologies are set up on a large scale. Such technologies will help to illustrate the significance of environment protection in locals. There are many advantages of such technologies like the resources required for its constructions are easily available and sourced from local resources. They require low maintenance and operations costs. The process is entirely natural and no extra energy is required for its functioning. The system generates minimum wastes and requires no extra skills and expertise and is economically manageable. The following figure 14 represents a typical system comprising of Reeds. The entire system can be either above ground or below ground. In the above grounds Reed beds no digging is required, is easy to implement and maintain. It is more resistant to changing water levels. The only disadvantage of these types of Reed beds is that a more rigid base material is essential. The
below grounds type of Reed bed is advantageous in unflooded areas. Its base requires less material and is durable. The main disadvantage of these Reed beds is that the initial installation is labor intensive. Moreover, to ensure a smooth functioning is also difficult as compared to above ground Reed beds (Charmian Wong 2009).

Figure 14: A typical system comprising of Reeds

A height control chamber can be installed in a Reed bed system that can facilitate the control of the height of the water level. However, the installation can be optional. These chambers work on the basis of levels of water in this systems that will correspond level of pipe therein. These chambers can be installed for few species of Reed beds that are able to grow faster at lower water heights. The following figure 15 depicts a typical height control chamber. The figure 16 represents a chamber for control of height. The base of the system is the principal constituents as they incorporate all the wastes fed therein. This chamber must satisfy three main criterias of chemical inertness, rigidity and cost effectiveness (Lismore City Council 2005).
Figure 15: A chamber for control of height (Smith T. 2009)

Figure 16: An illustration of a height control
Recycled materials like unused barrels, discarded water tanks/septic tanks etc. can be used to construct the base of a typical Reed bed. These systems can be also combine with each other if they are smaller in size and a integrated systems of small systems as represented in figure 17 can be constructed that can be easy to handle and cost effective.

![Figure 17: A small scale treatment system of Reeds](image)

The construction of these systems can be facilitated by cheap resources like rocks, gravels and the inlet and outlet pipes can be made with dimensions upto hundred mm diameter (Lismore City Council 2005). Ideally, there are various types of Reeds that may be used for the construction of a Reed bed system. The table 10 highlights on some commonly used Reeds for this purpose.

<table>
<thead>
<tr>
<th>Species</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Baumea articulata</em></td>
<td>2.5</td>
</tr>
<tr>
<td><em>Baumea rubinigosa</em></td>
<td>1</td>
</tr>
<tr>
<td><em>Bolboschoenus fluviatilis</em></td>
<td>2.5</td>
</tr>
<tr>
<td><em>Eleocharis sphacelata</em></td>
<td>2</td>
</tr>
<tr>
<td><em>Lepironia articulata</em></td>
<td>4</td>
</tr>
<tr>
<td><em>Phargmites australis</em></td>
<td>4</td>
</tr>
<tr>
<td><em>Schoenolectus mucronatus</em></td>
<td>1</td>
</tr>
<tr>
<td><em>Schoenolectus validus</em></td>
<td>3</td>
</tr>
<tr>
<td><em>Typha Orientalis</em></td>
<td>4</td>
</tr>
</tbody>
</table>

The unique properties of different Reed Bed systems depend on their biochemical nature for example certain species of Reeds like the *Phragmites Karka* have excellent proportions of O\textsubscript{2} in the entire plant system in a natural manner. These inherent environments therein ensure that the appropriate conditions are provided to ensure effective microbial growth therein that
ultimately facilitates the treatment of a variety of effluents from different sources by the microbial actions. Apart from the Reed itself, gravels and rocks in the entire Reed bed system may facilitate the eliminations of metals from the effluents as the gravels have a natural affinity for certain metals and so when the effluents pass through the systems the gravels will retain these metals and ultimately results in detoxification of the effluents. Thus, it can be envisaged that when effluents pass through a system build up by Reeds it will be thoroughly treated (Johnston Smith, 2009). The Reed bed technologies can also be applied to sludge treatment as it provides sludge dewatering through plant uptake, evapo-transpiration and drainage. In this technology final end product can be used as soil amendments. As compared to the conventional (asphalt) beds that can dewater approximately 20 gallons of sludge per square foot per year, previous research had indicated systems using Reeds for treatment are far more superior. The Reed bed systems allow storage of surplus sludge whereas in the asphalt systems surplus sludge needs to be removed periodically (NYSERDA 2006).

**General wastewater pollutants**

The general pollutants found in waste effluents include microbial communities, the solids that are suspended therein, the organics and other nutritional constituents (Henze 1997, Warren 2000, Reed 1995). When these effluents are disposed of they tend to decrease the DO of the receiving end mainly due to the action of the microbial community present due to the organics. Certain effluents also tend to result in Eutrophication of receiving water bodies. Also, the solids that are in suspension have the potential to be detrimental to receiving waters as high suspended particulate matter can enter surface waters and reduce the DO. The primary requisite for most wastewater treatment processes is the removal of pathogenic organisms (Warren 2000). Inadequate treatment of wastewaters can result in pathogenic organisms to enter the surface waters, or contaminate crops and grazing animals (Reed 1995). Thus, these pathogens can disturb the natural food cycle and can result in a variety of ailments as represented in table 11. These pollutants not only cause fatal diseases in humans but are also responsible for environment pollution. As shown in the table the pathogenic microorganisms that are present in wastewaters are categorized mainly into bacteria group, protozoan group, helminthes group and the viruses group (Kadlec 1996). The category wise caused illness by these pathogens is described in the table. These conditions are mainly fatal like polio, Meningitis, disorders of Gastroenteritis, Hepatitis and Typhoid fever to name a few.
Table 11: Pathogens and respective human illness (Kadlec 1996 and Britton 1994)

<table>
<thead>
<tr>
<th>Pathogen type</th>
<th>Pathogen</th>
<th>Illness caused</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viruses group</td>
<td>Enterovirus</td>
<td>Polio, diarrhea</td>
</tr>
<tr>
<td></td>
<td>Echovirus</td>
<td>Meningitis, common colds</td>
</tr>
<tr>
<td></td>
<td>Hepatitis A</td>
<td>Hepatitis that is fatal</td>
</tr>
<tr>
<td>Bacteria group</td>
<td>E. Coli</td>
<td>Gastroenteritis</td>
</tr>
<tr>
<td></td>
<td>S. Typhi</td>
<td>Typhoid fever</td>
</tr>
<tr>
<td>Protozoan group</td>
<td>Crypto-sporidium</td>
<td>Diarrhoea, Nausea, Fever</td>
</tr>
<tr>
<td></td>
<td>G. Lamblia</td>
<td>Diarrhoea, Giardiasis</td>
</tr>
<tr>
<td>Helminths group</td>
<td>A. Lumbricodides</td>
<td>Roundworm</td>
</tr>
<tr>
<td></td>
<td>F. Hepatica</td>
<td>Liver fluke</td>
</tr>
<tr>
<td></td>
<td>Species of Taenia s</td>
<td>Tapeworm</td>
</tr>
</tbody>
</table>

The nitrogen component that is present in wastewater facilitates the nutrient requirements of plants and enhances their growth, however, if it is in excess concentrations than it can stimulate excessive algal blooms. The phosphorus component of wastewater is commonly a limiting factor in vegetative growth in aquatic environments.

**Artificial wetlands**

The adoption of artificial treatment technologies for effluents has gained popularity in recent days and especially constructing these treatment systems comprising of Reeds at the site of generation of these effluents has turned out be a handy option (Burgoon 1995, Griffin and Upton 1999). These treatment systems are mainly categorized into two types i.e., open system and closed system. The former system allows the wastewater to be exposed to the atmosphere and the later system is constructed in a manner that the wastewater will flow below the bed layer via a medium that is permeable and thus it is not exposed to the atmosphere (Reed 1995). The former systems are constructed in a manner so that they can range from 0.2 to 0.8 meters and can have a depth of 0.5 meters. The system naturally promotes habitat for other species and provides essential nutrients for the plant growth. The levels of oxygen are naturally maintained in the system therein (Kadlec and Knight 1996). The later systems are 0.8 meters deep with porous media through which wastewater will flow and simultaneously get treated as represented in the below figure 18 (Reed 1995).
Generally, the later systems are superior to the former systems as it has more area to treat the wastewaters and as the area is large more microbial communities can dwell and effectively control the treatment process. As the system is not exposed to atmosphere there are no chances of mosquito breeding and creates less environmental pollution. Also, there is negligible emission of foul smell to be generated and is not fatal to nearby locality (Cooper 1996). Moreover, the system is least affected by the variations in the ambient temperature so the processes therein can function smoothly without any interference of outside hindrances (Hill 1998, Kadlec 1996). The pollutant removal processes operating within Reed beds can be controlled by variety of parameters like type of Reeds planted, incubation time and prevalent climatic conditions. Previous research of comparing systems of Reeds with planted and unplanted types had indicated that the planted wetlands are superior in wastewater treatment. This is due to the environment that is created therein by microbial community (Tanner 1995, IWA 200, Brix 1994). They create appropriate levels of oxygen within the system and remove the contaminants (IWA 2000). The main benefits gained from planted macrophytes within Reed beds are summarized in the following table 12. The major advantage of planting these macrophytes within Reed beds is that they increase the overall aesthetic value of the treatment system.
Table 12: Key functions of Macrophytes in Reed based systems (Adapted from Brix 1994)

<table>
<thead>
<tr>
<th>Component</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macrophytes part protruding outside</td>
<td>• Protects system from climatic variations</td>
</tr>
<tr>
<td></td>
<td>• Increase overall aesthetic value</td>
</tr>
<tr>
<td></td>
<td>• Contain nutritional constituents</td>
</tr>
<tr>
<td></td>
<td>• Excess water if present therein can be evaporated</td>
</tr>
<tr>
<td>Macrophytes part beneath ground level</td>
<td>• Maintenance of appropriate anaerobic conditions for decontamination</td>
</tr>
<tr>
<td></td>
<td>• Nutrient utilization</td>
</tr>
<tr>
<td></td>
<td>• Toxic components excretion</td>
</tr>
</tbody>
</table>

Prior art search: Reed bed technology

Since long there has been worldwide attempts made to develop and effectively use Reed bed technologies for multi-purposes. In the year 2001, Fisher et. al. had studied on the phosphorous levels that were discarded by long term stored effluents of a typical Reed bed system and had indicated that these nutrients help maintain the natural nutrient cycles that are prevalent in the natural ecosystem and facilitates the nutrient balance. Their results confirmed that these levels of phosphorous that were discarded had a correlation with the levels of utilized oxygen within the system. The next year, Alain Lienard (2002) had studied on the aspects of constructing a filter based on Reeds that can treat wastewater after the parlors are washed and had recommended that a process combining septic tank and Reed bed filters can be a technical solution for washing parlor effluents. Moreover, if it is close to the farm than a surface of 2 to 3 m² per milk cow and with a natural slope of at least 2.5 m between inlet and outlet can be available. It was concluded that this solution is less expensive than storage, land spreading, especially when there are no other liquids to dispose of in the farm. Furthermore, Mamdouh S. Serag (2003) had indicated the importance of *Cyperus papyrus* L. for containment of papyrus. Their studies had helped the planning of using papyrus for making of paper and clean energy solutions. During the same year, Nathalie vaillant (2003) had studied on the construction of Hydroponics utilizing *D. Innoxia* and proved that the system can be effectively used to treat wastewater from different origins. During their experiments source of nutrients for plant growth were naturally provided by the wastewater. The following year, Zhao Y.Q. (2004) had developed...
a model that used Reeds as planting materials for construction of treatment systems for wastewater from cattle and had proved that their model had removal efficiencies of high grade and are more or less superior then that from mono-sized systems that were conventionally practiced at that time.

In the year 2007, M.M. Zhang Bao-hua had studied the treatment of effluents by Zeolites. These Zeolites were mainly obtained after processing fly ash wastes that is generated from the thermal power plants. Their experiments confirmed that these Zeolites can be effectively used to treat a variety of effluents. The next year, I.H. Farooqi (2008) had studied the artificial treatment systems based on Reeds for treating effluents and had reviewed the different types of artificial systems employed in treating effluents including its application as a polishing unit. They had also recommended the optimum parameters for the maintenance of this system. Moreover, Vijaya Tartte et. al. (2010) had done analysis of variations in efficacy of two biofertilizers formulated from cyanobacteria to treat effluents from households and had indicated that household effluents serve as excellent media for microbial growth like *N. muscorum* and *A. variabilis* that can be adopted for the formulation of biofertilizers. The same year, K. Kato (2010) had studied on the construction of a treatment systems based on Reeds that best suited low temperature climatic conditions and had got positive results. Recently, Dandigi M. N. (2011) had studied construction of treatment systems based on Reeds to treat the holy Ganga and had recommended that Reed bed waste water treatment systems would be very effective in tropical nations. They had suggested that the performances are better at lower depths of 0.3 meter in wetland systems and it will result in efficient removal of both pollutants and nutrients. Moreover, pathogenic bacteria removal efficiency was also observed good. During the same year, C. Kinsley (2011) had studied on septage treatment using Reed bed filters and had proved that Reed beds can dewater cum treat septage under Canadian climatic conditions. Moreover, the filtrate quality was observed to be similar to a low-strength domestic wastewater and the developed Reed beds can be operated by independent septage haulers, as a regional treatment facility or as a dewatering technology at a municipal WWTP. Thus, as per the prior art search done, there was a need of further research on Reed bed technology development for effectively treating and managing solid and liquid effluents. Therefore, present study had focused to develop Reed beds during the third phase. Thus, it was envisaged that the developed Reed bed will serve as dual purpose of management of solid wastes and treating wastewater.