Annex C – Technical Evaluation

CHENGDU FEASIBILITY STUDY

Digestion of Municipal Solid Waste

Technical Evaluation

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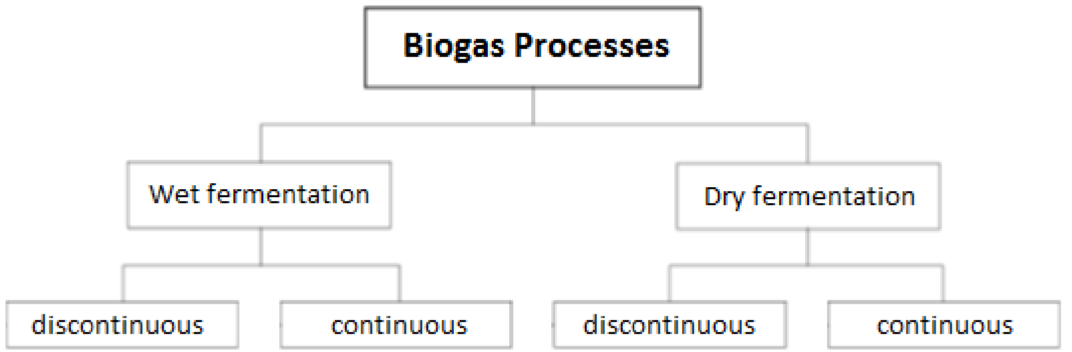
List of Abbreviations

AD	Anaerobic Digestion
CSTR	Continuously Stirred Tank Reactor
CHP	Combined Heat and Power plant
CMB	City Management Bureau
MBT	Mechanical Biological Treatments
MSW	Municipal Solid Waste
NGO	Non-Governmental Organization
OFMSW	Organic Fraction of Municipal Solid Waste
TS	Total Solids
VS	Volatile Solids

1. BASIC DIGESTION SYSTEMS

A large number of different types of feedstock are processed by anaerobic digestion like agricultural substrates (manures and residues), industrial and restaurant wastes as well as market residues and sewage sludge. The treatment OFMSW is among the most challenging feedstock because it presents very variable composition and contains physical impurities. In consequence, digestion systems for OFMSW need to be specially designed for this purpose and must include a pre-treatment technology, for separating organic digestible material from disturbing components. The technology of the separation and digestion unit needs to be adapted to the specific waste composition arriving at the biogas plant.

The systems that are technically proven follow a few basic designs: Wet or dry, batch or continuous, single or two-step.



Independent of the system applied, two basic conditions have to be fulfilled:

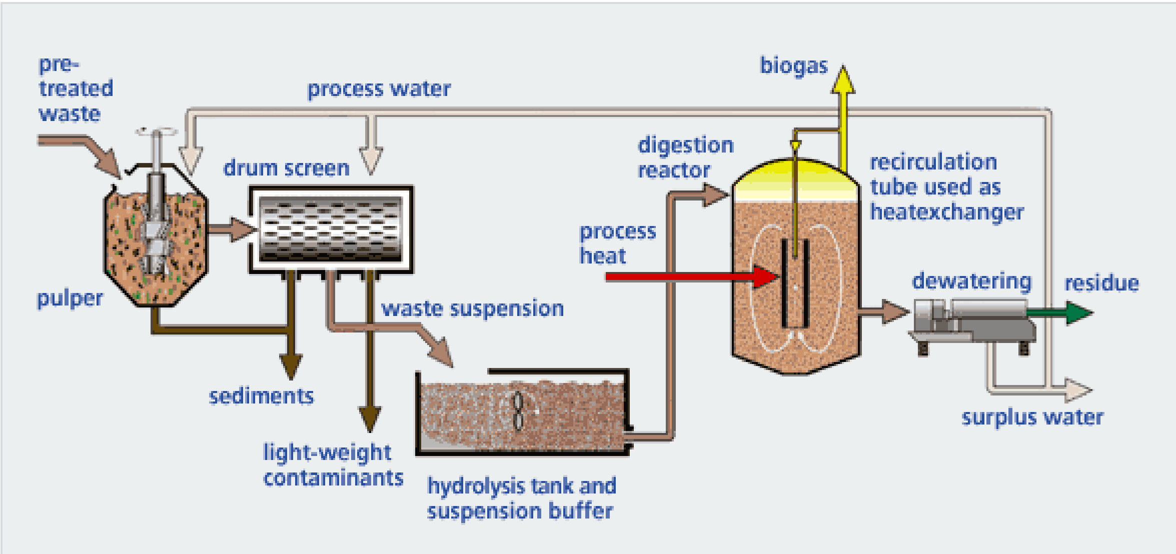
- The equipment has to be robust and withstand heavy abrasion
- Operators have to be well trained (key to success)

1.1 Wet (liquid) digestion systems

In wet digestion systems, the fresh substrate is slurried with a large portion of recycled process water to provide a dilute feedstock that can be pumped into a completely mixed tank reactor (CSTR). At the same time the liquid serves as inoculum.

One of the major problems in wet systems is the formation of sediments by sand and gravel because in dilute liquids the strong sedimentation takes place by gravity. There is also a high potential of scum formation in CSTR's if fibrous material is used as substrate. In other words, mixing of wet OFMSW digesters is a difficult undertaking. At first glance, the wet system appears attractive due to its seemingly simple design and because of its similarity to the well-known sewage sludge digesters. The physical consistency of organic solid wastes is made to resemble that of sludge, via pulping and slurring to less than 15 % TS with dilution water, so that a classical complete mix reactor may be used.

Some providers dissolve the solid waste first before it is separated others do the separation first. In Mechanical Biological Treatments (MBT) with non-separated waste it is recommended to separate first before liquefaction.



Pre-treatment and liquefaction of source separated waste

If not carefully separated and pre-treated upfront, liquefied wastes do not keep a homogenous consistency because heavier fractions sink and a floating scum layer of light material like fibers or plastic may be formed during the digestion process. As a result three layers of distinct densities, or phases, are formed in the reactor. The heavies accumulate at the bottom of the reactor and may form sediments hard like concrete while the floating layer may hamper effective mixing and gas release. It is therefore mandatory to install efficient pre-treatment steps to remove the light and heavy fractions from the material. Since sand does also damage pumps, it must be removed as much as possible before it enters the reactor.

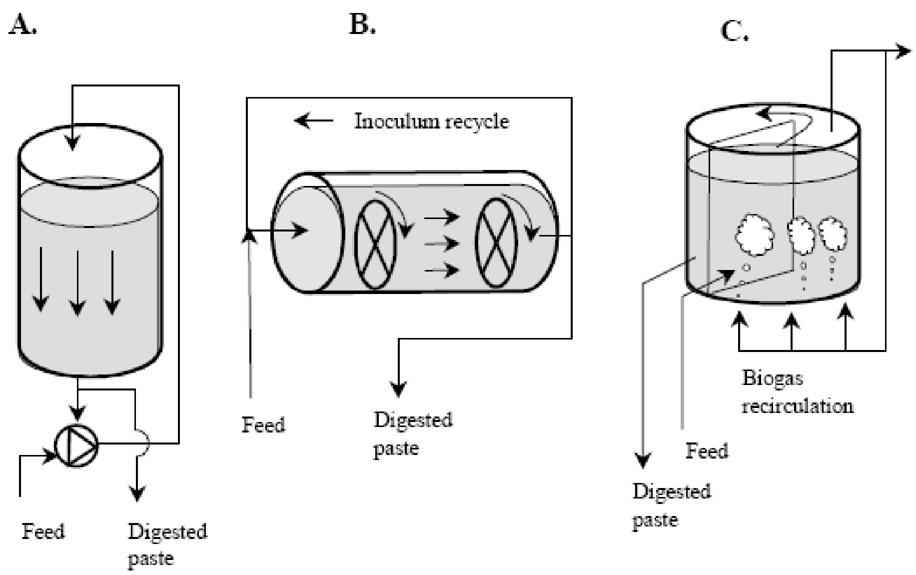
1.2 Dry continuous digestion

In dry digestion systems, the substrate within the reactor is kept at a solid state, i.e. in the range of 20 - 40 % dry matter. Only very dry substrates (≥ 50 % TS) need be diluted with recycled process water. The physical characteristics of the wastes at such high solids content impose technical approaches in terms of handling, mixing and pre-treatment which are fundamentally different from those of wet systems. Transport and handling of the wastes is carried out with conveyor belts, screws, and powerful pumps especially designed for highly viscous streams.

Most of the systems are far more tolerant to impurities such as gravel, glass or wood chips. In MBT pre-treatment by removal of the coarse impurities larger than 40 or 60mm is necessary. This is typically accomplished via drum screens often followed by hand separation.

Because the systems are more tolerant than their wet counterparts, they are very attractive for the digestion of OFMSW, which typically contain up to 25 % by weight of heavy inert material. However for MBT the difference in pre-treatment is marginal.

The different digester designs used in 'dry' continuous systems are illustrated in the figure below (A. illustrates the Dranco design, B. the Kompogas design, and C. the Valorga design). Due to their high viscosity, the fermenting wastes move via plug flow inside the reactors.



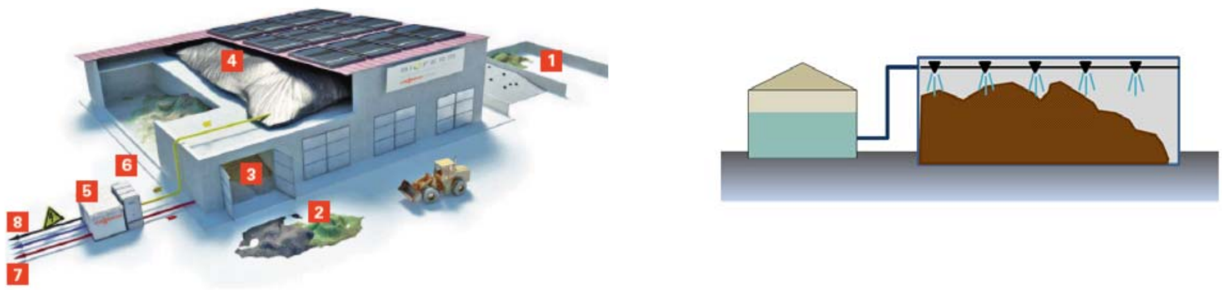
Digester designs of dry continuous digesting systems

The downflow system of Dranco is not suited for unsorted waste and has therefore no experience. The Valorga system has not proven successful with Chinese waste. Two installations built in Beijing and Shanghai are still not operational after more than two years.

1.3 Dry batch digestion systems

Dry batch digestion systems are characterized by garage-shaped digesters. The substrates are chopped and separated from impurities, before being mixed and inoculated with digested material on an indoor preparation area. Preparation as well as filling and emptying of the fermentation containers are done by wheel or front loaders. During the digestion cycle, a percolation system is keeping the feedstock wet and allows distribution of the microbial community. The liquid is recycled through a heating device to maintain temperature in the digester.

Usually, multiple digesters are combined into one block and can be operated with time lags in batch operation. This allows relatively constant overall gas production. The modular construction with multiple digesters let the plant be expanded at any time if the capacity needs to be increased at a later stage.



Schematic view of a garage system (four parallel digesters)

2. SYSTEM APPROACH IN CHENGDU

The choice of a specific system is always a long and difficult process even in Europe, where the composition and the physical, chemical and biological parameters of the waste are very well known. The evaluation is even more difficult in Chengdu where very little is known about the waste composition, not to talk about the experience of sorting and digestion.

In a very short period of time we had to gather all information available throughout China on the waste parameters. At first we got in contact with German colleagues working in China for quite some years already in the field of AD. Locally, we had the support of Roots and Shoots, a befriended NGO. But more important, we led a large number of discussions with the top waste scientists in China and with officials of Chengdu administration. Their help was invaluable even more though as they allowed us to get in contact with people working in the field:

- Community (neighborhood) waste collection
- Compression station
- Landfill site
- Steel tank manufacturer

We were also happy to have contacts to the University of Sichuan, who analyzed the different waste samples that we have collected while visiting points of the waste chain.

Based on these facts we gathered, we selected the systems recommendable for the construction of a MSW digester. The criteria we applied were:

- Waste composition (wet and dry fraction)
- Dry matter (TS) and organic content (volatile solids; VS) of the wet fraction
- Tolerance to sand and/or removal of sand
- Availability of material and mechanical equipment in China
- Availability of motors and engines close to Chengdu if service is needed
- Integration into the existing waste system
- Flexibility to future developments

Taking all these parameters into account we were not yet able to come down with one single best option. Two basic processes are still under consideration: Garage System and a Continuously Stirred Tank Reactor (CSTR). As a further option a horizontal plug-flow working also with low dry matter contents is still on the radar. The final decision depends mainly on economy and availability of equipment and service.

2.1 Flow chart of Chengdu MSW digestion: Type CSTR

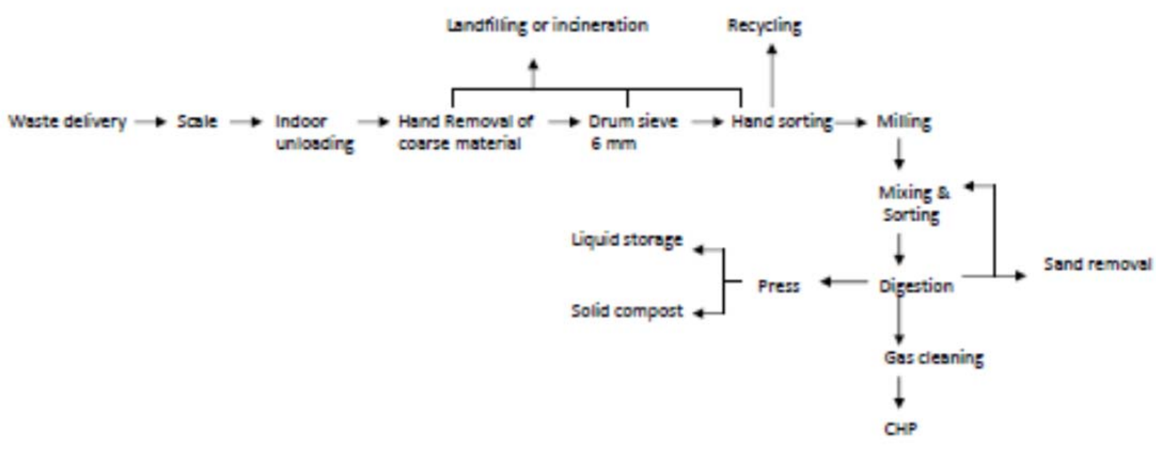
The un-compressed waste is delivered by a truck of the CMB, passes over a scale and unloads the waste in a closed reception hall. With a front loader it is slightly distributed and the coarse parts (especially iron and stones) are removed by hand. The waste is then placed along the walls and subsequently fed into a bag opener and into the drum screen. The overflow falls into a container going to incineration (it has a high energy content of >10 kJ/kg), the wet fraction passes over a sorting table where unwanted particles (mainly paper and plastic) are removed by hand. The working place is properly aerated.

After sorting, the organic fraction is transported into a chopper or a mill and falls into a tank where it is mixed with recycled digestate and – depending on the dry matter content – further diluted by press water. After mixing the raw substrate is fed into the digester. Digestion completed material, called digestate is transported by conveyer belts to a press where the solid and the liquid digestate are separated. The liquid fraction is partially recycled into the mixer where as the large bulk will be removed by truck and used as liquid fertilizer either directly on the fields or, after dilution, used in parks for flower fertilizer.

The solid fraction is either used directly on the fields, or after a post-composting phase and wind sifting as substrate for pot plants or in parks.

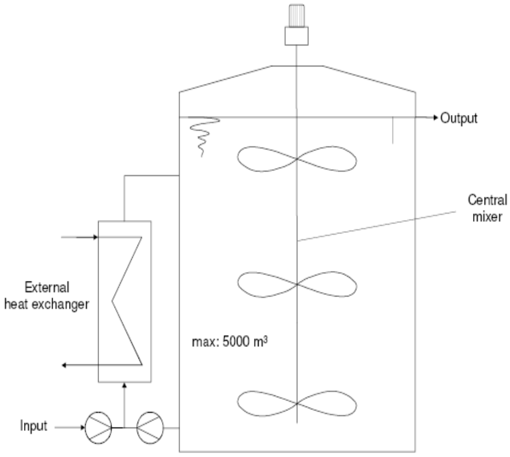
The biogas is cleaned (removal of water and hydrogen sulphide) and used in a combined heat and power plant (CHP or co-generator) producing electricity and heat. The electricity is fed into the grid while the heat has most probably to be vented off unless there would be an industrial application.

Flow chart of Chengdu MSW digestion: Type CSTR



2.1.1 Option 1: Vertical cylindrical CSTR

The vertical digester can be built in steel or concrete. It has a central mixer. The design is simple and straightforward. It resembles the large-scale anaerobic digesters in agriculture that are well known in China. The disadvantage is that the material has to be chopped very fine and has to be diluted down to < 12% dry matter content. Because the substrate is highly diluted, a lot of sand will settle during digestion and needs either a mechanical removal or the digester has to be emptied once a year and the sand removed.



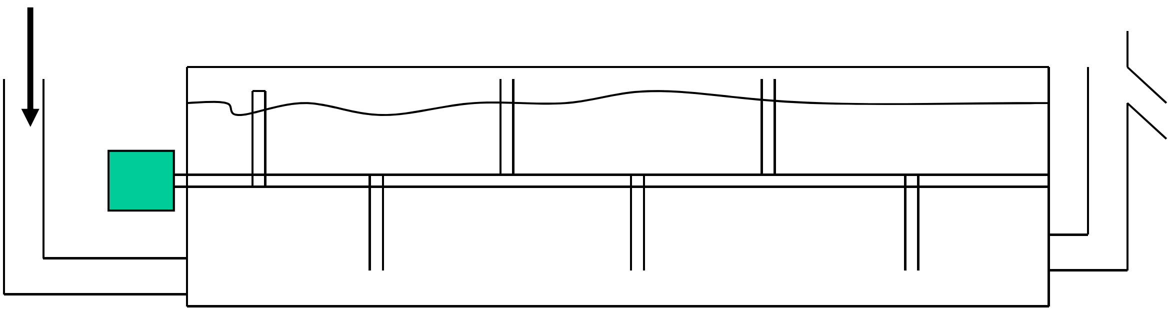
2.1.2 Option 2: Horizontal semi-plug-flow digester

Horizontal digesters are known for both, liquid and solid substrates. The design is virtually the same.

They belong to the oldest digester design developed in the fifties of last century, formerly called

" Braunschweig System". Today they are applied in both agriculture and municipal solid waste.

The advantage is that they are not critical to sand as it can be removed together with the waste. Because they can handle solid and liquid waste they would be well suited for the wet waste in Chengdu. The waste would not have to be chopped finer than 400mm. However, the construction requires high technical design and skills for the construction and is rather expensive.



2.2 Flow chart of Chengdu MSW digestion: Garage system

The un-compressed waste is delivered by a truck of the CMB to the site, passes over a scale and unloads the waste in a closed reception hall. With a front loader it is distributed on the ground and the coarse parts (especially iron and stones) are removed by hand. The waste is then placed along the walls and subsequently fed into a bag opener and the drum screen. The overflow of the screen falls into a container going to incineration (it has a high energy content of >10 kJ/kg), the wet fraction passes over a sorting table where unwanted particles (mainly paper and plastic) are removed by hand. The working place is properly aerated.

After sorting, the remaining fraction is transported into a hammer mill. Following, the raw substrate is fed by a front loader into the digesters and mixed with a part of the digestate. After closing the doors, heated percolate is sprayed over the material for additional inoculation. The gas phase will be inertized with recycled off-gas from the CHP.

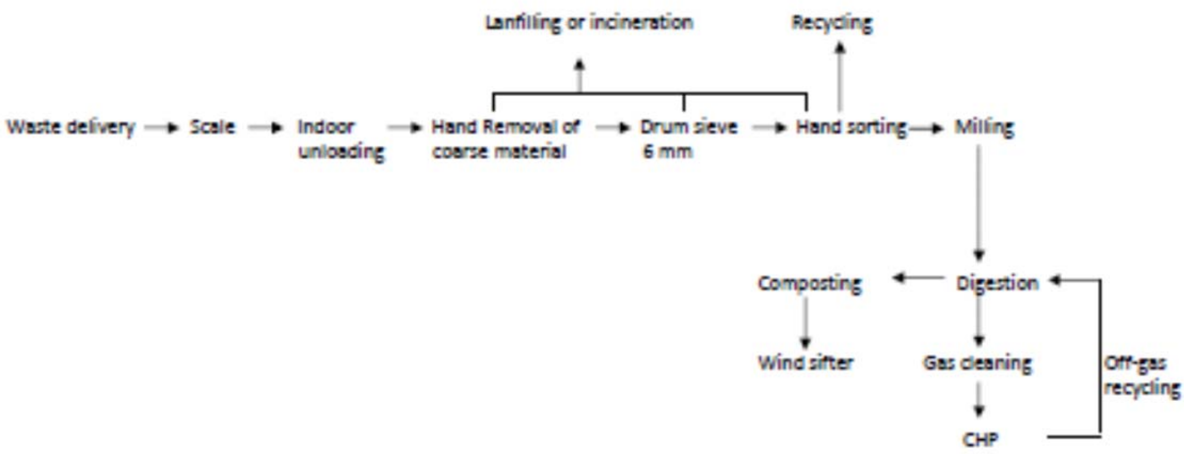
Once the digestion process is completed, the digestate is removed and composted. After maturation, the remaining plastic and paper will be removed by an air classifier.

The excess liquid fraction is removed by truck and used as liquid fertilizer either directly on the fields or, after dilution, used in parks as flower fertilizer.

The compost is either used on the fields or as substrate for pot plants or in parks.

The biogas is cleaned and used in a combined heat and power plant (CHP or co-generator) producing electricity and heat. The electricity is fed into the grid while the heat has most probably to be vented off unless there would be an industrial application.

Flow chart of Chengdu MSW digestion: Type Garage system



3. CONSTRUCTION SITE

The digestion plant will be a demonstration unit corresponding to a medium scale installation in Europe, i.e. of industrial scale but still small in comparison to the sizes needed to replace land filling by 100% as has been expressed by the Chengdu government.

The plant will be able to treat 20,000 tons per year (tpy). Ideally, it should be placed adjacent to or integrated into a compressing station to create a win-win situation.

Integration would save cost:

1. The waste arrives by truck in a loose form before compression, a part of it could be deviated for anaerobic digestion
2. There is no additional transport cost because the trucks carry a same amount of waste anyway
3. The same scale can be used
4. The management is the same and office space is available

5. The electricity produced can be used to operate the compression plant
6. There is no need for a treatment of the press juice from compression. The juice is an excellent source of for biogas production
7. The amount of material going into compression is reduced
8. The heating value of the dry fraction is considerably increased which is a valuable asset for incineration

However, it is precondition that in the vicinity there is still space available. A 20,000 tons per year plant would typically need 5000 m^2 or ½ hectare of land. If the material is composted it would need another 1000m^3 to 3000m^3 of land. However, composting can be done near the place of the compost's utilization.

4. DESIGN DATA

4.1 Continuous Flow System

		12,000 tons per year			24,000 tons per year		
	Topic	**Unit**	**Amount**	**Remarks**	**Amount**	**Remarks**	**30d HRT**
1	Input MSW	tpd	35		70		70
2	Input MSW	tph	2.2	16hr; 2 shifts	3	24hrs; 3 shifts	3
3	Wet fraction [80%]	tpd	28		56		56
4	Wet fraction [80%]	tph	1.8		2.4		2.4
5	Dry fraction to incineration	tpd	7		14		14
6	Density wet fraction	kg/m3	0.79		0.79		0.79
7	Volume of wet fraction	m3/d	35.4		71		71
8	HRT	d	25		25		35
9	Digester volume gross	m3	1063		2130		2982
10	Digester volume net	m3	886		1775		2485
11	Digestate liquid (after press)	m3/d	20	70%	39	70%	39
12	Digestate solid (after press)	tons/d	8	30%	17	30%	17
13	Digestate solid (density 0.5)	m3/d	17		34		34
14	Surface of closed composting	m2	75	3m high & wide; 20d	149	voluntary	149
15	Surface of open composting	m2	336	90d	672		672
16	Gas production	m3/d	2240	80m3/t wet	4480		5040
17	Electricity production (nü=35%)	kWh/a	1'540'000	5.5kWh/m3	3'080'000		3'080'000
18	Process Energy	%	20			15	
19	Electric power	kW	203	7600 hrs/a	405		405
20	Dry matter	%wet	25		25		25
21	Organic matter	%TS	88		88		88
22	Loading rate	kg/m3*d	0.9		0.9		0.9

4.2 Garage (Batch) System

		12,000 tons per year			24,000 tons per year	
	Topic	**Unit**	**Amount**	**Remarks**	**Amount**	**Remarks**
1	Input MSW	tpd	35		70	
2	Input MSW	tph	2.2	16hr; 2 shifts	3	24hrs; 3 shifts
3	Wet fraction [80%]	tpd	28		56	
4	Wet fraction [80%]	tph	1.8		2.4	
5	Dry fraction to incineration	tpd	7		14	
6	Density wet fraction	kg/m3	0.79		0.79	
7	Volume of wet fraction	m3/d	35.4		71	
8	HRT	d	35		35	
9	Inoculation	%	50		50	
10	Total digester volume gross	m3	2532		5064	
11	Size of digester	m [W*H*L]	6x6x17.5		6x6x20	20.1
12	Number of digesters	-	4		7	
13	Digester volume gross	m3	633		723	
14	Digestate liquid (after press)	m3/d	15	55%	31	55%
15	Digestate solid (after press)	tons/d	13	45%	25	45%
16	Digestate solid (density 0.7)	m3/d	18		36	
17	Surface of closed composting	m2	1941	3m high& wide; 10d	3858	voluntary
18	Surface of open composting	m2	1134	90d	2268	
19	Gas production	m3/d	1960	80m3/t wet	3920	
20	Electricity production (nü=35%)	kWh/a	1'540'000	5.5kWh/m3	3'080'000	
21	Process Energy	%	10		10	15
22	Electric power	kW	203	7600 hrs/a	405	
23	Dry matter	%wet	25%			
24	Organic matter	%TS	88%			
25	Loading rate	kg/m3*d	-			