ACTIVITIES TO APPLY THE EUROPEN EXPERIENCE ON ANAEROBIC DIGESTION OF BIOORGANIC MUNICIPAL WASTE FROM SOURCE SEPARATION IN CHINA

THE SINO-GERMAN RRU-BMW PROJECT IN SHENYANG

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Summary

To tackle solid waste disposal problems and its negative impact to the environment EU countries are applying, based on the 'EU Directive on land filling of waste, CD1999/31/EC', a stringent bioorganic waste management policy (BMWM) within their national legislation. Biogas from organic wastes is already one of the major sources of renewable energy in EU countries. The EU biogas production from anaerobic digestion in 2002 amounts to 2,762,000 tons oil equivalent.

The Sino - German cooperation project on 'Resource Recovery and Utilisation of Bioorganic Municipal Waste, RRU-BMW' in Shenyang, is aiming to develop the basis to employ appropriate AD technologies for 'clean renewable energy' production and to produce 'clean compost' for land application in China. The project provides information about the attitude and behaviour of the population towards participation in source separation of BMW, is analysing different ways of BMW collection and carries out field- and lab-tests to assess quantities, qualities, biodegradability and the pollution level of biogas and compost. BMW will be collected in 4 different pilot areas and the investigations include the utilisation of remaining waste (RMW) with an increased calorific value.

The feasibility to further introduce anaerobic digestion of urban bioorganic wastes will depend on the availability of economic instruments such as the introduction of 'waste fees' (ongoing since 2002 [4]), the planned stepwise allocation of 2 % of China GDP for environmental protection, the success applying the CDM mechanism and emission trading and the enforcement of supporting policies on renewable energy.

MSW Generation in China

2003 in China 146 million metric tons of Municipal Solid Waste collected in 660 cities from about 26 % of the total population (see Figure 1) [1]. The amount of waste is constantly increasing (5 – 7 % p.a) due to the urbanisation process and as collection rates are growing. Food wastes from restaurants (estimated quantity in Beijing only is about 1,200 t/d), market waste and organic waste from industry and sewage sludge are additional valuable sources for biogas production. Some Chinese cities, such as Beijing, Shanghai, Shenzhen, Nanhai, Guangzhou and Heng County in Guangxi [2] are considering the treatment of organic wastes (in parallel to MSW incineration and landfilling), and for most of the other cities anaerobic digestion of BMW might be appropriate to solve waste disposal problems and to provide clean resources and renewable energy.

The specific MSW production relates to 0.8 - 1 kg per capita and day (or about 300 kg/c.a), but only about 50 % of the collected waste is disposed of in controlled landfills, from which a small number, (such as in Beijing, Wuhan, Guangzhou) have an operating landfill gas collection and utilisation system. Up to 80 % of MSW (in the average 66 % FM, analysis from 27 cities during the last 10 years [3]) is bioorganic material, which is causing the problems during landfilling and incineration. About 5 % of the collected MSW is incinerated in 2003 (e.g. in Shanghai, Beijing, Hangzhou and Shenzhen), with an increasing tendency. But these facilities are working inefficiently due to the low calorific value (BMW contains 80 % FM water). Another 7 % are treated in MSW composting plants from which the compost is not accepted due to contamination and high ballast mater content. But still more mixed waste composting plants are going to be built.

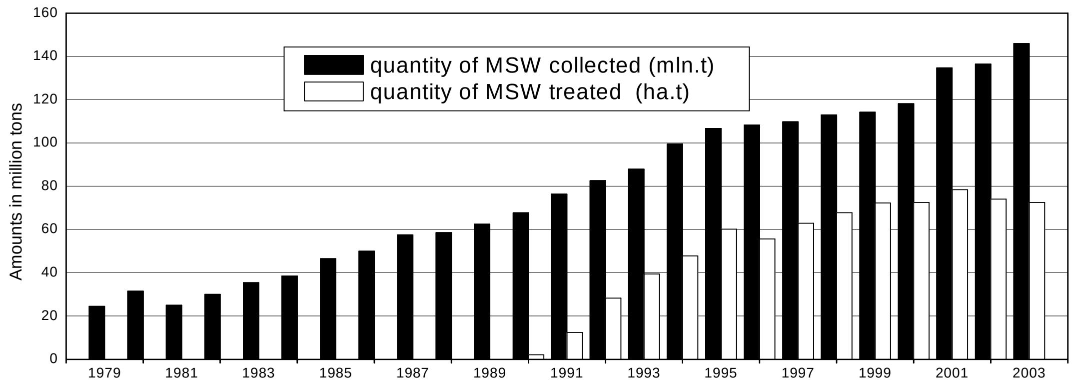

Figure 1: *MSW collection and controlled disposal in China, 1979 to 2004 (source ESETRC-MOC) [1].*

Source Separation of BMW - Pilot Projects in China

Chinese authorities have the unanimous opinion that the population is not able to separate the waste at the source, as it was introduced in Europe 10 years ago and they still rely on 'future' technologies to separate the mixed waste by mechanical sorting, which failed in the western countries already since 20 years (Vienna/AUT, Herne/GER, France). The newly developed high-tech technologies using x-ray fluorescence spectrometer, infrared sensors, optical and other physical identification techniques are mainly used to detect and sort recyclable materials or to improve their purity after collection, but they are not sufficiently proofed for MSW and anyway it will be a question of costs to apply this techniques in China. The contribution of the general public to separate their waste at the source is required to implement a cost effective waste treatment system, which complies with the objectives of the recycling economy model of China.

Separation projects in China so far are focusing on recyclable materials, but from various reasons they have failed (lack of public information, lack of treatment plants and the informal sector is too strong in this sector). Only one Project in Heng county Guangxi is collecting BMW from 15.000 households and und producing clean compost since 2002 [2]. The pilot activities on source separation of BMW by the RRU-BMW project were started in 2004. The pilot areas were selected jointly with Green Liaoning NGO, the district EPBs and construction administration, considering different social living standards, different geographical areas in Shenyang (2 districts), and different approaches to segregate the waste. The positive feedback from the participating households in Huanggu district has motivated the District Government and even the management of other residential communities to request for an extension of the pilot areas.

BMW Quantity and Quality

The BMW collected via primary source separation (PSS) during the first 6 months from 505 persons (97 % participation) amounts to 79 kg/c.a (61 – 102 kg/c.a). By PSS 83 %m/m of the wastes are collected as BMW, and by secondary separation (SSS) 73 %. The content of ballast matter of the PSS BMW is with 2.7 % FM more than that from SSS BMW (1.6 % FM) where the worker are only pick visible clean BMW. Table 1 provides the detailed information about BMW and RMW quantities and the projected annual per capita amounts after 182 days [8].

Table 1: *BMW and RMW quantities collected during 6 months from pilot areas in Shenyang, 2005*

14-03 till 11-09-05	**Persons in pilot areas**	**BMW**			**Non BMW**	**RMW**		**MSW**	
(182 days)	**[n]**	**[kg]**	**[kg/c.a]**	**[%m/m]**	**[%m/m] n=3**	**[kg]**	**[%m/m]**	**[kg]**	**[kg/c.a]**
Primary Source Separation – PSS									
Beifang Yiyuan	155	7575	98		2	1436		9011	117
Van Ke	143	4759	67		3.4	772		5532	78
Quan Yuan	207	7342	71		2.7	1847		9189	94
TOTAL PSS	505	19676	**79**	***83***	**2.7**	4055	***17***	23731	**94**
Secondary Source Separation - SSS									
Dong You	180	6574	73	*76*	1.6	2098	*24*	8672	97

Impact of the Type of Separation

Clean biowaste is a prerequisite to a complete environmental sound utilisation. The advantages of PSSS are the higher amounts of BMW collected (+12 %), the lower heavy metal contamination, the significant higher heat value of the remaining waste (2.5 times), the better acceptance of the participants and the fact that there are no additional permanent costs for separation work, although there will be expenses for public information campaigns to introduce and maintain this new policy. Public awareness regarding waste quantities produced and the awareness to have a possibility to influence (later) the waste disposal fees by own behaviour is to be seen beneficial (PPP). The benefits from SSS are: a slightly better aerobic biodegradability due to a better structure of the feedstock, and a lower content of visible ballast matters. The information about both systems is shown in Table 2. The material – and energy flow of source separation from household MSW is, showing that 20 % of RMW (refuse derived fuel - RDF) contains 80 % of the Energy which can be used as a fuel by the industry.

Table 2: *Impact of primary and secondary source separation on the quality of BMW and other aspects in 4 pilot areas in Shenyang (3 – 8/2005).*

Criteria	[ ]	Primary Source Separation PSS	Secondary Source Separation SSS
Preference of Participants	%	**64**	12
Quantity of BMW	% m/m	**83 (+ 12%)**	74
	kg/c.a	**78**	66
BMW ballast matter	% m/m	2.7 (positive sorting)	**1.6** (negative sorting)
Heavy metals content	ppm	**low** (Zn 120, Pb 10, Ni 2)	high (Zn 220, Pb 28, Ni 22)
Heat value of RMW	kJ/kg FM	**16,446**	6,674
Composting (biodegradation)	-	-	slightly better
Biogas building potential	l/kg ODM	No differences expected, but still subject of further investigation	
PR & communication costs	-	required	**no**
Separation costs	-	**no –** by public participation	staff for manual sorting
Waste avoidance awareness	-	**high –** by public participation	low
Polluter Pays Principle (PPP)	-	applied on community basis	not easy applied
Recycling of packaging	-	**high** quality from RMW	Low efficiency from MSW

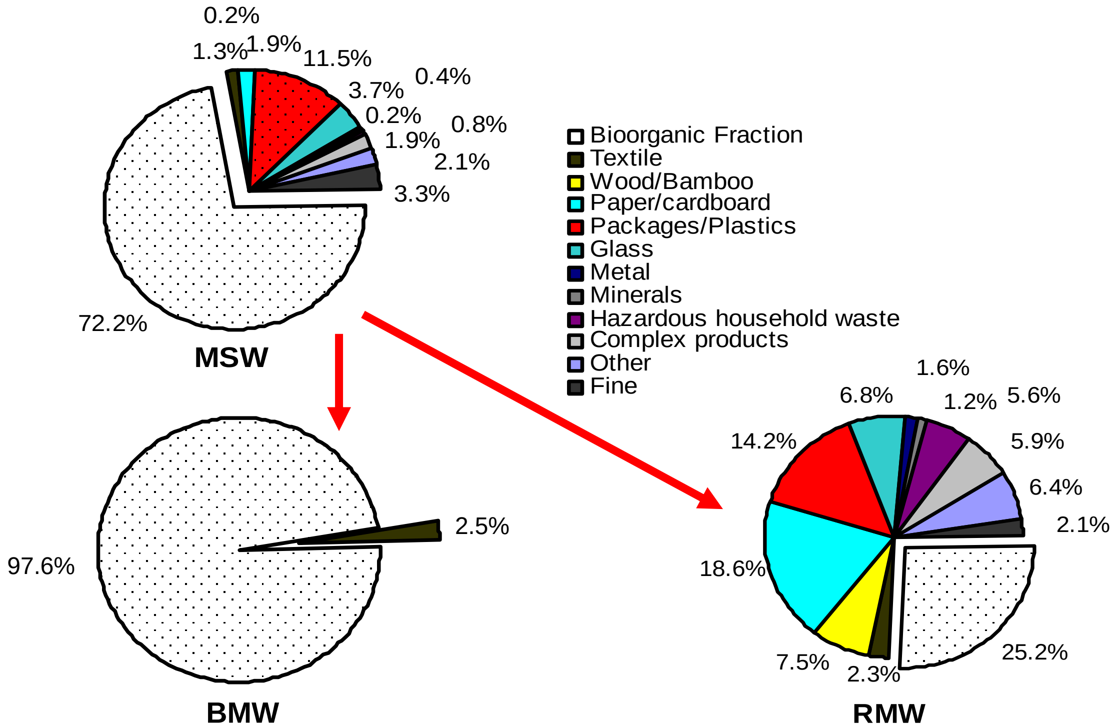

Figure 2: *Composition of wastes from the RRU-BMW pilot areas in Shenyang, MSW is diversified into RMW and BMW from PSS (April – September 2005)*

Biogas from BMW in EU

Biogas from mainly non-lignocelluloses biomass materials is one of the major sources of renewable energy as demonstrated f. e. in various EU countries (England, Germany, France, Denmark, Sweden, Finland, Netherlands, Austria, Switzerland, Italy, and Spain). The EU crude biogas production in 2002 amounts to 2,762,000 tons oil equivalent and the production took a 6.4% leap forward compared with the figures for 2001. Overall, the European Union counts 4,390 biogas plants in 2002.

The overall EU biogas sources are deriving 38 % from engineered landfills (which does not lessen the problem that only about 50 % of the gas generated from landfills can be collected), 33 % from sewage sludge fermentation at waste water treatment plants, 24 % from industrial organic wastes and sewage digestion, 2 % each from direct digestion from agricultural waste and from BMW and 1 % from other co digestion units. England is the number one country in Europe with 952,000 tons produced in 2002. Germany is found in second place position with 659,000 tons, recording a 9.8 % advance with respect to 2001. France holds a third place position reinforced by a 13.2 % growth rate with respect to 2001.

Biogas Production Potential from PSS BMW in Shenyang

The quantity of biogas, which is produced under anaerobic conditions from BMW source separation in the 4 RRU-BMW pilot areas, was investigated by applying a standardised and internationally proved methodology [7]. The CH_4 was analysed by GC-MASS. The tests were conducted over a period of 50 days, at 37 ºC. The course of biogas and CH_4 generation from pilot areas' PSS-BMW is shown in Figure 4 and 5. The net- biogas production ranges between 100 and 120 m^3 biogas per t of BMW feedstock, respectively the net-CH_4 production per ton of volatile solids (VS DM) was found to be in the average 455 Nm^3 (388 – 499), which is within the upper range of the anticipated amount of 200 – 500 Nm^3/t VS [7]. For further investigations and to simulate a full scale BMW process a 4 x 30 l AD simulation lab equipment will be operated during the 2nd half of the project.

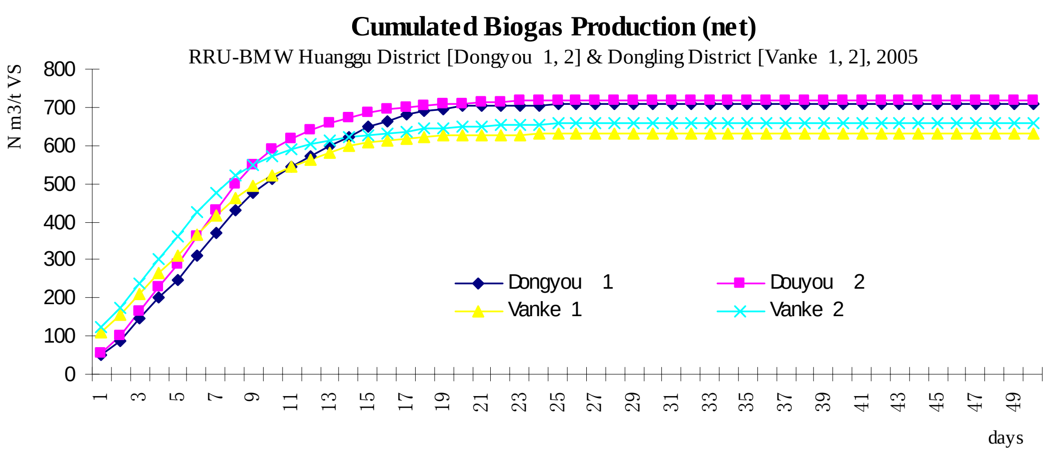

***Figure 4**: RRU-BMW Course of cumulated net--biogas production anaerobic fermentation, 37 ºC over 50 days, from BMW PSS in Beifang, Dong You and Van Ke pilot areas (09/2005), ICEEE Laboratory.*

The biogas from BMW can be generated under controlled conditions in anaerobic digestion (AD) plants. China is famous for applying small scale biogas plants in the rural areas in the south, were under suitable climatic situation about 7 million households can cover 60 % of their energy demand from their own BW resources. The provincial Government of Sichuan Province for example supported this development by providing financial subsidies to each farmer to install small-scale ADs.

But China has still limited experience with larger-scale biogas digesters for applications in the agricultural and industrial sectors, especially in the northern parts. The reasons for this are lack of technology, limited acquaintance with international best practices, low financial returns from small-sized biogas systems and so far lack of incentive policies to support increased biogas production. However large-scale anaerobic fermentation plants to produce biogas from BMW are so far not widespread (some industrial AD plants exist and new pilot projects using urban waste are ongoing in Guangzhou, Shanghai and in Beijing for restaurant waste). To manage the high amounts of waste from the cities and to cope with the climatic situation in North of China and to ensure an annual 8,000 hours operation more advanced technologies are required. These technologies can be adapted from EU where the production of biogas from all kind of BW during the last 20 years was applied and where biogas production is having a renaissance under the renewable energy policy.

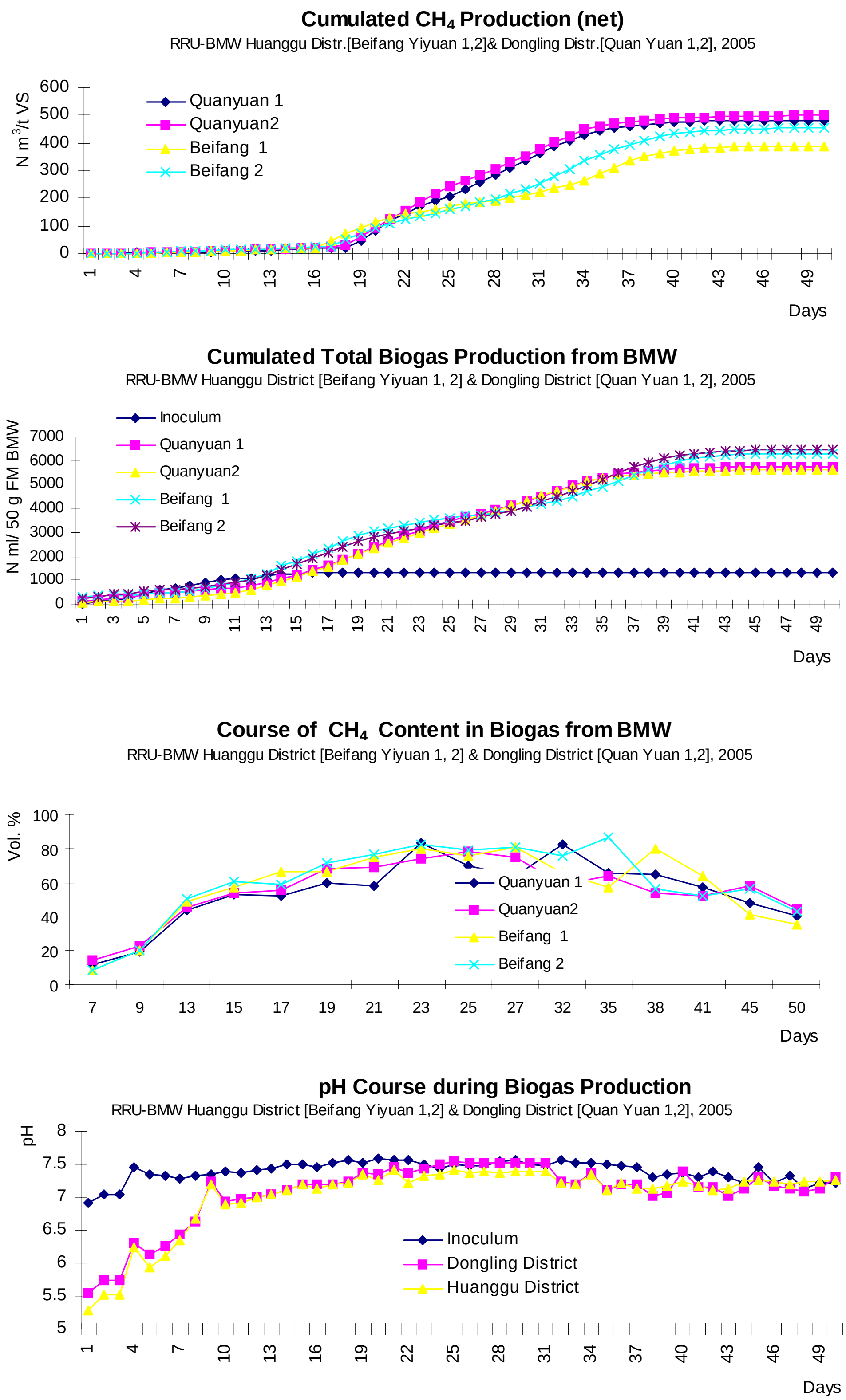

Figure 5: *RRU-BMW Course of cumulated net-CH_4 and net-biogas production, CH_4 content and pH (stabilisation with NH_4HCO_3) during anaerobic fermentation, 37ºC during 50 days, from BMW PSS in Beifang Yiyuan and Quan Yuan pilot areas (05/2005), ICEEE Laboratory.*

Advanced EU Biogas Generation Technology

Biogas from BMW and rural wastes can be one of the major sources of renewable energy as demonstrated f. e. in the Scandinavian countries (Denmark, Sweden, Finland, Netherlands,). For example Austria is operating 4 municipal level central technical biogas plants, producing about 6 million m^3 of biogas annually (app. 2 % of total biogas produced in Austria). One of these plants is the biotechnological treatment plant in Wels, where the following feedstock is treated: 1) yard waste and sewage sludge composting and 2) 10,000 t/a of PSS-BMW is generating annually 1 million m^3 Biogas and app. 5,000 tons of 'clean' compost.

Wels is a medium-sized city in Austria, which applied an advanced integrated waste treatment concept in 1996 to treat annually totally 185,000 tons of wastes. The facilities, especially the waste incineration plant with its 5-step flue gas-cleaning system, meet the highest environmental protection standards. Of the input material, 39 % is recovered as secondary raw materials such as paper, metals, wood, construction waste and compost and 36 million kW electric power is provided from waste incineration and biogas production. The biogas technology is based on a 2-step, liquid mesophilic anaerobic fermentation in a flow – trough, biogas mixed, vertical enamelled-steel fermenter (technology supplier Linde KCA, Germany). The other BMW AD plants in Austria are operated by Dranco technology from OWS/ Belgium (20,000 t/a) in Salzburg and Kompogas technology from Switzerland in Dornbirn.

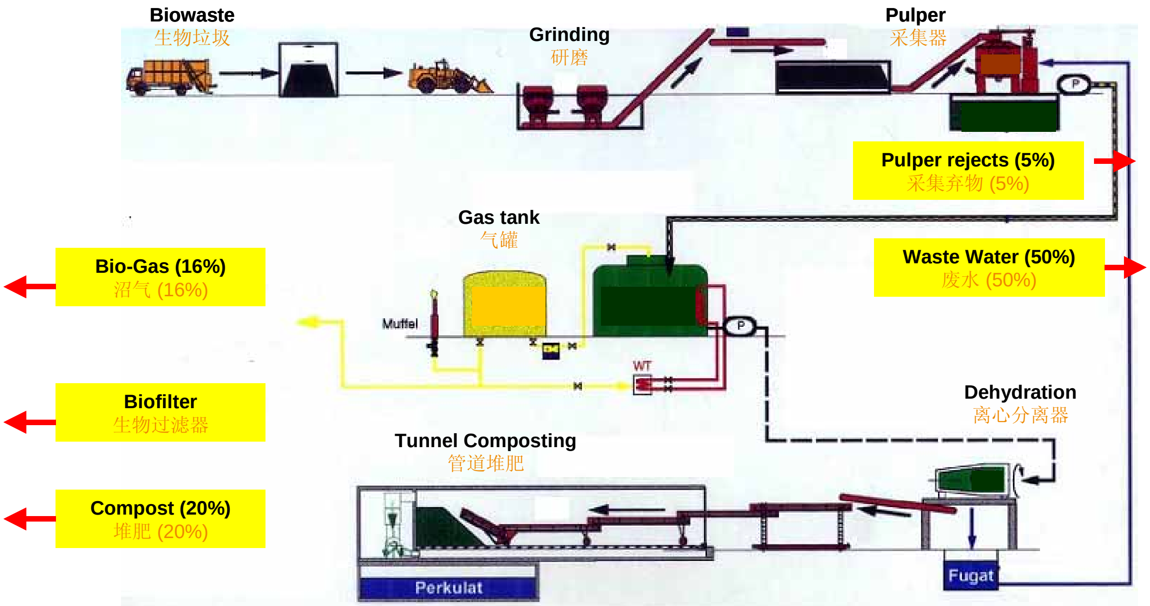

Figure 6: *Basic proposed system design of an AD plant for BMW processing and digestat composting for China.*

Why not Biogas from MSW?

MSW can basically be used for biogas production if the appropriate technology is applied. It is obvious to explain that the non-bioorganic content of MSW will reduce the specific gas yield and the demand for more mechanical processing is considerably higher. So far it is already well known all over China that compost from MSW cannot not (never) meet the requirements for 'clean compost' suitable for farming (food production) and landscaping under the aspect of sustainable soil protection. The technologies to generate the biogas from MSW are available. But in the concept for a proposed Shenyang BMW AD plant, MSW treatment will not be recommended, in order to sustain with one of the main objectives 'to produce clean compost' as the second valuable output fraction (MSW / BMW comparison in Table 3).

Biogas Utilisation

Biogas can be used in different ways; the main options are a) directly burning without major refining to operate gas boilers. Biogas can be mixed with natural gas and if a certain quality (constant heat value) is required cleaning of the biogas from anaerobic fermentation is required. b) for vehicle operation and c) for CHP generation in up to 2 MW gas engines. In order to receive the highest revenues for the energy the electricity might be directly used by the producer without being feed into the grid, or as nowadays applied in many countries, that renewable energy will have financial support legally enacted. For the best ecological performance the utilisation of the heat (about 50 % of the total energy) should be obligatory all over the year. From 100,000 t/a BMW (which might be the size of a reasonable pilot demonstration plant for Shenyang/China) about 12 (8-15) million m^3 of biogas will be produced from which 6-7 MW CHP gas engines can be operated to generate 2 MW Electricity and 4-5 MW heat [6].

Table 3: *Comparison of MSW and source sorted BMW fermentation showing similar gas yields but the solid output material compost from MSW is clearly contaminated with heavy metals [4].*

Type of Waste	**[ ]**	**MSW**	**BMW**
Fermenter (18 – 21 days)			
pH	-	7.0 – 7.2	
Organic load	kg/VS DM.m^3.d	7.5 – 9.0	
Biogas			
CH_4 content	%	54	56 - 62
CH_4 production	Nm^3 CH_4/t.VDM	210 - 240	200 - 250
Heavy metal content in compost			
Cd	ppm (mg/kg) DM	2 - 3	**0.5**
Cr		100 - 250	**23**
Cu		70 - 150	**27**
Hg		2 - 3	**0.1**
Ni		30 - 50	**7.6**
Pb		350 - 850	**67**
Zn		400 - 750	**190**

Ecological Benefits from Biogas Utilisation in China

Chinese municipal solid waste (MSW) contains in the average 66 % bioorganic matter. If this BMW is converted in to biogas (BG production average 100 m^3 per t/FM BMW) and the BG is utilised for energy production the following amount of standard coal can be replaced by renewable Energy:

- 0.95 % (based on the current waste quantity collected in Chinese cities 2003) and
- 2.77 %, average 1.86 % (based on the anticipated total BMW quantity in China)

In China 85 % of energy derives from coal burning by using 1,370 million t/a standard coal from which 85 % is used for energy production. Due to the lower CO_2 emission factor from Biogas combustion – related to the energy equivalent (heat release) produced from BG - 40 million t/a, resp. 117 million t/a of fossil CO_2 from coal (resp. 1.3% or 3.9% of total 3 bio tons CO_2 released from fossil fuel in China) can be replaced. The renewable CO_2 release from BG combustion amounts to 17 million t/a, resp. 49.8 million t/a (about a factor in China 2.35).

Table 4: *Estimation for BG production and biogas potential to replace coal energy equivalent in China*

Biomass for BG production	**Average Quantity estimation**	**Standard Coal-equivalent**	**Total Bio Gas**	
	[mill t FM/a]	[mill tce]	[bio m^3]	[% J/kg]
BW Municipalities	250	30	28	2.8
BW Industry	80	9		
Sewage Sludge	300	34		
Animal Manure	150	12		
Agricultural waste	620	75		
TOTAL	**1,400**	**163**	**145**	**14%**

If the BMW is not utilised to produce energy from biogas in controlled biogas plants the BG (60 % CH_4) will be released from microbial biodegradation from dumping and even from engineered land filling to the stratosphere. The ecological Green House Gas effect of CH_4 is about 25 times higher than that from CO_2 (one reason why land filling of BMW in the western countries is going to be banned, EU policy,). It can be calculated that the ecological effect of the CH_4 emitted by organic wastes (BMW) in China is equal to 29 % (current waste collected) resp. 86 % (based on total MSW/BMW produced) of the CO_2 released by coal combustion in China. Even landfill gas (LFG) collection would be applied all over China (gas collection factor at engineered LFs = max. 60%, estimation that 50% of LFs in China will be equipped with gas collection) and manure from domestic animal breeding, which amounts to 580 million t/a, equivalent to 130 million tons standard coal, and sewage sludge are other sources of biogas production. In total there are about 1.4 billion tons of biomass estimated, from 145 billion m^3 biogas can be produced, which would replace 14 % of the coal. Other dry biomass resources (straw, wood,) are considered for incineration or thermal utilisation and therefore not included in this calculation. To apply BG production in China will be beneficial to contribute to the Kyoto targets as well as to the policy to increase renewable energy.

Conclusions

Source separation of bioorganic waste is seen as an essential tool to further develop waste management practice in China. The ability of the population to carry out source separation of BMW (a key argument weather to go into this direction) could be proven with this project time first time in an urban municipal area during a 3 months period. The public acceptance towards BMW separation is high and the RRU-BMW project will follow up the people's attitude over a one year period.

Primary source separation by the participants in the households were analysed against the 'Chinese' approach to separate the BMW in a second step from already mixed MSW. Lower heavy metal pollution, higher quantities and a better quality of MSW are the arguments for introducing primary source separation which on the other hand requests for more visible support of the government for introduction and maintenance over a certain period. It is required to adapt this new practice into the daily people's behaviour, which usually takes some time. Within the RRU-BMW campaign the positive effect on the waste disposal costs was be communicated and the population will benefit if a future waste fee system considers the 'polluter pays principle' on a community level.

The BMW collected in Chinese cities has a high content of biodegradable organic matter, at least two times more than in MSW from urban areas in Europe. Composting can only be done by applying high amounts of structure material (> 50 Vol% using Mays straw, wood ships are not easily available in China), therefore anaerobic fermentation and the production of biogas (renewable energy) and of 'clean compost' from the digestat are recommended. The projects have investigated a methane gas production rate, ranging at the upper level of BMW.

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Abbreviations

AD	Anaerobic digestion (fermentation)
BG	Biogas
BMW	Bioorganic Municipal Waste
BMWM	Bioorganic Municipal Waste Management
CIM	Centre for International Migration and Development, D
EPB	Environmental Protection Bureau
CHP	Combined Heat and Power
ICEEE	Institute of Clean Energy and Environmental Engineering
LFG	Landfillgas
MSW	Municipal Solid Waste
PSS	Primary Source Separation
RMW	Remaining/Residual Municipal Waste
RDF	Refuse derived fuel
SSS	Secondary Source Separation