**COST/BENEFIT ANALYSIS**

# Digestion of Municipal Solid Waste
Cost/Benefit Analysis

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# COST/BENEFIT ANALYSIS

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# 1.0 GENERAL INFORMATION

## 1.1 Purpose

The basic contents of China's energy policies are: "giving priority to conservation, relying on domestic resources, encouraging diverse development, protecting the environment, promoting scientific and technological innovation, deepening reform, expanding international cooperation, and improving the people's livelihood." The state strives to advance the transformation of its energy production and utilization modes, and builds a modern energy industrial system which features secure, stable, economical and clean development, so as to support sustainable economic and social development with sustainable energy development.1

A living example of the governments aim to invest into a clean environment is Chengdu city. Here, most of the taxies and public busses run on natural gas and motorized two-wheelers run with electricity. This impression was reflected by all the different meetings we had with Government offices, Universities and partnering NGO's. Government plans and policies increasingly include renewable energy forms in order to reduce pollution. With our project idea, the doors are randomly open and we got access to the information needed to carry out the study.

A huge effort has been taken to research and find solutions in order to treat and convert organic waste into energy. ADRA in collaboration with Triple E&M with its extensive know how would like to assist this process in the sector of urban organic waste treatment. ADRA and Triple E&M invested its time and knowhow to conduct a feasibility study in order to get the necessary insights. The study gave us very good access to all the important information and insights for future planning of the project. All the meetings and visits indicated the enormous need for a functioning urban organic-waste treatment solution. This feasibility study with all the gathered information and insights reveals enormous potential to build an anaerobic digester plant to treat urban organic waste produced at households. There is random high motivation by the responsible government offices as well as the universities to be part of a future project to build a demonstration plant. This motivation derives from an increasing amount of waste production, a decreasing availability of space for landfill as the city grows rapidly. Waste treatment cost need to be reduced, while the environment needs to be protected. The production of energy is another motivator that includes the planned project.

In order to take a decision for the investor, ADRA and Triple E&M formulated a Cost/Benefit Analysis.

## 1.2 Scope

The Cost/Benefit Analysis has a financial, an environmental, a social component with various benefits:

| *Cost/Benefit* | *Cost* | *Benefit* |
|---|---|---|
| ***Financial*** | • Engineering<br>• Plant construction<br>• Start-up<br>• Operation until full capacity<br>• Training (technical & managerial) | • Gate fee<br>• Income from electricity or biofuel production for road transport<br>• Income from selling fertilizer<br>• Saving transportation cost of waste<br>• Saving landfilling space |

[1] China's Energy Policy 2012

| | | |
|---|---|---|
| | | • |
| ***Social*** | • Awareness program<br>• Waste separation info campaign<br>• Incentive mechanism | • Receive good quality wet fraction<br>• Creation of additional working places<br>• Improved environmental awareness among communities<br>• Less littering |
| ***Environmental*** | None | • Treat run-off liquid during waste compression – no need to build a separate waste water treatment unit<br>• Reduction of CO2 emission<br>• Better separation of contaminated or hazardous waste |

Comparison of current waste treatment versus Biogas Production

| | ***Incineration*** | ***Biogas Production*** |
|---|---|---|
| Cost of input | Estimate: 80 to 140 SFR/to | Same price |
| Calorific value | Very low (approx. 4200kJ/kg), not burning without oil addition, value higher after separation of organic fraction | Calorific value is high (in the order of 8.000kJ/kg) independent of the water content |

## 1.3 Project Overview

| | | |
|---|---|---|
| **Project Title** | Urban Waste to Energy | |
| **Project Category** | Anaerobic digestion of urban organic fraction | |
| **Project Environment** | Number of Communities at one Chengdu district | |
| **Project Content** | - Establish an appropriate organic waste upgrading plant<br>- Production of renewable energy<br>- Active promotion and behavior change to waste separation | |
| **Responsible Organizations** | Triple E&M<br>Chatelstrasse 21<br>CH-8355 Aadorf, Switzerland<br>Tel.: +41 52 365 43 85<br>Fax.: +41 52 365 40 20 | ADRA Switzerland<br>Gubelstrasse 23, P.B. 5126<br>CH-8050 Zürich<br>Tel.: +41 (0) 44 515 03 10<br>Fax: +41 (0) 44 515 03 10 |
| **Authors:** | Arthur Wellinger | Marcel Wagner |

## 1.4 Project References

### 1.4.1 Triple E&M Reference Projects

**Projects in emerging countries**

| | |
|---|---|
| 1984 - 1991 | Development of the Centre de Recherche d'Energie Renouvelable (CDER) in Marrakesh, Morocco. Responsible for Biomass (Biogas, Short Rotation Forestry, Aquaculture incl. algae) for US AID. Construction of approx.. 40 family scale digesters (Chinese design) |
| 2004 | Consulting with the Indian government for a biogas programme |
| 2001 - 2005 | Development, design and construction of a new mechanical-biological waste water treatment plant on a natural rubber factory including ammonia stripping, digestion and aquaculture. Hainan, PCR |
| 2003 | Design and construction of an adapted digester system and evaluation of potential biogas sites in North Korea (DPRK) for ADRA |
| 2008 | Development of a digester for palm oil waste in Ivory Coast for Matprem |
| 2009-2011 | Planning of a waste treatment installation in Chetumal, Mexico |
| 2010 | Planning of a biogas digester on a sugar refinery in Paraguay for WFF |
| 2011 | Expert work on biogas upgrading for Empresas Públicas de Medellín, Colombia |
| 2012 ongoing | Evaluation of a MSW digestion plant in Chengdu City, PRC for ADRA |

**Projects in industrialized countries**

| | |
|---|---|
| 1991-1997 | Development and construction of a pilot plant and a demonstration plant (10,000 TPY) of a horizontal solid waste plug-flow digester |
| 2000 | Development of a PC program to design aerobic and anaerobic industrial waste water treatment plants |
| 2000 - 2001 | Design, construction and control of a 20'000 TPY Percolator demonstration unit in Buchen, Germany; 20’000 TPY |
| 2001 - 2003 | Design and construction of a pilot plant for aerobic/anaerobic treatment of biowaste (percolation) in Sydney; 165,000 TPY |
| 2002 | Evaluation of a digestion system for the treatment of rendering waste in Switzerland; 30’000 TPY |
| 2002 | Evaluation of a digestion system for the treatment of slaughterhouse waste in Germany; 20’000 TPY |
| 2002 | Etude sur l’injection de biogaz dans le réseau et sur l’utilisation de biogaz comme carburant. Aspects économiques et législatifs, fiabilité et maintenance. Etude Francaise |
| 2002 - 2003 | Evaluation and layout of a large-scale MSW digester in Iowa, USA; 120’000 TPY |
| 2003 | Evaluation and design of a large farm scale plant (5’000 TPY) digesting solid animal waste, grass clippings, herbaceous crops and waste water from a goat cheese factory. |
| 2003 | Preliminary tests for the construction of an AD-plant for waste cardboard degradation in Iceland<br>5’000 TPY |
| 2003 | Qualification process for the design and the construction of a large-scale biowaste digester in Sweden<br>28’000 TPY |
| 2003 | Improvement and extension of a solid-waste digester in Sweden<br>12’000 TPY |
| 2003 | Comparison of installations in Europe on mechanical-biological treatment with digestion for a German Company |
| 2001-2004 | Development and design of a percolation system in Buchen, Germany, for ISKA; 130’000 TPY |
| 2003 -2005 | Development and design of a percolation system in Heilbronn, Germany, for ISKA; 90’000 TPY |
| 2003 – 2005 | Development and design of a percolation system in Sydney, Australia for ISKA and GRL; 168’000 TPY |
| 2005 | Gas injection into the natural gas grid. Study on behalf of GDF |
| 2006 | Evaluation of a German biogas company on behalf of a Swiss Private Equity group |
| 2009-2011 | Planning of a waste treatment installation in Mexico |
| 2010 | Planning of a biogas digester on a sugar refinery in Paraguay |
| 2006 | Planning of an agricultural digester on a agricultural school in Switzerland (Mezzana) |

| | |
|---|---|
| 2006 | Technological and economical evaluation of new small-scale biogas plants in agriculture, industry, MSW and wastewater treatment. ADEME. |
| 2009-2011 | Planning of a waste treatment installation in Mexico |
| 2010 | Planning of a biogas digester on a sugar refinery in Paraguay |
| 2010 | Planning of a digester on a poultry farm in Switzerland. |
| 2009-2011 | Planning of a waste treatment installation in Mexico |
| 2010 | Planning of a biogas digester on a sugar refinery in Paraguay |
| 2007 | Evaluation of a French biogas company on behalf of a French Private Equity group |
| 2007 | Evaluation of a Swedish gas upgrading plant for GDF |
| 2006 – 2008 | Planning and design of a centralized agricultural plant for 1600 cattle units in the USA |
| 2012 - 2013 | Pre-study for a digester in BC, Canada |

### 1.4.2 ADRA Reference Projects

| | |
|---|---|
| 2002-2003 | Development and Construction of cold climate household biogas for one smallholder farmer family in DPRKorea. |
| 2003 | Consolidate household biogas technology and include technical improvements and lessons learned for 10 farmer families. |
| 2003 | Facilitation of feasibility study with Nova Energie (Switzerland) to develop biogas technology in DPRKorea and build a concise energy program with the academy of sciences at Pyongyang Technical University. |
| 2004 | Development of solar energy to generate warm water for cooperative farmers in rural DPRKorea. |
| 2004-2005 | Development and Construction of an agriculture cold climate biogas plant attached to an animal farm, producing biogas for 3 villages in rural DPRKorea. |
| 2005 | Closing the bio circle of the agricultural plant by utilizing its outlet (solids and liquids separate) in agriculture, non-soil gardening indoors and fish farming. |
| 2005 | Development and Construction of a pilot industrial waste water treatment plant to produce biogas for a pediatric hospital in DPRK. |
| 2007 | Development and construction of small scale Biogas plant for farmers in desert areas of Afghanistan. |
| 2011 | Development and engineering of community Biogas plant for village tracts |

| | |
|---|---|
| | in semi-urban Haiti. |
| 2012 | Design and construction of a desalination plant for a children institution in Kalmykia, Russia. |
| 2012 -2013 | Construction and support of rural biogas plants for farmers in mountainous Sichuan province, China. |
| 2013 ongoing | Construction of small Hydropower for one district hospital in Bamyan, Afghanistan. |
| 2013 ongoing | Consulting services to ADRA Bangladesh to economize public high schools through the integration of agricultural Biogas. |
| 2013 ongoing | Consulting services to ADRA Burundi in project design of public school sanitation facilities including Biogas and Bioremediation. |
| 2013 Ongoing | Consulting services to ADRA Mongolia in project planning of greenhouse heating solutions with renewable energies, to extend growing season from 3 to 6 month per year. |

## 1.5 Acronyms and Abbreviations

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

# 1.6 Points of Contact

## 1.6.1 Project Stakeholders

| ***Stakeholders*** | ***Role*** | ***Priorities*** | ***Means of intervention*** |
|---|---|---|---|
| Chengdu City Management Bureau 1 | Responsible for Waste treatment | • Less waste for landfill | • Main partner to implement to implement the treatment plant |
| Chengdu City Management Bureau 2 | Responsible for waste transportation, road cleaning | • Reduce transportation and treatment cost<br>• Less waste for landfill | • Main partner to implement waste separation at source apart from education dept. |
| School of Environment, Tsinghua University, Beijing | Biomass research center | • Successful urban anaerobic waste treatment solution<br>• Develop technology | • Reference and liaison when negotiating with the government<br>• Additional knowledge and expertise |
| Department of Environmental Science and Engineering, Beijing University | Biomass research center | • Successful urban anaerobic waste treatment solution<br>• Develop technology | • Reference and liaison when negotiating with the government<br>• Additional knowledge and expertise |
| Department of Environmental Science and Engineering, Sichuan University | Biomass research center | • Successful urban anaerobic waste treatment solution<br>• Develop technology | • Reference and liaison when negotiating with the government<br>• Additional knowledge and expertise |
| Landfill cooperative | • Provide enough space<br>• Extract methane gas<br>• Treat run off liquid | unknown | None |
| Waste Incineration Plant | Alternative treatment to land filling | • Produce energy by incinerating waste<br>• Incinerate without adding fuel | None |
| Waste Compression station | Compress all waste to 1/3 before transport to final treatment | • Being able to compress the amount of waste<br>• Reduce- and treat press liquid | Aim to build the AD Plant at the compound or neighboring property |
| Waste transportation companies | Transport waste from community to compression station | • Maintain good business<br>• Better separation results in more income??? | Close partner to improve waste quality through separation |
| Waste collectors with Tricycle (Subcontractor of waste transportation company) | • Collect waste from the homes to the community collection point<br>• Collect recyclable waste from the homes and sell to recycle companies | • Keep their jobs<br>• Better income thanks to higher prices of well separated waste | Close collaboration to sensitize waste producers to separate waste |
| Community Property Management Offices (Private Company) | Responsible for waste management and cleanliness in the living area | Keep their business running | • Provide data on waste management in the community.<br>• Support the waste separation process at source |
| Community Residence Committee | Liaison with the households | • Keep the fee management fee per household low<br>• Cleaner community<br>• Good reputation | • To introduce separation<br>• Share information and their needs<br>• Ensure residents' cooperation to separate waste |
| Waste Producer | To separate dry from wet waste | No additional work with their own waste | Close collaboration to change behavior and separate wet and dry waste |
| Component suppliers | • Manufacturing of parts and systems<br>• Supplying of components | Sell products and goods | Have domestic suppliers for all components and material |

| | | | |
|---|---|---|---|
| Government Contractors (Private Companies) | Build AD plant to treat restaurant waste | Being the only one in the business | Seek collaboration to share knowhow and experience |

## 1.6.2 Project Partners

| ***Stakeholders*** | ***Role*** | ***Priorities*** | ***Means of intervention*** |
|---|---|---|---|
| REPIC | • Donor<br>• Knowhow provider | • Build demonstration plant<br>• Disseminate and replicate technology | • Financial support<br>• Technical know how |
| ADRA Switzerland | • Project manager<br>• Development Knowhow<br>• Donor | • Promote biomass technology<br>• Replicate technology in the third world to provide energy<br>• Environmental protection | • Networking with external and internal partners<br>• Pro-active planning to find most economic solution |
| Triple E&M | • Project partner<br>• Technical Knowhow<br>• Donor | • Promote biomass technology<br>• Replicate technology in emerging economies to close cycles<br>• Environmental protection | • Technical, knowhow and expertise to calculate and outline AD plant<br>• Consult best practice |
| German Biogas (Private Company) | Experienced builder of agricultural AD plants | • Provide biogas technology to big farmers and since recently for Household waste | Potential and reliable contractor to build fermenter and control system |
| ADRA China | Responsible to coordinate all project activities in China | • Promote biomass technology<br>• Replicate technology in emerging economies to provide energy<br>• Environmental protection | • Liaison with outside experts and partners on site.<br>• Build relationships and trust among the responsible government offices |
| South Center for Environmentally Sound Technology Transfer (SCESTT) | • Liaison between government and Universities<br>• Responsible for CDM | • Environmental protection<br>• Promote environmental sound technology | Ensure the participation of local technical expert, sharing information with Department of Science and Technology in Sichuan Province |
| Roots & Shoots Chengdu Office | • Working at community level to achieve waste separation (dry-wet matters)<br>• Educational training | • Promote waste separation<br>• Faster introduction of waste separation<br>• Share best practice | • Technical partner to launch waste separation with the producer at source<br>• Sharing of information and insights<br>• Government liaison<br>• Behavior change communication |
| Dr. Hongyan LU Biochar & Biogas Lab - Sichuan University; Chengdu | Runs a research lab and educates graduate students | Chemical analysis and monitoring | Lab work required for analysis of waste and chemical analysis for start-up and operation of plant |

# 2.0 MANAGEMENT SUMMARY

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## 2.1 Assumptions and Constraints

### 2.1.1 Assumptions

- Urban organic waste will double within the next 10 to 15 years
- The urban energy consumption will raise by 8,16%[2] the next 5 years
- The well established waste treatment technology in Europe will be adapted to the local needs in China
- There is great need for an economic and environmental friendly waste treatment solution
- Close collaboration between the specialists from the different departments and organizations given
- The successful implementation of the project has great replication potential

### 2.1.2 Constraints

- Appropriate plant components (hardware) are not entirely available locally
- Know-how of plant construction for MSW dry systems not available yet
- Waste separation process among communities is a long lasting process of habitual change

### 2.1.3 Advantages

- Know-how transfer
- Sustainable Solution for organic fraction of MSW
- Reduction of CO2-emissions
- Less landfilling

## 2.2 Methodology

This Cost/Benefit Analysis includes the comparison of the current practices in waste management and energy production in order to qualify and quantify the investment of the biomass technology. In addition the analysis considers hard factors like financial investment and land use, as well as soft factors including social- and environmental elements.

## 2.3 Evaluation Criteria

The evaluation will outline the most suitable technical solution to treat urban organic waste. The following criteria will be included in the evaluation:

- Energy efficiency:
    - Output quality and recycling
    - Energy yield

[2] http://wenku.baidu.com/link?url=nkCV1TgWL-kp1QaRnEnIJOl7Wx6BI_JlFU8Xhfse-FGVwJTMv1uGhObirKb07J0Eg3ac2bKGu1JQuR8sLsedCrGJYN1vj60pOdEbr6Qokp_

  - Plant efficiency

- Operational cost and efficiency

- Economical efficiency;
  - Transportation distance of waste
  - Gas yield compared with landfill
  - Space needed for waste treatment versus waste storage

- Social benefits;
  - Improved cleanliness in public areas
  - Creation of new jobs

- Environmental protection;
  - Carbon dioxide emission
  - Reduced run-off liquid

- Government policy compliance
  - Policy on waste treatment
  - Policy on Energy production
  - Policy on environmental protection

# 3.0 DESCRIPTION OF AD OPTIONS

# 3.0 DESCRIPTION OF OPTIONS

China has only a limited number of waste incineration plants. Most of the waste is landfilled without using the gas produced. Large quantities are still dumped with high GHG emissions in form of methane. Waste incineration is not evident because Chinese's waste has a low calorific value of around 4200kJ per ton due to the high amount of wet organic fraction. The fire cannot be self-sustained and oil has regularly to be added.

In Chengdu they have two incineration plants of small scale (exact size not known) and a large landfill site about 30km out of town. It has been retrofitted and is actually well managed. However, the partially collected gas is not used nor flared and is released to the atmosphere posing a serious emission problems. The landfill will be full in a few years and new locations are difficult to find. As a result, there is no alternative to source separation and digestion/composting.

Even though Mr. Lee from Roots & Shoots recommended to start with a central separation, discussions with specialist having experience in the Chinese market showed that this is probably not the best way to go. Several years of experience in Shanghai (composting) have shown that even source-separated waste is still full of undesired components like sand, metals and plastics. We therefore prefer to work with at least partially separated waste. The project will include a social component with the targeted residents to improve source separation.

The choice of a new biogas technology and the design is not evident as there is no long-term experience on the composition of (separated) waste. There are a few reliable data from analysis e.g. of separated waste in Shanghai (total solids $\geq$ 30%) and some random determinations by us of hand-picked waste samples in Chengdu (TS 22 -29%). One of the major criteria for the design of a system is the total solids (TS) content. If it is $<$ 20% TS then the basic design is a continuously stirred tank reactor (CSTR); is the dry matter content is around 28% then the choice is rather a continuously operated horizontal plug-flow system or a batch digester, i.e. a so-called garage system.

- **Technology: Selection of fermenter type**

  The criteria we applied to select the most suitable type of MSW digester 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 electric motors and combustion engines close to Chengdu if service is needed
  - Robustness towards earth quakes
  - Integration into the existing waste system
  - Flexibility to future developments

  Taking all these parameters into account the choice of system was reduced to three basic designs: vertical cylindrical digester (CSTR), horizontal semi-plug-flow digester (CSTR) and a Horizontal plug-flow digester with gas injection. The final decision depends mainly on economy and availability of equipment and service.

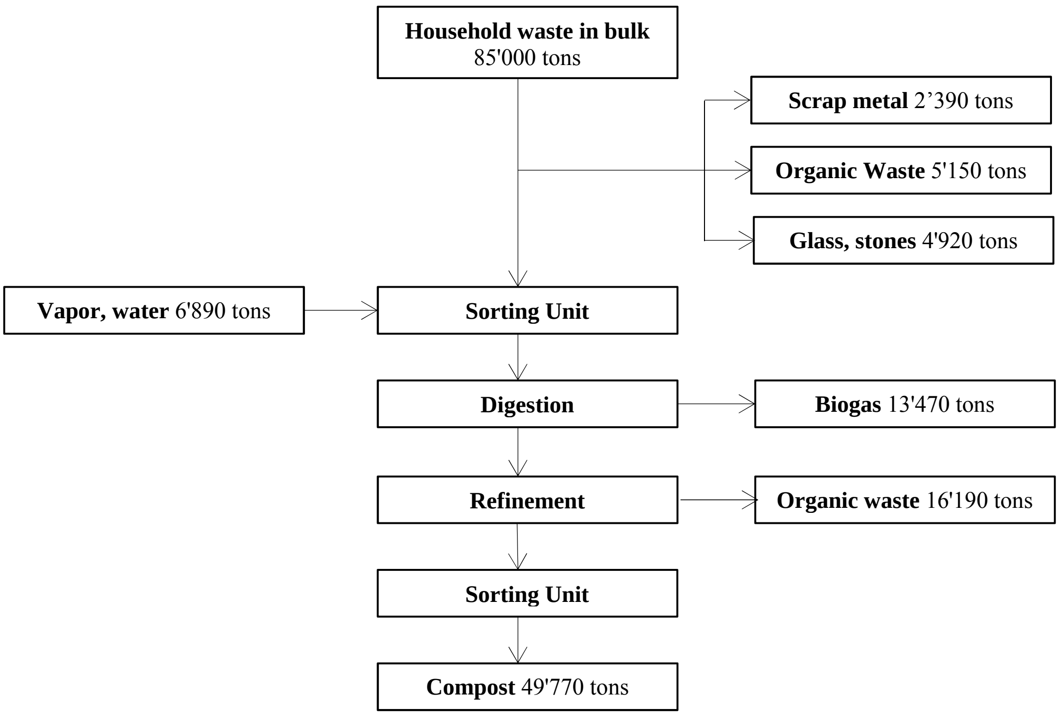
- **Technical description of the waste chain:**
  The un-compressed waste is delivered by a truck of the City Management Buro, passes over a scale and unloads the waste in a closed reception hall. With a front loader it is slightly distributed and the coarse parts (especially iron and stones) are removed by hand. The waste is 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 MJ/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. Digested material, called digestate is further treated before composting if the TS content is low (≤15%), or water content is alternatively reduced by a centrifuge. 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 as 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.

  If the digestate has a high TS content (>20%), fresh solid material might be added to achieve a TS content of > 30% allowing a direct composting without going through an expensive press or centrifuge.

  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 or if the quantity is high enough, an adsorption pump can be operated to produce cold.




The mass balance of a full-scale system in Europe

## 3.1 Current System

Currently some of the unsorted waste is incinerated in two incineration plants with a capacity of 650,000 tons annually (Chengdu Xiangfu Environmental Power Plant) and 400,000 tons annually (Chengdu Luodai Incineration plant). Price for incineration is not known, however there is no net energy production, which is shown by huge fossil fuel tanks next to the incinerator.

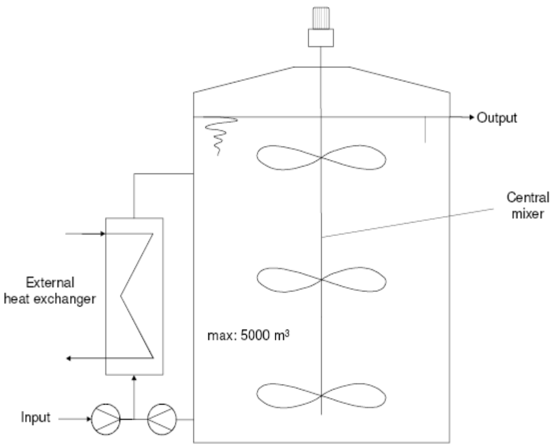
Most of the waste is going into landfill. Since a few years the landfill is properly covered and part of the gas is collected (< 50%) but it is neither flared nor used in a CHP. This is not only a waste of energy but creates also substantial GHG emissions.

## 3.2 Proposed Systems

Independent of the system chosen it has to be built with an earth quake secure construction, i.e. it has to be placed on a sand bed with an extra thick concrete plate (≥ 50cm).

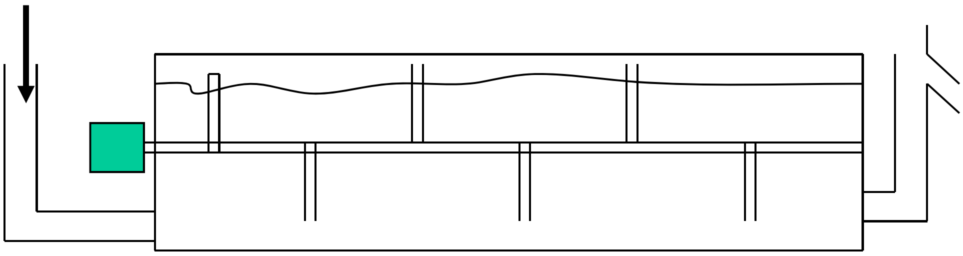
### 3.2.1 Option 1: Type CSTR vertical cylindrical digester

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. The system is very well suited for restaurant waste.



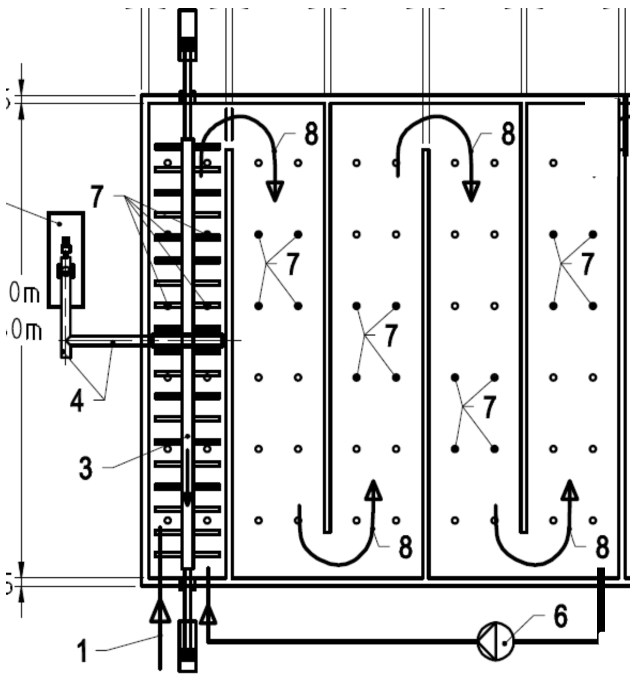

### 3.2.2 Option 2: Type CSTR horizontal semi-plug-flow digester

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.



## 3.2.3 Option 3: Horizontal plug-flow digester with gas injection

In discussion with a Swiss engineer (Ch. Widmer; AFAG-engineering) a new system has been developed that would get away from the risky and cost-intensive mechanical mixing by introducing a combination of walking floor and gas injection.




1: Fresh Substrate
3: Walking floor
4: Sediment discharge
6: Recycling of incoculum
7: Gas lances
8: Material flow

## 3.3 Preferred Choice

The **most appropriate design for the demonstration unit** of 10’000 tons per year (20 tons per day) is **option Number 2**. This is due to several reasons:

- The goal is to use source separated waste however, as separation is not introduced yet and we don’t know the material we are going to collect. In the beginning there will be a lot of undesirable material, i.e. plastic, wood, etc. The digester option 2 is the most versatile of all design when it comes to bulky material or mixtures of wet and dry material.
- In a region with heavy earth quakes the horizontal steel tank is the most robust and safest
- The design can easily be extended by additional tanks next to each other

The fermenter can be built in steel or concrete (see cost calculation in section 4.1) of which the concrete vessel will be more expensive. Therefore we propose to build the fermenter with a steel body. The cost/benefit analysis will focus only on the horizontal plug flow digester with a mechanical paddle stirring system in steel.

This technology will help to reduce the land requirement for landfilling, help improving environmental challenges and promote a changing attitude to consumer’s current behavior of waste disposal.

# 4.0 COST/BENEFIT

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As proposed above, we suggest a **horizontal plug flow digester with a capacity of 10'000 tons per year**. The plant consists of a pre-treatment unit, a digestion unit and a post treatment unit.
Tentative offers to build the plant have been asked among Chinese Companies and builders. The figures below provide the basis for this cost/benefit analysis. These are **tentative values** within plus/minus 10% that needs adjustment at a later stage. The cost/benefit ratio with the available information and assumptions is profit oriented. This is a demonstration plant (small scale) with **European technology but built mainly with Chinese products** and components. This project assumes that the **government will provide the land** preferably next to a compressing station.

## 4.1 Comparative Overview of Cost

The costs indicated below correspond to a plant size of 10'000 tons per year (20 tons per day) with a retention time of 25 days.

| ***Phase*** | ***Activity*** | ***Cost*** [Yuan] |
|---|---|---|
| Plant property[1)] | Land and building | 1'900'000 |
| Technical equipment | Front loader, compost filter, etc. | 850'000 |
| Digestion plant | Material and Equipment | 5'440'000 |
| Design | Detail engineering | 880'000 |
| Construction management and Start-up | Personnel cost | 956'000 |
| | **TOTAL** | **10'026'000** |

[1)] **The most suitable place to build the plant would be next to a compressing station.**

## 4.2 Operational Costs

| ***Phase*** | ***Activity*** | ***Cost / year*** [Yuan] |
|---|---|---|
| Labor (gross) | 1 Leader: 16150 USD x 6,1 = 98'515 CNY (13x)<br>1 Driver: 1210 USD x 6,1 = 7'381 CNY (13x)<br>1 Mechanic: 1000 USD x 6,1 = 6'100 CNY (13x)<br>2 Sorter: 650 USD x 6,1 = 3'965 CNY (2staff 13x)<br>**TOTAL** | 1'280'695<br>95'953<br>79'300<br>103'090<br>**1'559'038** |
| Plant operation | Electricity consumption 25% of produced electricity (435'000 kWh/year a 0,4777 Yuan/KWh[3]) | 207'800 |
| | **TOTAL** | **1'766'838** |

[3] http://www.chengdutime.com/business/business.asp?id=costofinvestment

## 4.3 Economical estimation

All non-recurring cost (Capital Investment Costs)

| **Gas production from** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Organic waste | Grass silage | | 500 | t/a | 180 | m³/t | | 90000 | [m³/a] |
| | Market Waste | | 1000 | t/a | 140 | m³/t | | 140000 | [m³/a] |
| | OFMSW | | 6500 | t/a | 120 | m³/t | | 780000 | [m³/a] |
| | Restaurant waste | | 2000 | t/a | 160 | m³/t | | 320000 | [m³/a] |
| | | | | | | | Total gas production | 1330000 | [m³/a] |
| Gross energy production | Days without gas production or utilization | | 30 | [d/a] | | | | | |
| | Availability | | 92 | [%] | | | | | |
| | Energy content of biogas | | 6 | [kWh/m³] | | | | | |
| | Electric efficiency | | 0,37 | [%] | | | | | |
| | Operation time of CHP | | 8040 | [h/a] | | | | | |
| | Calculated power of CHP plus 20% security measure | | 440 | [kW] | | | | 7324109 | [kWh/a] |
| | | | | | | | | 7324109 | [kWh/a] |
| Heat production | | | 50 | [%] | | | | 3662054 | [kWh/a] |
| | Process heat and loss through flare to be deducted | | 600 | [kWh/m³ Fermenter*a] | | | | 360000 | [kWh/a] |
| Usable heat | | | | | | | | 3302054 | [kWh/a] |
| Net electricity production | | | | | | | | 2709920 | [kWh/a] |
| Income from electricity | up to kW | 150 | 0,65 | [CNY/kWh] | 150 | 1206000 | | 783900 | [CNY/a] |
| | up to kW | 500 | 0,65 | [CNY/kWh] | 290 | 2331600 | | 977548 | [CNY/a] |
| | up to kW | 5000 | 0,65 | [CNY/kWh] | 0 | 0 | | 0 | [CNY/a] |
| | Up to kW | 2000<br>0 | 0,65 | [CNY/kWh] | 0 | 0 | | 0 | [CNY/a] |
| Income from heat | | | 0,3 | [CNY/kWh] | | | | 990616 | [CNY/a] |
| Total annual income | | | | | | | | 2752064 | [CNY/a] |
| Investment cost | | | | | | | Cost per kW installed electricity [CNY/kW] | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Construction and technology | Digester volume | | 600 | [m³] | | | 25000 | 30000 | 50000 |
| | Average retention time | | 22 | [d] | | | [CNY] | [CNY] | [CNY] |
| | Total invest | | | | | | 8800000 | 13200000 | 22000000 |
| | CHP | | 4400 | CNY/kW | | | 1936000 | | |
| Total investment | | | | | | | 8800000 | 13200000 | 22000000 |
| Invested capital | Subsidies | | 0 | [%] | | | 8800000 | 13200000 | 22000000 |
| | | | | | | | | | |
| Estimate of annual cost | | | | | | | [CNY/a] | | |
| Amortization | Construction | | 0,54 | [%] | 20 | [years] | 237600 | 356400 | 594000 |
| | Technology | | 0,46 | [%] | 15 | [years] | 269866 | 404800 | 674666 |
| | CHP | | | | 5 | [years] | 0 | 0 | 0 |
| Interest rate | | | 0,06 | [%] | | | 528000 | 792000 | 1320000 |
| Insurance | | | 0,005 | [%] | | | 44000 | 66000 | 110000 |
| Maintenance | Construction | | 0 | [%] | | | 0 | 0 | 0 |
| | Technology | | 0,03 | [%] | | | 121440 | 182160 | 303600 |
| | CHP | | 0,05 | [%] | | | 96800 | 96800 | 96800 |
| | Hourly rate | | 7500 | [h/a] | 208 | [CNY/h] | 1560000 | 1560000 | 1560000 |
| Cost of energy crops | Whole rye silage | | 70 | [CNY/t] | 0 | [t/a] | 0 | 0 | 0 |
| | Grass silage | | 0 | [CNY/t] | 500 | [t/a] | 0 | 0 | 0 |
| | Market Waste | | 0 | [CNY/t] | 1000 | [t/a] | 0 | 0 | 0 |
| | Restaurant waste | | -80 | [CNY/t] | 2000 | [t/a] | -160000 | -160000 | -160000 |
| | OFMSW | | -50 | [CNY/t] | 6500 | [t/a] | -325000 | -325000 | -325000 |
| Electric process energy | | | 0,477 | [CNY/kWh] | 50 | [kWh/m³] | 14310 | 14310 | 14310 |
| Total annual cost | | | | | | | 2387016 | 2987470 | 4188376 |
| **Net benefit [CNY/a]** | | | | | | | **365048** | **-235405** | **-1436311** |

## 4.4 Non-Recurring Benefits

The plant will be designed to partially separate undesirables in the source separated waste.
Source separations will have to be introduced:

- Best case of wet/dry separation at source: promoted by a community information/mobilization initiative (starting with 2 Sorter) The project aims to work with the targeted communities to improve garbage separation (wet/dry) to improve the quality of the organic fraction

- Improved separation of garbage separation at community level will increase the calorific value of the remaining waste going into incineration (reduced fuel cost at incineration plant)

- Production of organic fertilizer

- Gain of land space (reduced landfill space)

## 4.5 Recurring Benefits

These are the yearly recurring benefits of operating and maintaining the horizontal plug flow digester over the system life of 12 years, including:

| ***Income item*** | ***Unit*** | ***Cost*** [Yuan] |
|---|---|---|
| Electricity (assumption 0,65 Yuan/KWh) | 1.5 GWh per year | 975’000 |
| Heat (assumption 0,30 Yuan/KWh) | 1.5 GWh per year | 450’000 |
| Gate fee (28 tons per day, 360 days/year) | 50 Yuan per ton | 500’000 |
| Fertilizer production | Unknown | Unknown |
| GHG Reduction (12’500 ton/year) | 5€/ton or 40 Yuan/ton $CO_2$ | 500’000 |
| Extended lifetime of landfill site | Unknown | Unknown |
| **Total** | | **2’425’000** |

a) The price of produced KWh depends on its source of energy

- 1 KWh produced with coal: The cost is around 0.39-0.40 Yuan. The price is affected by the fluctuation of the fuel. Price to power grid is around 0.50 Yuan per KWh. Each year the state and the local government make price adjustments.
- 1 KWh produced with water: The price varies. The price to the power grid is between 0.20 to 0.30 Yuan. Each power plant has different price to power grid based on the price approved by the Development and Reform Commission. The price fluctuates with the seasons and availability of water.
- 1 KWh produced with biomass: In Chengdu region the price per KWh fed to the power grid is assumed around 0.65 Yuan.

## 4.6 Work with the Community

| ***Cost item*** | ***Unit*** | ***Cost*** [Yuan] |
|---|---|---|
| Behavior change communication and capacity building of targeted community to promote waste separation at source. | 1 year | 500’000 |

# 6.0 Annex

**Annex A** – Authors summarized Curriculum Vitae

## Dr.sc.nat ETH Arthur Wellinger

Arthur Wellinger is managing director of Triple E&M, an internationally operating consulting company located in Aadorf, Switzerland. Before he was for several decades' founding director of Nova Energie, a research and consulting company located in Switzerland.
After having earned his PhD in natural sciences (ecological microbiology) he spent a couple of years teaching at the University of Illinois, Department of Civil Engineering before he specialized in Research & Development, consulting and PR in the field of renewable energies and efficient energy utilization.
Arthur Wellinger has been working worldwide for more than 40 years in the whole field of renewable energies with a focus on biomass and waste in industrialized, emerging and developing countries. He is best known for his contributions in the development of AD processes for agricultural wastes and MSW including gas-upgrading utilities. He has also merits in editing and policymaking. As Technical Coordinator of IEA Bioenergy- an Agreement of the International Energy Agency - he organizes workshops, conferences and round tables on all aspects of biomass including production, utilization and sustainability aspects. As Guest Professor at the University of Technology in Vienna he is still involved in education. He is member of a number of national and international associations and expert groups. He is currently president of the European Biogas Association (EBA), Chairman of the European Sustainable Biofuel Forum (ESBF), vice-president of the Swiss AD and composting plant operators' association (VKS-ASIC) and board member of the Swiss Biomass Association (Biomasse Schweiz).

## Marcel Wagner

Marcel Wagner is managing director of the NGO ADRA Austria, the Austrian Branch of a worldwide humanitarian organization. Before moving to Austria in 2009, he was Director of ADRA Northkorea (4 years), ADRA Afghanistan, ADRA Myanmar, ADRA Morocco (1 year each), managing multi-million Dollar operations with up to 320 staff.
Before joining the humanitarian sector, Marcel Wagner was trained and worked for 18 years in the Engineering Business. As mechanical engineer with MAAG Zahnräder AG, Zurich, he specialized on material technology and travelled worldwide (much in Asia) for material development with focus on auditing and internal as well as external quality control. Later, he worked with SR Technics AG (a subsidiary of Swissair) introducing and implementing new maintenance procedures for the fleet of Swissair long-range aircrafts and customer aircraft engines. He attended SWISSMEM Kaderschule for Management and Leadership. In his free time, he attended the commercial pilot school and worked as flight instructor for airplanes and helicopters.

During his career with ADRA, he developed a broad program of up to industrial size renewable energy projects for cold and warm climate, with special focus on biogas technologies. These energy plants are continuously operating successfully under very complex circumstances. As member of the ADRA Renewable Energy Working Group, he provides consulting to other NGOs for renewable energy projects, but also brings with him the experience and knowledge of mobilizing communities and the organization of complex processes and behavior change initiatives.