Pre-feasibility study of a waste-to-energy (WTE) plant for Baotou city, China

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EXECUTIVE SUMMARY

With the rapid development of economy and population growth in China, the "garbage siege" problem has affected many Chinese cities. Baotou is one of these cities, in the province of Inner Mongolia.. In 2014, the generation of MSW was 0.626 million tons, i.e., about 1715 tons/ day. In Baotou city, there is only one Waste-to-Energy plant and two landfill sites. An estimated 58% of municipal solid waste is disposed by landfilling, which causes secondary pollution and a loss of potential energy.

Compared with landfills, the waste-to-energy technology significantly reduces the volume of the waste to be disposed and produces electricity; it also avoids the emission of methane to the atmosphere and the contamination of groundwater and soil. The WTE technology can also solve the problem of the scarcity of urban land for landfills and conserve arable land in China. This technology is very mature and has been adopted in more than 50 countries.

Based on the development of WTE technologies and the operating experience in China, this study compared two major WTE technologies: moving-grate (MG) and the circulating fluidized bed (CFB), and finally recommends the latter for implementation in Baotou city. At present, China is at the advanced level in the use of fluidized bed combustion technology for burning low calorific value fuel worldwide. The project evaluated for Baotou city is a three-line CFB WTE plant of total capacity of 1500 tons/day.

The generating capacity of the Baotou Power Grid must be increased by at least 400 MW by 2020. Therefore, the power to be generated by the WTE plant, estimated at about 20 MW, will be welcome.

Next to the furnace and boiler, the air pollution control(APC) system is a vital part of a WTE plant. The system recommended for the Baotou WTE consists of semi-dry scrubbing by $Ca(OH)_2$, NO_2

control by ammonia injection, activated carbon injection for dioxin an volatile metal control, and fabric filter baghouse, for capturing particulate matter. Nearly all new WTE plants, in China and other coutries, are provided with such high-efficiency APC systems.

From the economic aspect, implementing a new waste to energy (WTE) plant in Baotou will be a good investment. The capital investment of the 1,500 ton/day plant was estimated at US$80 million (US$183 per ton of annual capacity at 80% plant availability) . Of this amount, US$56 million will be provided by a loan from the local bank at 6.5% interest and US$24 million dollars from private investment. It was ascertained that the local government will pay a gate fee of US$9.56 per ton of MSW processes at the plant and the Baotou grid will purchase the power generated at the price of US$100 per MWh.

ACKNOWLEDGEMENT

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1.Background

1.1 Waste Management in China

Because of rapid urbanization, population growth, rapid economic development and improvement of living standards, the volume of municipal waste generated in the cities of China has increased rapidly in the last few decades.

At the last National People's Congress &Chinese People's Political Consultative Conference of China (NPC&CPCC), waste management was one of the important issues to be discussed during the congress, in which representatives from 17 different provinces proposed their perspectives for waste management.

The waste management industry is not only needed for improving the Chinese environment, but is also considered to be a" hot "industry for the China's economy during the "China's 13th five-year development Plan (from 2016 to 2020) (Ge Mo, 2016).

At present, the municipal solid waste (MSW) deposited in China's urban landfills amounts to more than 8 billion tons, covering an area of more than 530 square kilometers (about 15 tons/square meter). The MSW output is still growing at the rate of 5% to 8 (CEP, 2016).

Compared with landfill technology, waste-to-energy (WTE) not only can significantly reduce the volume of the waste and produce electricity, but also avoid the potential secondary pollution of groundwater and soil. The WTE can also solve the problem of the scarcity of urban land for landfills, near cities, and conserve arable land in China.

The sanitary landfilling, called "harmless treatment", of MSW in China's cities has reached 89.3% of the total MSW generated, of which 70% is landfilled, and 25% to 28% goes to combustion. The current waste combustion (with energy recovery) rate is 25.6%. During the period of the 13th five-year development plan, the disposal of MSW by WTE will increase further (NPC&CPCC, 2016).

According to the agency of CAFEP (Chinese Academy for Environmental Planning), during the period of the thirteenth five-year development planning "environmental protection investment is expected to increase to about 330 billion U.S. dollars per year. The total investment for environmental protection industrial will be about 2.7 trillion U.S. dollars during the period of "the thirteenth five-year development planning". According to the expected industry development, in the next few years, the management of solid waste will account for around 30% of the total investment on environmental protection. The present rate is about 24% of total and, according to estimates, during "the thirteenth five-year development planning", investment in the solid waste management industry will range between 700 to 850 billion U.S. dollars. Therefore, the scale of the market for China's solid waste treatment industry will reach 1,500 billion dollars by 2020 (Figure 1) (China Solid Waste Treatment Industry Market Research and Investment Forecast Report, 2016).

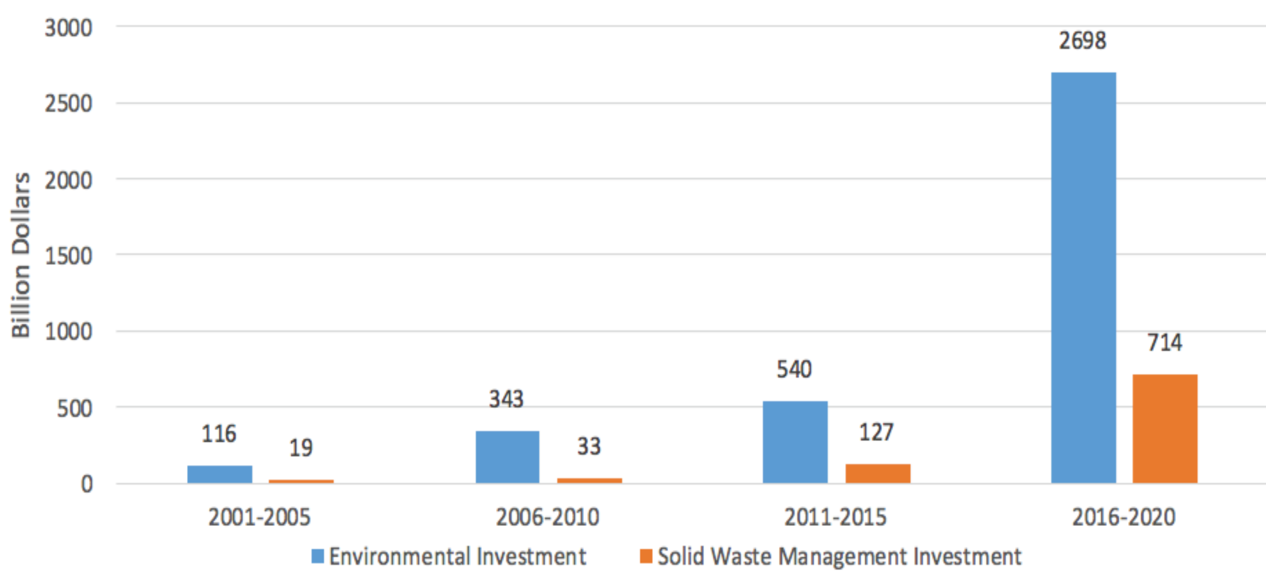

Figure 1 Investment in total environmental protection and in solid waste treatment in China from "10th five-year" to "13 five year" plan

1.2.Introduction to Baotou city of Inner Mongolia

1.2.1 Geography of Baotou City

Baotou is the largest manufacturing and industrial city in the Inner Mongolia of China. The area of Baotou is 27,768 square kilometer (Baotou City Information). Baotou is located in the west of Inner Mongolia, as shown in Figure 2, and is the junction of two economic zones: the Bohai Economic Circle and the Upper Yellow River Economic Circle. Baotou is the global center for rare earth metals production and a critical industrial center in China. The Baotou region rare earth reserves account for 87% of the national and 40% of the world reserves (Cheng et al., 2010). Baotou is one of the important hubs, connecting the north and northwest China, the key development area of Inner Mongolia opening to the outside world, one of China railway transport hub city (The government of Baotou city)

Figure 2 The location of Baotou city

1.2.2 Gross Domestic product (GDP) in Baotou City

Baotou is an important economic city in China. As shown in Figure 3, the GDP of Baotou has been increasing at a rather high rate with the average is 17.65% between 2001 and 2015. In 2015, the GDP of Baotou reached 58 billion dollars.

The three-sector theory divides economies into three sectors: primary(nature resources), secondary(manufacturing) and tertiary(service). Upgrading of tertiary- industry represents that the proportion of consumer service and producer service is increasing. The process of shifts economy from the primary industry, through the secondary industry and finally get the tertiary industry will improve the quality of life (Jiang Xiaojuan, 2004).

The contribution of Tertiary-Industry GDP in total GDP kept rising from 2001 to 2015. It means Baotou’s economic structure is transferring from secondary industry to tertiary-industry. It also means the people who live in Baotou can spend more money to consume by a high percentage of tertiary-industry GDP in total GDP of Baotou (Guo Jun et al., 2003).

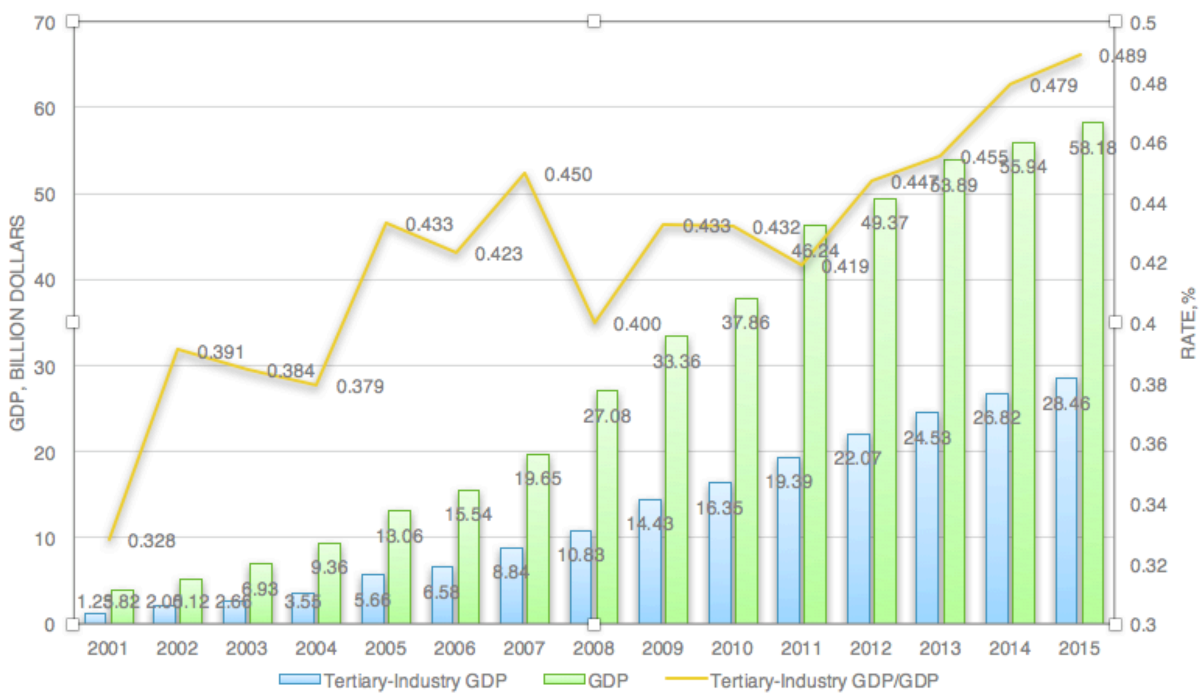

Figure 3 The GDP of Baotou from 2001 to 2015(Source: National Bureau of Statistic of China; Bureau of Statistic of Baotou; Guo Jun,2003)

Baotou is the economic leading city in Inner Mongolia, and also in China (National Bureau of

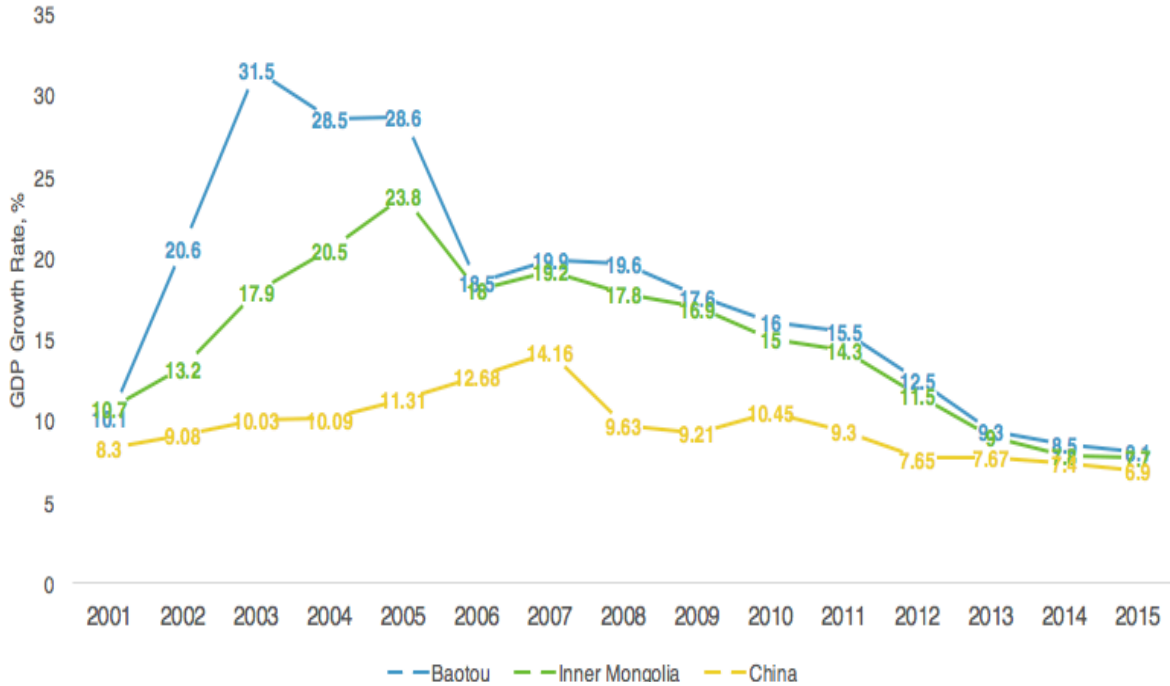

Figure 4 The GDP of Baotou, Inner Mongolia and China,2001-2015 (Source: National Bureau of Statistic of China)

Statistic of China, 2015). As shown in Figure 4, in the last fifteen years, the growth rate of the Baotou GDP was always higher than that of Inner Mongolia and also of China.

1.2.3 Population Analysis of Baotou City

From 2000 and 2014, the population of Baotou city keeps increasing (National Bureau of Statistic of China), as shown in Figure5. In 2000, the population of Baotou was 2.27 million, and in 2014 it was 2.80 million, primarily due to the fact that industry development and the regional economic growth attracted a massive influx of foreign population. Based on the data of the population in Baotou city from 2000 to 2014, the author establishes GM(1,1) (Kalyan et al., 2015; Tan, 2011) model to predict the population growth in next 20 years, and the model is:

$x^{(1)}(t+1) = 14800.357e^{0.01531t} - 14652.897.$

Figure .5 is a graphical representation of this equation and shows a steady upward trend of the Baotou population.

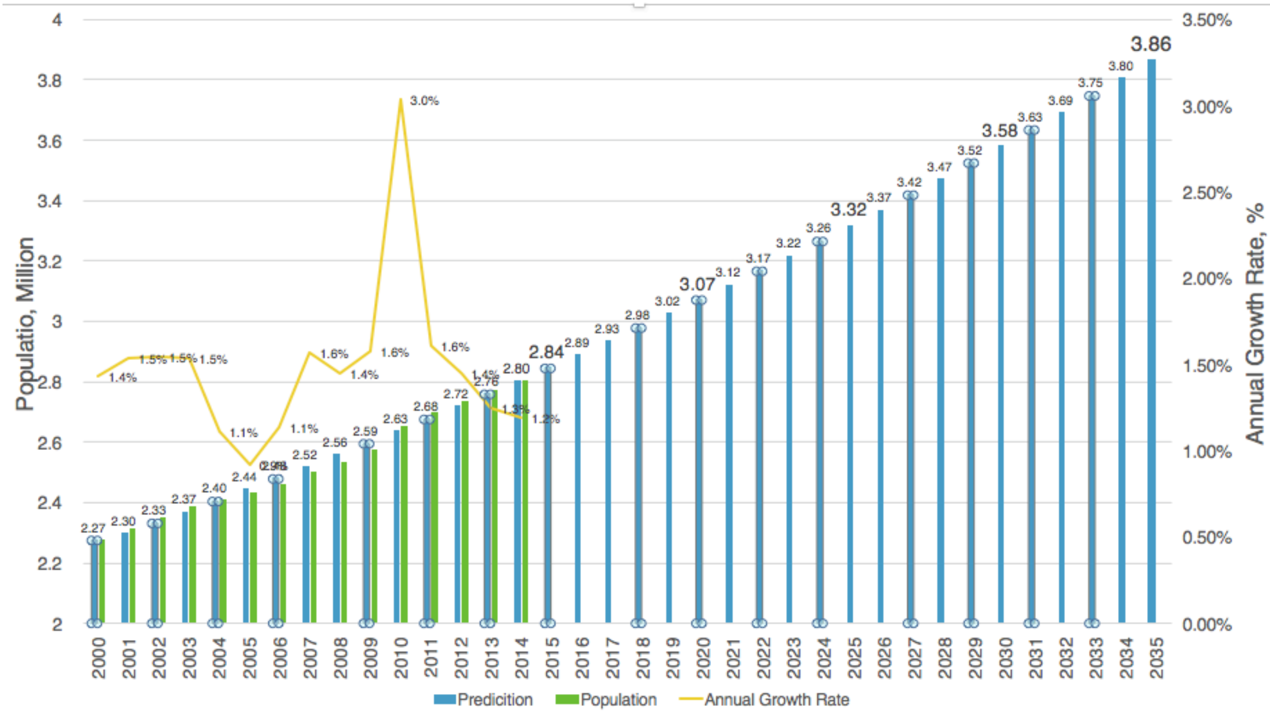

Figure 5 The population and its prediction of Baotou city(data from National Bureau of Statistic of China)

In 2020, 2025, 2030 and 2035, the population will be 3.07, 3.32, 3.58 and 3.86 million respectively. Yan analyzed the combination of the population with population age structure, GDP, the rate of death and birth and other conditions of Baotou (Yan, 2012). Yan found that the population of Baotou will keep increasing at a stable rate.

There is 683,067 migrant population (people living in Baotou who do not have the ID card of Baotou) in Baotou in 2015 (Public Security Bureau of Baotou). The growth of migrant population should match that of the resident population. Therefore, the total population of Baotou in 2020, 2025,2030 and 2035 is projected at 3.80, 4.11 and 4.79 respectively.

It is important to note that China's opening the "Second-child policy" in 2015, it will ensure continued population growth of Baotou in the future.

2. Waste management in Baotou

Based on the waste management information of Baotou city in 2015 provided by Baotou Environmental Protection Bureau, the author writes the part.

Table 1 shows the treatment capacity of the Baotou city for different sorts of wastes. In 2014, the generation of industrial waste was 22.3 million tons, hazardous waste was 28,000 tons, hospital waste was 1,463 tons, and MSW was 626,000 tons, it is equal to 1715 tons/ day.

Table 1 Generation of various solid waste streams in Baotou in 2015

	Generation
Industrial Waste	22.3 Million tons
Hazardous Waste	28,000 tons
Hospital Waste	1,463 tons
MSW	626,000 tons

2.1 Industrial Waste

In 2014, the total generation of industrial solid waste in Baotou was 22.3 million tons, 66%(14.7 million tons) of recycling, 23% (5.1 million tons) goes to landfill and combustion, and 11% (2.5 million tons) was stored, which can be recycled further, as shown in Table 2.

Table 2 Industrial waste treatment techniques in Baotou in 2014

	Capacity, million tons	Percentage
Recycling	14.7	65.90%
Disposal	5.1	23.10%
Storage	2.5	11.00%
Total	22.3	100%

The mainly component of the industrial waste in Baotou is coal ash, smelting waste, tailing, cinder, desulfurization gypsum, and sludge. In 2014, the industrial solid waste consists of 29.1% coal ash, 26.1% smelting waste, 25.4% tailing, 8.2% cinder, and 5.6% desulfurization gypsum. The recycling rate was 88.7% for coal ash, 99.4% for smelting waste, 2.2% for tailing, 80.1% for cinder, and 63.5% for desulfurization gypsum, as shown in Table 3.

Table 3 Composition of industrial waste in Baotou in 2014

Indicators	Coal Ash	Smelting Waste	Tailing	Cinder	Desulfurization Gypsum
Yield (k-tons)	6486	5825	5654	1838.4	1239
Yield Percentage (%)	29.1	26.1	25.4	8.2	5.6
Recycling (k-tons)	5753	5803	122	1475.6	786
Recycling Percentage (%)	88.7	99.4	2.2	80.1	63.5
Disposal (k-tons)	13	0.3	5068	54.6	0
Disposal Percentage (%)	0.2	0	89.6	3	0
Storage (k-tons)	720	35	464	310.9	453
Storage Percentage (%)	11.1	0.6	8.2	16.9	36.5

The top five industrial solid waste producers are:

1. Baotou Steel (Group) Corporation;
2. East Hope Rare Earth Aluminum co., LTD;
3. Baotou Shibao Iron Group co., LTD;
4. Baotou Walter(Group) co., LTD.;
5. East Power Company Shen Hua Salaqi Power plant;

The generation of industrial solid waste from these five companies was 12.163 million tons, accounted for 54.5% of the total amount of industrial solid waste, as shown in Table 4.

Table 4 The top 5 producers of industrial solid waste in Baotou in 2015, k-tons

Producers	Total Industrial solid waste	Tailing	Smelting Waste	Coal Ash
Baotou Steel (Group) Corporation	599.5	----	426.8	91.8
East Hope Rare Earth Aluminum co., LTD	228.2	----	----	169.2
Baotou Shibao Iron Group co., LTD	156	156	----	0
Baotou Walter(Group) co., LTD.	116.8	116.7	----	
East Power Company Shen Hua Salaqi Power plant	115.8	----	----	87.5
Total	1216.3	272.7	426.8	348.5

2.2 Hazardous Waste

In 2014, the generation of Hazardous waste in Baotou was 28,015.8 tons, and 77.3%(21783.3 tons) was recycled, 16.2%(4571.0 tons) was stored, and 6.5%(1925.2 tons) was disposed, as shown in Table 5.

Table 5 The percentage of the hazardous waste in different treatment in Baotou(2014)

	Capacity, tons	Percentage
Recycling	21738.3	77.3%
Disposal	1825.2	6.5%
Storage	4571	16.2%
Total	28015.8	1

Types of produce industrial hazardous waste in the city mainly are, waste acid, steam distillation residue, inorganic fluoride waste, waste containing arsenic, waste containing phenol and others. The top five categories hazardous waste production amount are shown in Table 6.

Table 6 The Composition of hazardous waste in Baotou (2014)

	tons	Percentage in total hazardous solid waste
Waste acid	12471.2	44.5%
Steam distillation residue	5302.9	18.9%
Inorganic fluoride waste	3244.7	11.6%
Waste containing arsenic	2116	7.6%
Waste containing phenol	1931.9	6.9%

The top five hazardous waste producers are:

1. Baotou Huamei Rare Earth Hi-tech co., LTD.;
2. Baotou steel(group) company;
3. Inner Mongolia Baotou Rare Earth Steel company;
4. Baotou Huading Copper Industrial Development co., LTD.;
5. Baotou Aluminum co., LTD.;

These companies generated about 25,085 tons of hazardous solid waste, accounting for 89.5% of the total amount of the hazardous waste in 2015, as shown in Table 7.

Table 7 The top 5 producers of hazardous solid waste in Baotou (2015)

Company	Yield(tons)
Baotou Huamei Rare Earth Hi-tech co., LTD.	12470
Baotou steel(group) company	5631.7
Inner Mongolia Baotou Rare Earth Steel company	2806.4
Baotou Huading Copper Industrial Development co., LTD.	2116
Baotou Aluminum co., LTD.	2061
In total	25085.1

Three companies got license to manage hazardous waste in Baotou city:

Baotou Huineng Renewable Resources co., Ltd and Inner Mongolia Jiuduan Energy Technology co., Ltd are licensed by the Department of Inner Mongolia Autonomous Region Environmental Protection and Baotou; HuiQin Waste Lubricating oil recycling station is licensed by the Baotou Jiuyuan District Department of Environmental Protection, as shown in Table 8.

Table 8 Licensed companies for hazardous waste management in Baotou (2015)

Name of company	Categories of permission to disposal hazardous waste	Capacity(tons/year)	Actual scale in 2014	Categories of permission	Time of Permission
Baotou Huineng renewable resources co., LTD	Mineral waste oil	1500	459.4	Collect, Transportation, Storage, Disposal	5 Years
Inner Mongolia Jiuduan energy technology co., LTD	Mineral waste oil	20000	527	Collect, Transportation, Storage, Disposal	5 Years
Baotou HuiQin waste lubricating oil recycling station	Mineral waste oil	Less than 5000 KG per time and with 90 days		Collect	1Year

2.3 Hospital Waste

For the management of hospital waste there is only one company in 2015 as presented in Table 9.

Table 9 Inner Mongolia Baotou sunshine beauty environmental protection co., LT

	Inner Mongolia Baotou sunshine beauty environmental protection co., LT
Capacity(tons/year	248
Actual scale in 201	146
Categories of permission	Collection, Transportation, Storage, Disposal
Period of Permission	1 Year

2.4 Municipal Solid Waste (MSW)

2.4.1 MSW Composition

The nature of municipal solid waste mainly includes physical, chemical and sensory properties. The nature of municipal solid waste is closely related to its composition. Physical properties of MSW mostly refer to moisture content, bulk density, calorific value; chemical properties refer to an elemental composition, ash, and volatile grading.

Knowledge of the calorific value of post-recycling MSW is necessary since its part that is not landfilled can be the fuel of a WTE furnace. Themelis et al. found that the closely approximated chemical formula of the mix of organic compounds in MSW can be expressed as C6H10O4. The chemical equation for full combustion of the organic compounds in MSW is shown as following:

$$C_6H_{10}O_4 + 6.5O_2 = 6CO_2 + 5H_2O$$

This is a highly exothermic reaction, and heat generated during combustion is 2.7 MJ/kilo mol of organic compound at the combustion temperature of 1000. The calorific value of MSW decreases due to the presence of moisture and non-combustible materials. (Themelis et al., 2011)

Due to the waste sorting is not implemented in China, the high moisture and non-combusted waste are not separated from the MSW. And most Chinese residents just recycle the waste with high heating value, such as plastics bottles, because they can be sold to some pedlars. Due to the lack of kitchen waste separation, the largest proportion of MSW is food remnants, and they are sent to the landfilling of WTE plants. Therefore, the three key features of MSW in China are low calorific value, high moisture content and a high proportion of organisms. (Jun et al., 2011)

Table 10 The component of MSW in China' cities (Source: Tao et al., 2009; Zhang et al., 2014; Li et al., 2008; Zhuang et al., 2008; He et al., 2008; Shao et al., 2009)

City	Kitchen Waste	Paper	Plastics	Textile	Wood	Non-combustible	LHV [kJ/kg]
Baotou	**55.3**	**8.21**	**10.51**	**3.09**	**3.09**	**15.6**	**5880**
Chengdu	47.06	15.76	14.98	1.72	0	20.48	5590
Chongqing	72.97	9.34	8.4	3.16	1.91	4.22	3572
Dalian	59.86	14.39	6.19	4.67	2.1	1.36	4491
Hangzhou	64.48	6.71	10.12	1.22	0.05	17.42	4626
Shanghai	69.17	9.11	13.26	2.91	1.26	5.29	5050
Suzhou	62.63	10.89	18.59	4.18	0.86	2.85	5445
Urumqi	75.95	2.41	5.37	4.19	2.53	9.55	8322

As shown in Table 10, kitchen waste is the largest fraction of MSW in China's cities, while the high heating value waste, such as plastics and paper, are the small fraction. Compared with US MSW

In China, MSW composition is more complex, mainly affected by residents living standards, socio-economic level and climatic conditions such as seasonal changes. (Qdais et al., 1997).

In recent years, as Baotou city implemented more gas supply and expanded the centralized heating area, the non-combusted component of MSW such as coal ash is decreasing With the rapid development of the residents living standards, organic contents in municipal solid waste is increasing, while a proportion of inorganic component relative declined.

Organic components consist of kitchen residue, garden waste, plastic, rubber, paper and a small amount of cloth fiber and bamboo. Kitchen waste includes vegetables, eggshells, food residues. Plastic and rubber mainly are plastic bags, lunch boxes, and industrial waste material, in which plastic bags were mostly used for packaging and collecting small pieces of garbage such as peel, paper, and kitchen residue. Papers are mainly from daily family utilization and a small amount from office and industries. Fiber cloth is mostly waste fabric from industrial production and used clothes. Bamboo comes from disposable sanitary chopsticks.

According to the city sanitation department reported in June 1999, after pretreatment to remove glass, brick, stone and non-combustible components, the calorific value was 5,880KJ/kg (1406.6kcal/kg). Compared with the other cities in China, Baotou city has a relatively higher LHV, due to the consumption habit of the people in Baotou.

2.4.2 MSW Generation

As for all other cities of China, the amount of MSW generated has grown with population growth and also social and economic development. The former reason is dominant. Based on the generation of MSW for every person for every day is about 0.8~1 kg/capita/day (Fu, 2007; Omran, 2009), the MSW generation per year in Baotou city would be:

$$M = 0.8 \sim 1 kg/day \cdot capita \times population \times 365 days$$

Figure 6. shows the past trend and the projection of MSW generation in the future. The yellow columns in Figure 6 are the MSW disposal capacity in Baotou, and in 2011, 2012, 2013, 2014 and 2015 is 0.823, 0.515, 0.585, 0.626 and 0.758 million tons respectively(data from of Baotou Environmental Sanitation Industry Co., Ltd). The light green columns are the MSW generation per year if the average generation is 1.0 kg/capita/day and the light green columns are from the number of 1 kg/capita/day. Only in 2011, the treatment capacity higher than the total generation when the average generation is 0.8kg per capita per day. There are some reasons for the problem. The most important and possible reason is that there is still some MSW is disposed of illegal. In Baotou, there are still have many “illegal landfill sites” (i.e. waste dumps). These sites landfill or set fire to MSW without any equipment or treatment, as shown in Figure 7.

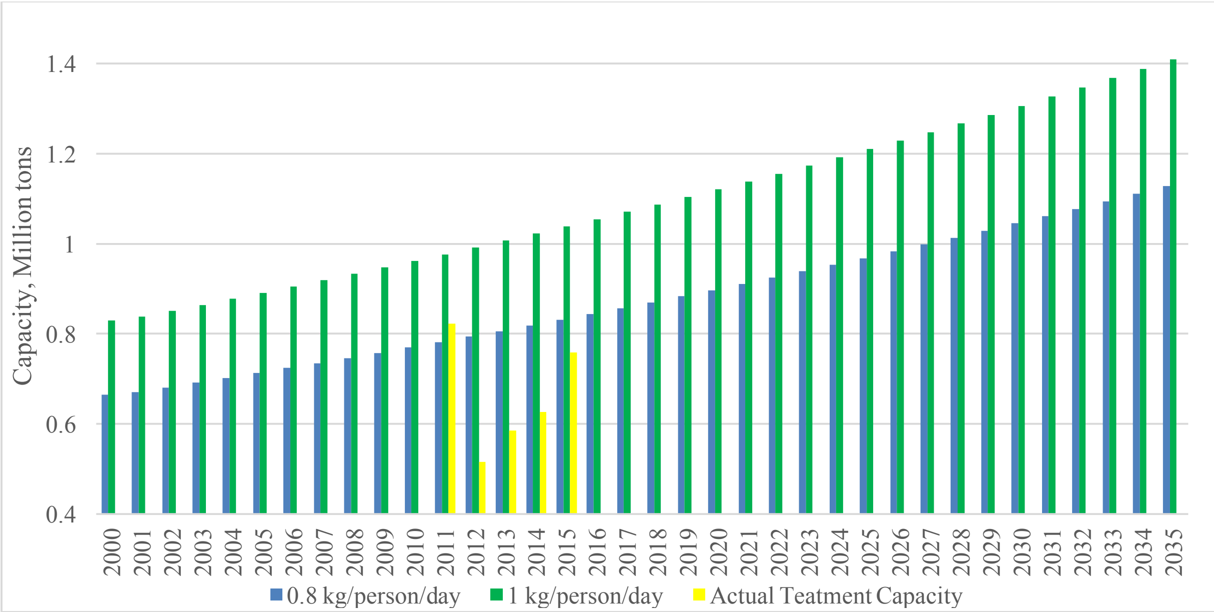

Figure 6 The PER CAPITA generation of MSW in Baotou and its prediction

Figure 7 Illegally MSW disposal in Baotou

2.4.3 Current MSW Collection and Transportation System in Baotou

In Baotou, each MSW collection station cover the area of 1~1.5km^2 and the collected MSW is transported by sanitary trucks from these stations to 2 landfills fields or the Pulangte WTE plant. These sanitary trucks usually pick MSW up from the stations after 4:30 pm in winters and after 7:00 pm in summers, and residents are allowed to pour their MSW anytime.

There are three different collecting stations in Baotou city:

<u>1.Container collecting station</u>

Container collecting station collects MSW from residential areas directly and then put them onto a truck by a crane. Due to no compression device in the container, the deficit load is a problem for this type of MSW collection.

<u>2.Ground collecting station</u>

MSW is poured directly on the ground, and then collected and loaded on trucks by hands. Some recycle such as plastic bottles will be collected by these workers. The outdated collecting station will lead to MSW exposure; it will make the nearby residents live in a awful environment.

<u>3.Closed collecting station (transfer station)</u>

Each transfer station has the service area of 1~1.5km^2. Its main characteristic is to set up a room that can put two MSW containers simultaneously and also a parking lot for MSW collection trucks, and also equipped with lifting and compressing devices. The MSW is poured into the containers, compacted after filled up, loaded onto the trucks and transported to the landfill sites or WTE plants and unloaded, then returned the empty containers and repeating. This collection method solved the problem of waste exposure and secondary pollution but required a significant amount of investment. At present, Baotou city adopts this approach for MSW collection and transportation.

There are 89 transfer stations in the city. These transfer stations are sorted into 62 compressional and 27 vessel type. Compressional transfer stations scattered all over the city: 20 in Qingshan District, 19 in Kundulun District, 17 in Donghe District, 2 in Jiuyuan and 4 in Gaoxin. The compressional transfer stations can be sorted as horizontal compressional and vertical compressional.

2.4.4 Current MSW Plants in Baotou

Baotou has two landfill sites, one is the Baotou Donghe MSW landfill site, as shown in Table 11. Its investment was 22 million dollars, and its total capacity is 5.2 million cubic meter, and capacity is 600 tons per day.

The another landfill site is the Baotou MSW Disposal Center, as shown in Table 12, which is processing the MSW from Kun District and Qingshan District. Its investment was 25 million dollars; total capacity is 6.7 million cubic meter, capacity is 800 tons per day.

Table 11 Donghe District landfill site

	Donghe District landfill site
Investment	22 Million Dollars
total capacity	5.2 Million m3
Capacity	600tons/d

Table 12 Baotou MSW Disposal Center

	Baotou MSW disposal center
Investment	25 Million Dollars
total capacity	6.7 Million m3
Capacity	800tons/d

Pulangte Transportation Energy is owned by Jinjiang Group, and located at Machi town. The plant covers an area of 88445 square meters (8.8 hectares). The plant is equipped with 3 x 450 t/d circulating fluidized bed furnaces and 3 x 12 MW turbo-generator set. In 2015, the plant disposed 267,000 tons of MSW and generated 98,330 MWh of electricity, corresponding to 0.37MWh of electricity per ton MSW.

3. Technologies used for WTE

By now, recycling, composting, WTE and landfilling are the four MSW disposal methods used worldwide.

With the rapid development of China, landfills have occupied more and more urban land nearby the cities; this has led to conflicts between landfills and other used of land and has become a serious problem for China's next development stage (Xin Gang, 2016). Another potential problem for landfill is that leachate of MSW contains lots of organic acids, and can pollute surface and underground water for many decades (Matthews, 2016). In China, kitchen waste is collected, transported and treated in a mixed state. The leachate percolation and unpleasant odors of kitchen waste have also led to serious environmental problems.(Jun Tai et al., 2011)

Composting requires a sophisticated MSW collection system with a high level of waste sorting, and the composting process of MSW requires a long-term storage (1year) (Déportes, 1998).

In comparison to landfilling and composting, there are several advantages in using WTE to dispose MSW:

1. No strict requirement for waste sorting and the processing of WTE is very fast (Tian, 2013).
2. The history of incineration of MSW is more than 100 years, and the technologies are very mature and stable, the schematic diagram of the process shows in Figure 8.
3. Significantly reduce the volume of MSW more than 90%. One WTE plant can not only save up land but also can be closed to cities; it will reduce the cost of transportation of MSW (Pianqiao Duan, 2013).
4. Efficiently recover energy and material values contained in MSW, and get both economic and environmental benefits (Nickolas Themelis, 2011).
5. Reduce the environmental impacts, the high temperature in the incinerators can completely kill the pathogen and decompose the harmful ingredients. Some viral contaminants, flammability carcinogens, and toxic organic compounds can be deposed effectively (Jiakun Li, 2010).

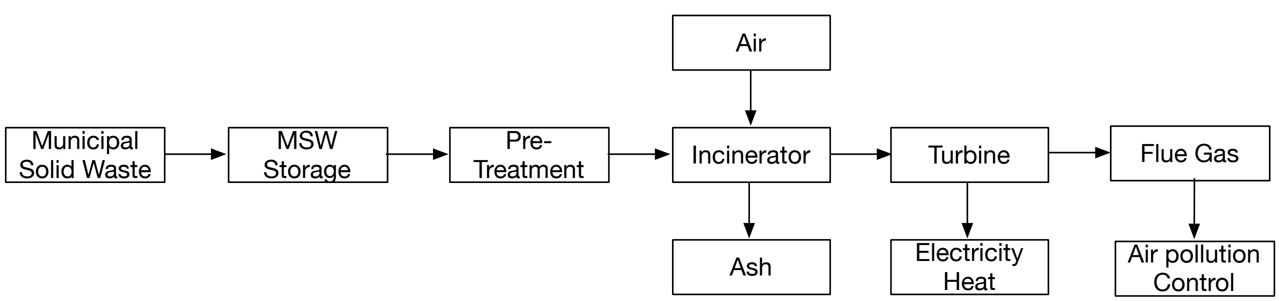

Figure 8 The schematic diagram of the process

3.1 Moving Grate (MG) WTE Technology

A typical WTE plant mainly consists of the three systems, incinerator, turbine and air pollution control system. And the incineration technology is the most important part of WTE plants, and they can be classified by the several types, such as moving grate incinerators, circulating fluidized bed incinerators et. (Zheng et al. 2014)

The typical grate combustion WTE plant process is described and illustrated by the example of Shulin WTE plant, as shown in Figure 9. ShuLin WTE plant is owned by EPB Taipei County, Taiwan. The disposal capacity of the plant is 1,350 tons per day of MSW. The plant consists of three lines and each line rated at 450 TPD. The plant is equipped with Martin moving grate and operates at a temperature of 950°C. (Liang et al., 2011). The heating value of MSW in Taitwan is about 9,945KJ/KG (Shang-Hisu, 2005). The heat of the combustion of MSW is recovered in a boiler and used to generate 24 MW of electricity. (Liang Chia Chang, 2011)

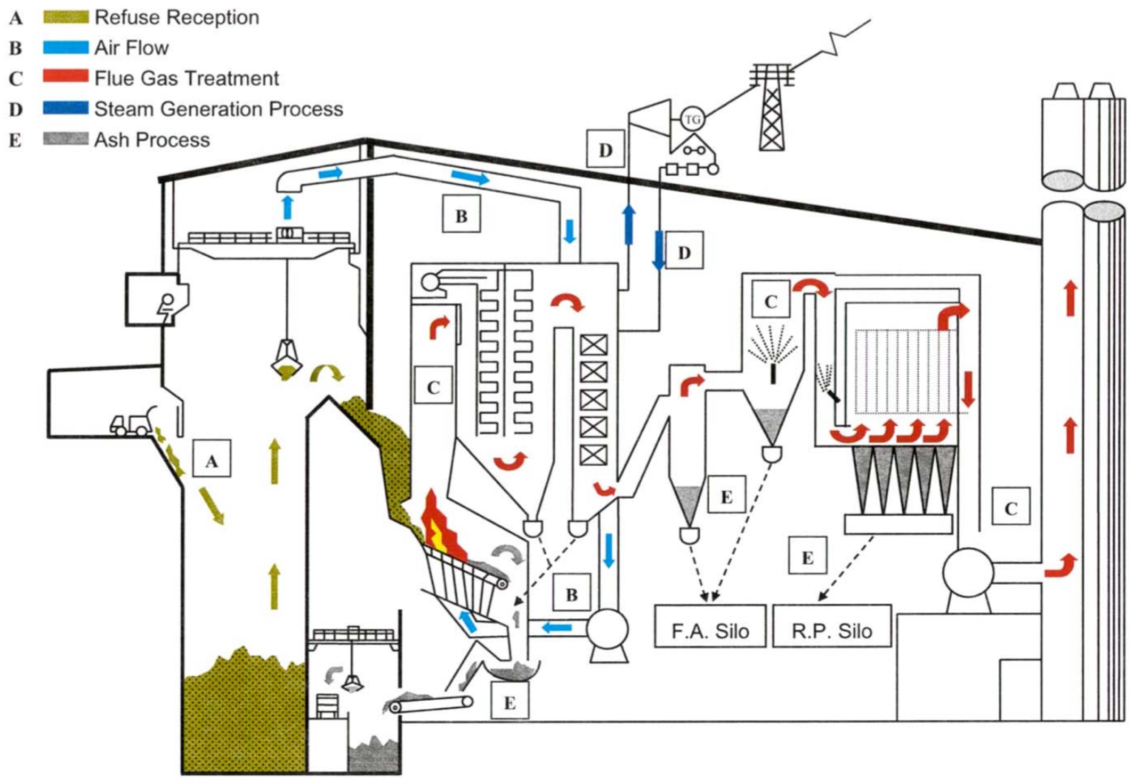

Figure 9 Shulin moving-grate WTE plant flow process (Sources: Liang Chia Chang, 2011)

The MSW is collected and transported to the WTE plant by trucks. After arriving the plant, the trucks will pass through the weighing station and then enter in an enclosed building to upload the MSW into the waste pit. Some bulk non-combustible items such as bulk electronics and concrete will be removed. The enclosed building will remain negative pressure to prevent odor leakage. Typically, the waste bunker can hold a week's feedstock. MG incinerator has the advantage that except bulky waste such as mattress must be pre-treated by shredding, the remaining part does not require any pre-treatments before fed into the furnace. A claw crane will pick up the waste from the bunker into a hopper which can move the waste to furnace.

During the combustion process in the furnace, the motion of the moving grate can slowly move the waste through the combustion chamber. In some WTE plants with the inclined grate, the gravity will also help the waste move toward the lower side of the combustion chamber, as shown in Figure 10. In the combustion chamber, the primary air is blown from the bottom of the air chamber which is under the grate into the furnace, through and mix with the MSW, to promote the MSW combustion. The secondary air is insufflated from the tube above the grate. The primary role of the secondary air is promoting the combustion of the volatile gas such as CO and the unburned MSW.

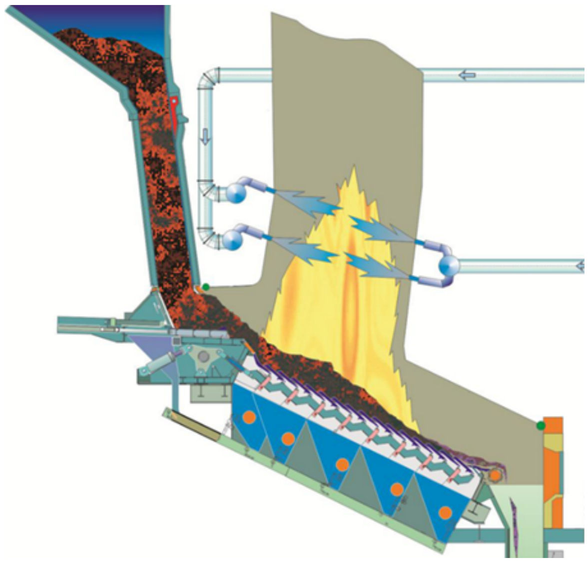

Figure 10 Schematic diagram of a moving grate combustion chamber (Martin Gmbh)

The ashes can be collected at the lower end of the grate. The hot gasses after the combustion of the MSW are pass through heat exchangers to heat up water. The water will become superheated steam which will drive the turbine to generate electricity. After cooling process, the flue gas will go through the Air pollution control (APC) system and finally emitted to the air.

3.2 Circulating Fluid Bed (CFB) WTE Technology

3.2.1 Fluidization regimes

In a fluidized bed reactor, the solid fuel and the inertia bed materials are suspended by upward flowing gas flue during the combustion process. With increasing gas velocity in fluidized bed reactor, several flow regimes will be formed; they are fixed bed, bubbling regime, turbulent regime, fast fluidization and dilute pneumatic conveying regimes (Grace et al., 1997), as shown in Figure 11.

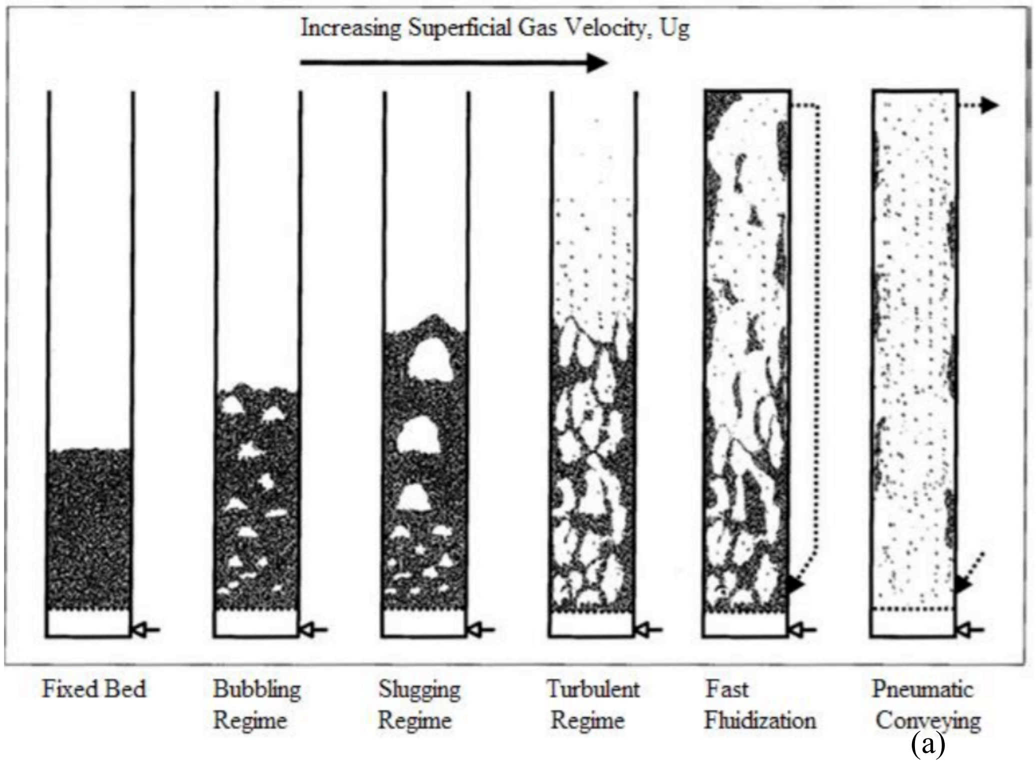

Figure 11The regimes in a fluidized bed reactor(Source: Grace et al, 1997)

For the paper, the author just introduces the two main regimes: bubbling fluidized bed(BFB) and circulating fluidized bed(CFB). The fluidized beds employed gas flow with velocity to keep the particles inside of the chamber in the fluidized state. When the V0 is less than minimum fluidizing velocity, U_{mf} (given by Ergun, 1952), the reactor will be fixed bed, as shown in (a) in Figure 12, the particles are supported by the air distributor on the bottom of the reactor. Keep increasing of the velocity of the gas flow, when the V_0 is greater than the minimum fluidized velocity U_{mf} and less than the full fluidization velocity U_{ff} (given by Ergun, 1952), the solids will be suspended and supported by the gas flow; this fluidization regime is called bubbling fluidized bed (BFB). When V_0 keeps increasing, more and more bubbles will be formed, and theses bubbles will rise, coalesce, and finally rupture, the phenomenon is like boiling water.

When V_0 is greater than the terminal velocity, U_t (given by Haider et al., 1989), the particles will be blown out of the reactor. If there are no new solids added into the reactor, the reactor will be blown empty quickly. Therefore, it is necessary to replace the fresh solids and if mount a separator on the top of the reactor to return heavier and larger particles back to combustor, the CFB is formed (Raji, 2012), as shown in Figure 12 (d)

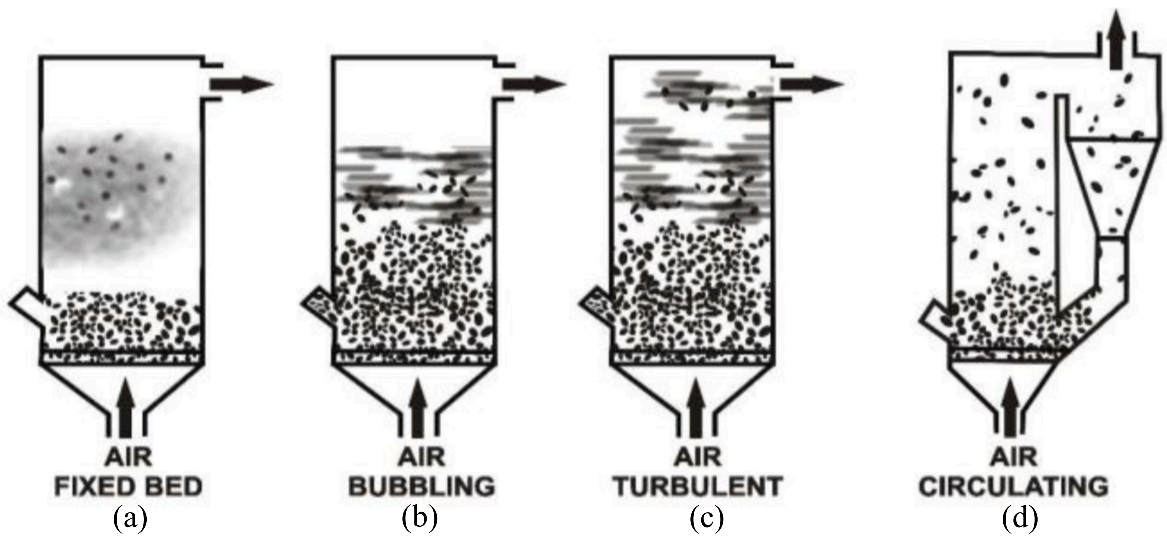

Figure 12 schematic drawing shows transition from packed bed to circulating bed

In a typical BFB combustor, the gas velocities are between 0.5 and 3.0 m/s. The size of the feed should be not very fine to avoid the feed is not complete combusted before it is blown out of the chamber. In circulating fluidized bed reactor, the gas velocities are between 3.0 and 9.0 m/s(Reference Van Caneghem, 2012).

3.2.2 CFB WTE plant

The typical CFB WTE plant process is described and illustrated by the example of Cixi, China, provided by Zhejiang University, as shown in Figure 13.

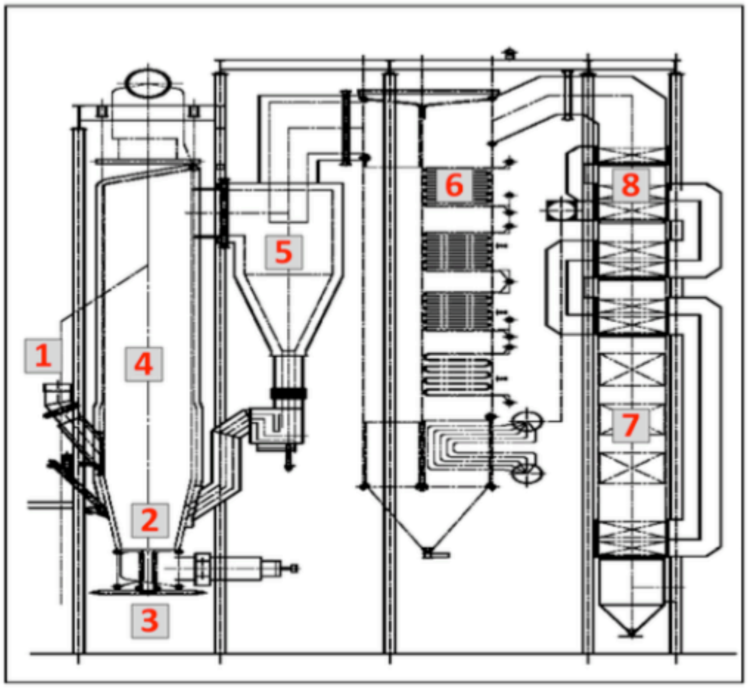

Figure 13 Layout of 800 t/d CFB incinerator at Cixi, China(Qunxing Huang et al. 2013)

Two shredders are mounted on the walls of the pit, which is closed to the feeder, to ensure the MSW particles is less than 15 cm before they are feed into the incinerator. It is important to note that one of the two shredders used as a backup when another one is maintenance. It will make sure the plant can operate continuously. The shredded MSW are dropped into feeder (section (1) in Figure 12). The CFB reactor of CIXI WTE plant consists of two zones: bubbling fluidized bed (BFB) and circulating fluidized bed (CFB). The heavier and larger particles are engaged in bubbling bed. The particles are supported by gas introduced through air distributor (2) at the bottom of the chamber.

The temperature of the primary air is be increased to 300 °C by air preheater (8) to improve the combustion efficiency of the furnace. The gas flow carries the particles through the incinerator (4) to finish the combustion process and finally out of the chamber. Bottom ash discharger (3) is below the incinerator to collect the bottom ash, which is quenched with water. Mounting a cyclone separator (5) at the top of reactor to separate the heavier particles from the gas flow and return them to the furnace. And the reactor has to be continuously replaced the fresh MSW.

The hot gasses will pass through the superheater (6). Heat transfer from the hot combustion gasses boiled the water in the tubes of the superheater, producing high-pressure and high-temperature steam. The steam will drive the turbine to generate the electricity.

3.2.3 Co-combustion of MSW and coal in CFB incinerator

Due to the high moisture and low heating value of the MSW in China' cities, some WTE plants with CFB are not self-sustaining. These plants require auxiliary fuel to help the complete combustion of the MSW and ensure the temperature in the combustion chamber never dropped below 800 ^{o}C. For example, the WTE plant in Changchun city, China, as shown in Figure 14. The plant equipped with CFB incinerator and fed shredded coal by a screw conveyor into the furnace. In the furnace, the MSW mixed with the shredded coal and they are suspended by the upward-blowing flue gas to finish the combustion process together. The amount of the coal fed into the furnace can be controlled and it will be decided by the temperature of the furnace. (Hefa Cheng et al., 2007)

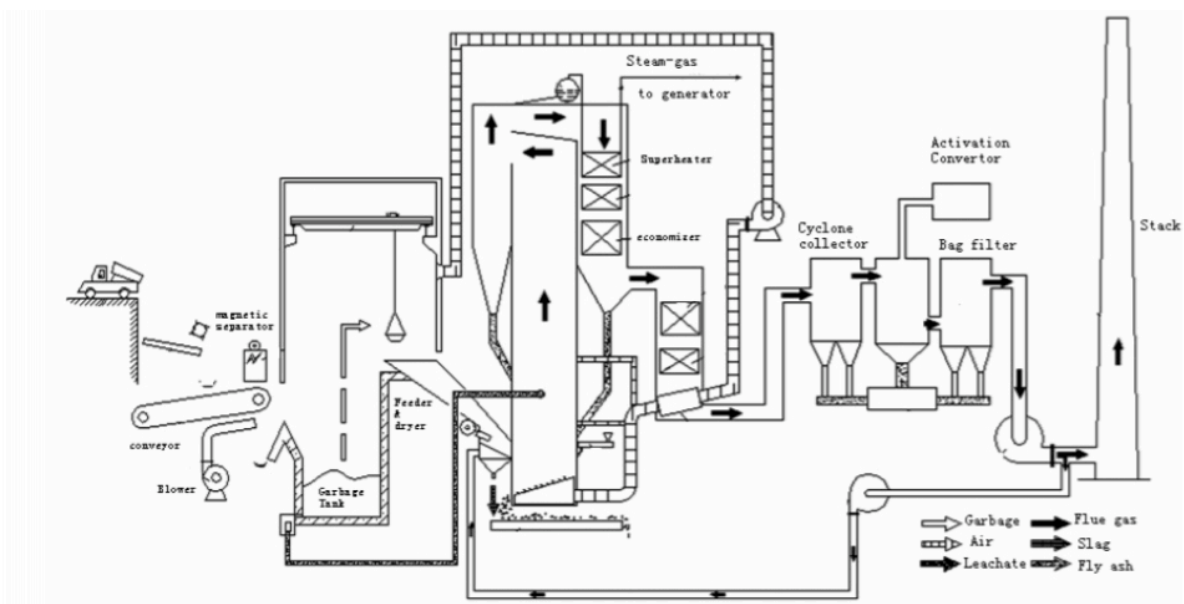

Figure 14 Schematic diagram of the WTE plant in Chang Chun, China (Source: Hefa et al., 2007)

3.2.4 Combined Heat and Power (CHP)

WTE plant use the heat from combustion of MSW to generate electricity; meanwhile the heat can be used for District Heating(DH) and Cooling. In western countries, combined heat and power in WTE plants has been developed widely. Compared with the WTE plants solely for power generation, CHP has the following advantages: higher thermal efficiency of WTE and reduction of carbon dioxide emissions to atmosphere. (Priscilla, 2007)

Generally the efficiency of thermal recovery in the WTE plants, which are generate electricity solely is 13%-25%; however CHP can improve it to 50%-70%(Zhu et al, 2011)

To encourage WTE plants improve the thermal efficiencies, the European Union has introduced the R1 rule(WTERT Guidebook).

$$\boldsymbol{R1} = \frac{\mathbf{2.6} \times \boldsymbol{MWh_{elec}} + \mathbf{1.1} \times \boldsymbol{MWh_{heat}}}{\mathbf{0.97} \times \boldsymbol{MWh\ stored\ in\ theMSW}}$$

Where MWh_{elec} and MWh_{heat} express the energy output of electricity and heat respectively. For example, one WTE plant generate 0.6MWh of electricity per ton, and the calorie value of the MSW is 2.8 MWh per, the R1 factor would be:

$$\boldsymbol{R1} = \frac{\mathbf{2.6} \times \mathbf{0.6}\ \boldsymbol{MWh}}{\mathbf{0.97} \times \mathbf{2.8}\ \boldsymbol{Mwh}} = \mathbf{0.63}$$

In Europe, WTE plants can generate o.5 MWh of electricity plus 1 MWh of heat, the R1 factor would be:

$$\boldsymbol{R1} = \frac{\mathbf{2.6} \times \mathbf{0.5}\ \boldsymbol{MWh} + \mathbf{1.1} \times \mathbf{1}\boldsymbol{MWh}}{\mathbf{0.97} \times \mathbf{2.8}\ \boldsymbol{Mwh}} = \mathbf{0.88}$$

The electricity lost from 0.6 MWh to 0.5 MWh because that extracted steam flow to the heat supplied cause the deduction of pressure in turbine in CHP. Generally, the ratio of the electricity lost will range 0.1-0.2 MWh of electricity per MWh of thermal energy obtained(Oliker et al., 1980). Based on the comparison of R1 in two examples, CHP can get a higher thermal efficiency.

A typical CHP system includes three principal components: thermal production plant(WTE plant), thermal transmission and distribution network (hot water or steam pipe) and customers' in-building equipment. The piping system of CHP can serve the heat up to 32km with limited heat loss (Priscilla Ulloa, 2007). Due to the location of the project is not clear by far, the revenue and cost of DH service is considered in the further work.

3.3 Other technologies

Gasification for WTE process is a thermal treatment process that uses partial oxidation to convert MSW to a gaseous fuel that contains hydrogen and carbon monoxide (‘syngas’’). The syngas is produced in the first furnace and can be completely combusted in the second furnace(WTERT guidebook) or can be used in gasses engine or turbine (Lombardi et al., 2011). Several major types of gasification reactors are used worldwide: fixed bed, fluidized bed, moving grate furnace, rotary kiln and plasma reactor (Arena, 2012).

A main weakness for MSW gasification is that the undesired compounds such as tar, chloride and sulfide will be produced in the syngas (Di Gregorio et al., 2012). Therefore the waste sorting is necessary for using WTE gasification. A variety types of waste can be fed to gasification processes: ASR (Vigano et al., 2010), RDF(SRF) (Lombardi et al, 2011); mixed plastic waste (Arena, 2011); packaging derived fuel (Di Gregorio et al., 2012); paper industry waste(Ouadi et al., 2013). Due to the mixed MSW state without implement waste sorting, the gasification is not recommended for Baotou city.

3.4 MG vs CFB technologies

Prof. Huang summarized five main features of CFB after 20 years of its development and applications in China (Huang et al., 2013), as shown in Table 13:

Table 13 Features of CFB incinerators to dispose MSW in China. (Huang, 2013)

High adaptability to different MSW	The pre-shredding of MSW and high turbulence in the CFB furnace can make sure the high combustion efficiency of almost all kinds of MSW.
Effective control of pollutants	The temperature in the furnace can be well controlled in the range of 800~950 °C. It will reduce the formation of pollutions, such as CO, NOx and dioxin at this temperature range.
Compact size	The heat flux rate per square meter of furnace cross section is commonly 4-6 MW/m2 in CFB plants in China, which is approximately four to five times higher than that per square meter of MG area.
Outstanding load adjusting capability:	Outstanding load adjusting capability: The waste treatment load of a CFB incinerator can be at the range of 50%~110% with stable combustion.
Excellent capability of co-combustion:	Excellent capability of co-combustion: When the moisture of the waste is too high or the heating value is too low, other auxiliary fuels, such as coal can be fed to maintain combustion temperature.

In China, CFB incinerators are less capital intensive than the MG incinerators, and can efficiently process China's MSW with the heating value as low as 5MJ/kg, and as the same time can dry discharge of bottom ash continuously. (Huang et al., 2013)

CFB incinerators are more adaptable to the waste with low heating value and high moisture than MG incinerators. (Van Caneghem et al. 2012) To burn the low heating value MSW with high moisture and keep the temperature of the incinerator in the range 800~950 °C, the pre-heating air is introduced in CFB incinerator. In the furnace, the inertia bed materials have large thermal storage capacity and they are in a fluidized state with MSW, and it will result in severe contact, mixing and heat exchange between them. Therefore, the bed materials as the heat carrier can heat MSW up instantaneously till MSW is burnt out. Finally, the changes in heating value and moisture content of the MSW can more easily be absorbed by the CFB than in MG (Brems A et al., 2011)

When the amount of MSW changes with seasons changes or calorific value is not stable, auxiliary fuel (e.g. coal) can be fed into the CFB incinerator and co-combusted with the MSW to guarantee the temperature in the chamber in the range 800~950 °C.

The development of WTE technology in China has achieved a significant breakthrough, especially the rapid one of CFB incinerators that created favorable conditions for waste incineration in recent years. At present, the usage of CFB in WTE plants in China is increasing, and the operation and management are getting mature. For this project, circulating fluidized bed incinerator is recommended.

4. Air Pollution Control

From 2014, China began to implement a new emissions standard, GB18485-2014, as shown in Table 14. Compared with the old standard (GB 18485-2001), the new standard requires stricter control of the pollutants from the WTE plants. In the new standards, the limitation of dioxins is 0.1 ng-TEQ Nm^{-3}, compared with it in the old standard is 1 ng-TEQ Nm^{-3}. Due to the tighter restriction of the emissions for waste incinerations, an advanced and stable air pollution control(APC) system is necessary to the project.

Table 14 Emissions standards in waste incineration (Source: Ji,L, 2016)

Pollutants	Units	GB 18485-2014	EU 2000/76/EC	GB 18485-2001	EU 1992
Particulate matter	mg m^{-3}	30	10	80	30
HCl	mg m^{-3}	60	10	75	50
HF	mg m^{-3}	-	1	-	2
SO_X	mg m^{-3}	100	50	260	300
NOx	mg m^{-3}	300	200	400	-
CO	mg m^{-3}	100	50	150	100
TOC	mg m^{-3}	-	10	-	20
Hg	mg m^{-3}	0.05	0.05	0.2	0.1
Cd	mg m^{-3}	0.1	0.05	0.1	0.1
Pb	mg m^{-3}	1	≤0.5	1.6	-
Other heavy metals	mg m^{-3}	-	≤0.5	-	6
Dioxins	ng-TEQ Nm^{-3}	0.1	0.1	1	0.1
Blackness	Ringelmann	1	-	1	-

To keep the emissions under the limitation of the regulation, the single equipment or technology cannot accomplish it. Therefore, a typical APC system includes several equipment or technologies to serve them particular purpose. Table 15 gives an indication of technologies used for the treatment of the flue gasses in WTE plants (WTERT Guidebook).

Table 15 Main APC systems in WTE plants

Parameter	Used abatement technology
Suspended solids	Cyclones
	Electrostatic precipitator (wet – dry)
	Bag filters
Acid gases	Dry sorption
	Semi dry sorption
	Wet scrubbers
Nitrogen oxides	Selective non catalytic reduction
	Selective catalytic reduction

Acid gasses neutralization and particulate removal are the main tasks for APC system. Table 16 shows the comparison of three different type of technologies combination used in APC system. Compared with the Dry scrubber, Semi- dry scrubber can remove acid gasses, heavy metal and toxic organics more efficient with a lower operating cost (Zhang, 2005). The semi-dry scrubber does not produce wastewater, since its operating temperature is higher than 140 ^{0}C; compared with wet scrubber, its water consumption is lower. (L Ji et at., 2016).

Table 16 Comparison of typical flue gas cleaning processes(Zhang, 2005)

Pollutants	Unit	Dry scrubber and Bag filters	Semi-dry scrubbers and Bag filters	Wet scrubbers and Bag filters
SOx	mg m−3	<300	<200	<60
HCl	mg m−3	<80	<30	<30
Particulate	mg m−3	<30	<10	<25
Removal rate of heavy metal and toxic organic		High	Very high	Little
Fly ash		Much	Middle	Much
Sludge and sewage		No	No	Much
Project investment		Low	Middle	Very high
Operating cost		High	Middle	Very high

Besides, due to MSW contains a large number of chlorinated organic compounds, it will lead to forming some toxic substances in the flue gas after the combustion process, such as dioxin. To reduce these volatile organic compounds, the project should keep the high combustion temperature (greater than 800° C) and the retention time (longer than 2s) of MSW in the furnace. Moreover, the active carbon is used as adsorbent to remove dioxin and other toxic gas in most of WTE plants (Lu, 2005)NH_3 or urea can be utilized for NOx removal based on selective non-catalytic reduction (SNCR) or selective catalytic reduction (SCR) (Jannelli et al., 2007). In the SNCR process, the NH_3 or urea can be injected into furnace directly, due to the operating temperature can be higher than 850^{o}C. However, the operating temperature in SCR process is at the range between 200^{o}C and 400^{o}C. Otherwise, the catalysts will be deactivated in strong acid media. Therefore, the SCR process should be installed after baghouse, it will lead to the necessity of re-heat gas up, which will cause the increasing of operating cost(Margarida et al., 2011). A comparison between SNCR and SCR processes shows in Table 17.

Table 17 The comparison between SNCR and SCR(Sources: Margarida et al., 2011)

	SNCR	SCR
Advantage	Lower investment cost Lower corrosion problem	More efficient
Disadvantage	Limited efficiency	Higher investment cost Higher pressure drop Requires higher O_2 excess
Efficiency for NOx reduction	Up to 70% Typical 30 to 60%	Up to 85% Typical 50 to 80%

Most of the WTE plants in China choose the semi-dry scrubbers, activated carbon, urea(SNCR) and bag filters processes as their APC system because of its operation is simple and stable, cover a small area, and low investment cost (Lihong, 2007). Based on the recommendation from WTERT Guidebook and the operation of China WTE projects, the following equipment or systems are recommended for the project:
Semi-dry scrubber, Powdered Activated Carbon Injection, Bag filters, NOx removal, ID fan and Chimney and Emissions monitoring, as shown in Figure 15.

Semi-dry scrubber: The hot flue gas after the combustion of MSW will enter into semi-dry scrubber first. The powder of $Ca(OH)_2$ will be sprayed into the reaction absorption system as a slurry. Water injected together with the absorber promotes the reaction of the acid gasses with $Ca(OH)_2$. As the hot flue gas enter the semi-dry scrubber, the slurry of $Ca(OH)_2$ will cool them down and react with HCL and SOx molecules. If the reaction time between these acid gas and $Ca(OH)_2$ is longer than 1s, the acids(Qinshen, 2007) will be removed efficiently. A large amount of PM is formed in the tower, and they should be removed by the following bag filters
The main chemical reactions are:

$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O$

$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$

$Ca(OH)_2 + 2HgCl_2 \rightarrow CaHgCl_2 + 2H_2O$

Powdered Activated Carbon Injection: Powered Activated Carbon can absorb heavy metal and dioxins. The heavy metals in the flue gas, such as, mercury and thallium, and dioxins can be absorbed into the pore of the PAC, and form the small dust, which can be removed by the following bag filter also. Therefore, the PAC can deprive dioxins and ions pf heavy metal in the flue gas efficiently. The PAC will be injected after the semi-dry scrubber and before the bag filter.

Bag filters: The react between the acid gas and absorbent will generate solid particles(<1 μm), it will be very harmful to the environment. A Bag filters are usually installed downstream of the process; they operate at least at 150 °C to avoid generating clogging (Bodénan et al., 2003)

The fabric layer of the bag filter can absorb the particles with a diameter of smaller than mikrons. Therefore, bag filters can remove heavy metals and dioxins with a high efficiency. Moreover, if the filter cake contains AC, the toxic organic pollutants, and heavy metals removal efficiency can be more than 99 wt%. (Grieco et al., 2009)

Bag filters can not only collect the small dust but also absorb the further acid residues at the same time. The unreacted lime will be retained in the bag filters and can continue to react with acid gas; it will improve the final removal efficiency (Ji, 2016).

NOx Removal: In SNCR, ammonia or urea will be injected into the furnace to reduce NOx emissions. The absorbent requires a strict temperature range. The NH3 should be reacted at the temperature range between 850 and 950 0C. If the temperature is too high, it will generate the unwanted NOx. If the temperature is too low, the efficiency of the reaction will be decrease and the NOx emissions will be increased (WTERT Guidebook). The main chemical reactions are:

$2NO + 4NH_3 + 2O_2 \rightarrow 3N_2 + 6H_2O$

$2NO_2 + 8NH_3 + 4O_2 \rightarrow 5N_2 + 12H_2O$

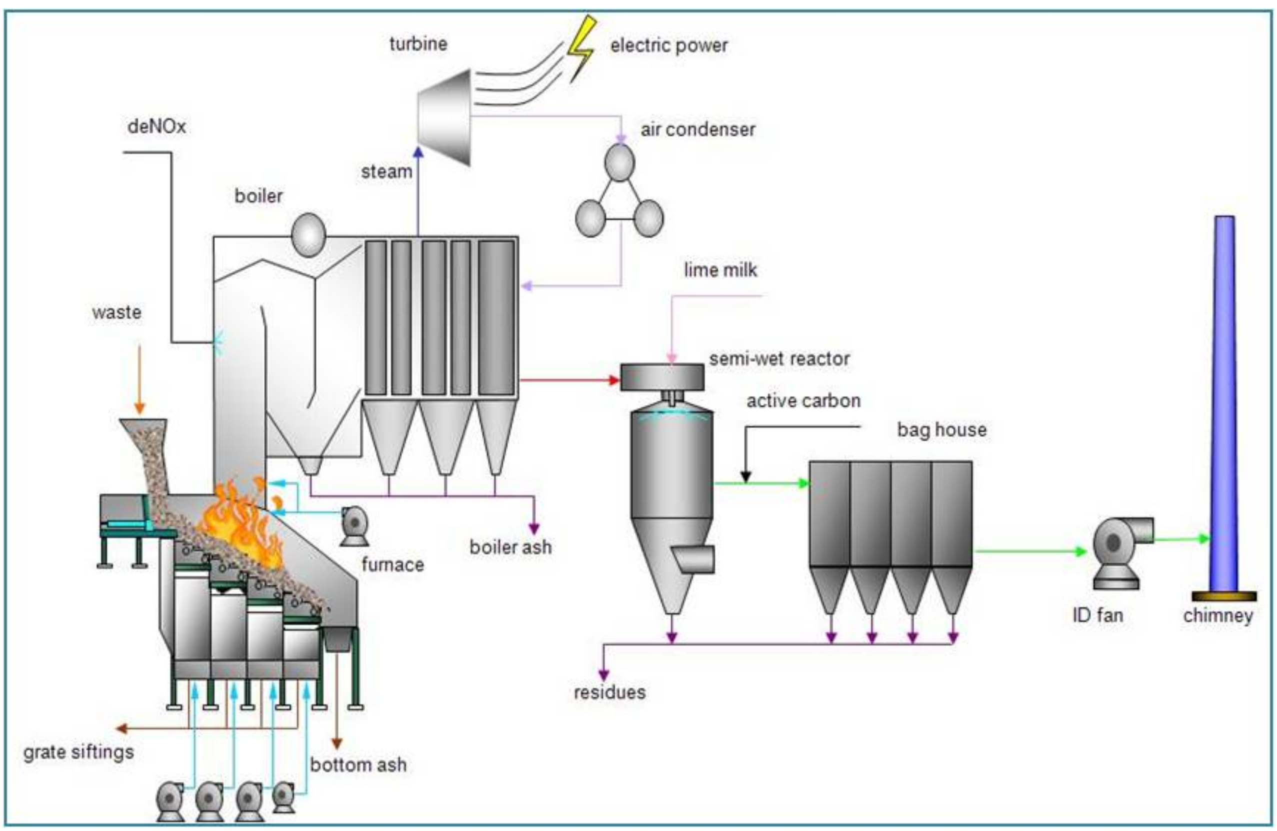

Figure 15 The schematic diagram of APC system (Source: Waste Control Website)

5. Electricity Grid in Baotou

5.1 Overview of Power Supply Sources

Base on the data from Baotou power grid development plan in China13th Five-Year development plan, the author write the following part to illustrate the project will also help the area of Baotou solve the problem of vacancy of electricity after 2020.

Table 18 The installed capacity of electricity grid in Baotou in 2014

No.	Name	Capacity (MW)	Constitution (MW)	Voltage (V)
	Total	**9007.5**	----	----
I	Thermal power plants	7274.5	----	----
(1)	Public	4986	----	----
1	Huadian Hexi power plant	1200	2×600	500
2	Shenhua Salaqi power plant	600	2×300	500
3	Baotou first power plant	350	1×100+2×125	220
4	Baotou Kundulun power plant	600	2×300	220
5	Baotou Second power plant	1000	2×200+2×300	220
6	Baotou Third power plant	600	2×300	220
7	Huadian Baotou Donghua Thermal Ltd.	600	2×300	220
8	Pulate (waste) power plant	36	3×12	110
(2)	Enterprise-onwed	2288.5	---	---
1	Hope Copper Ltd. power plant	1320	4×155+2×350	220
2	Baotou shancheng power plant	100	2×50	110
3	Baotou sugar factory power plant	9	1×6+1×3	6
4	Baotou Steel Factory power plant	92	2×25+1×12+5×6	110
5	Shenhua Coal Chemi	100	2×50	220
6	Baotou Copper Factory power plant	660	2×330	220
7	Yidong cement Factory power plant	7.5	1×7.5	110
II	Gas	275.2	---	
1	Baotou Steel Ltd. Gas Company power plant	275.2	2×137.6	110

As of the end of 2014, Baotou electricity grid has installed capacity of 9007.5 MW, as shown in Table 18, accounting for 17.64% of the total installed capacity of Inner Mongolia power grid. Among them, there are 8 public thermal power plants with total installed capacity of 4986.0MW; 7 enterprise-owned power plants with total installed capacity of 2288.5MW; 15 wind power farms with total production capacity of 1262.8MW;8 photovoltaic power stations with total output capacity of 195.0MW, as shown in Table 19 .

Table 19 The capacity of electricity producers in Baotou

No.	Name	Capacity (MW)	Constitution (MW)	Voltage (V)
III	New Energy	1457.8	---	---
(1)	Wind	1262.8	---	---
1	HongTeng Energy Wind power plant	99	80×1.25	220
2	Longyuan Wind Powe Plant	201	134×1.5	220
3	China Grid Invested Zhangze Wind Power Plant	49.5	33×1.5	220
4	Luneng Baotou Baiyun Wind Power Plant	94.5	36×1.25+33×1.5	110
5	Huaneng Maoming Wind Power Plant	99	66×1.5	220
6	Jinfeng Damao Wind Power Plant	198	132×0.75+66×1.5	220
7	Datang Baotou Huashuo Wind Power Plant	49.5	33×1.5	110
8	Beilian Wind Power Plant	49.4	61×0.81	220
9	Huadian Hongnichang Wind Power Plant	99	66×1.5	220
10	Longyuan Gaoyaohai Wind Power Plant	6	4×1.5	35
11	Zhonghang Kaihong Wind Power Plant	49.4	30×0.78+24×1+1×2	220
12	Jinjie Wind Power Plant	49.5	33×1.5	220
13	Longyuan Longnuoer Wind Power Plant	99.5	66×1.5	220
14	Jinjie Small Wind Power Plant	19.5	13×1.5	35
15	Huadian Baotou Bayin Wind Power Plant	100	66×1.5	220
(2)	photovoltaic	195	---	---
1	Baotou Damao Zhangze Photovoltaic Power Plant	20	80000×250Wp	35
2	Minghua Baotou Photovoltaic Power Plant	20	80000×250Wp	10
3	Honggetala Photovoltaic Power Plant	20	87200×230Wp	110
4	Bailingnao Photovoltaic Power Plant	30	130800×230Wp	35

5	Luneng Photovoltaic Power Plant	10	40000×250Wp	10
6	Huadian Bayin Photovoltaic Power Plant	20	80000×250Wp	35
7	Huadian Hongnijing Photovoltaic Power Plant	10	40000×250Wp	35
8	Xiangdao Yuneng Photovoltaic Power Plant	65	232160×280Wp	110

5.2 Analysis of Installed Capacity of Baotou Electricity Grid

The analysis of Baotou power grid is sorted according to the different power type, as shown in Table 20. Baotou power grid has installed capacity of 7274.5MW, among which gas power plants of 257.2MW and new energy plants of 1457.8MW. The largest installed capacity of coal proportion is 80.76%, and the new energy is 16.18%.

Table 20 Statistic of Baotou power type in the power grid

No.	Power type	Total capacity(MW)	Proportion
I	**Coal**	7274.5	80.76%
1	Public	4986	55.35%
2	Enterprise-owned	2288.5	25.41%
II	**Gas**	275.2	3.06%
III	**Renewable energy**	1457.8	16.18%
1	Wind	1262.8	14.02%
2	Photovoltaic	195	2.16%
	Summary	9007.5	---

5.3 Voltage Level of Power

The analysis of Baotou power grid can be sorted according to the power supply voltage level to the access system; the results are shown in Table 21. The table indicates that Baotou Power supply mainly concentrates on 220kV taking the proportion of 70.76%; 500 kV of 19.98%; 110kV of 8.32%; 35kV and below of 0.94%, as shown in Figure 17.

Table 21 Statistic of voltage level in Baotou power grid

No.	Voltage level	Capacity (MW)	proportion
1	500kV	1800	19.98%
2	220kV	6373.3	70.76%
3	110kV	749.7	8.32%
4	35kV and Below	84.5	0.94%

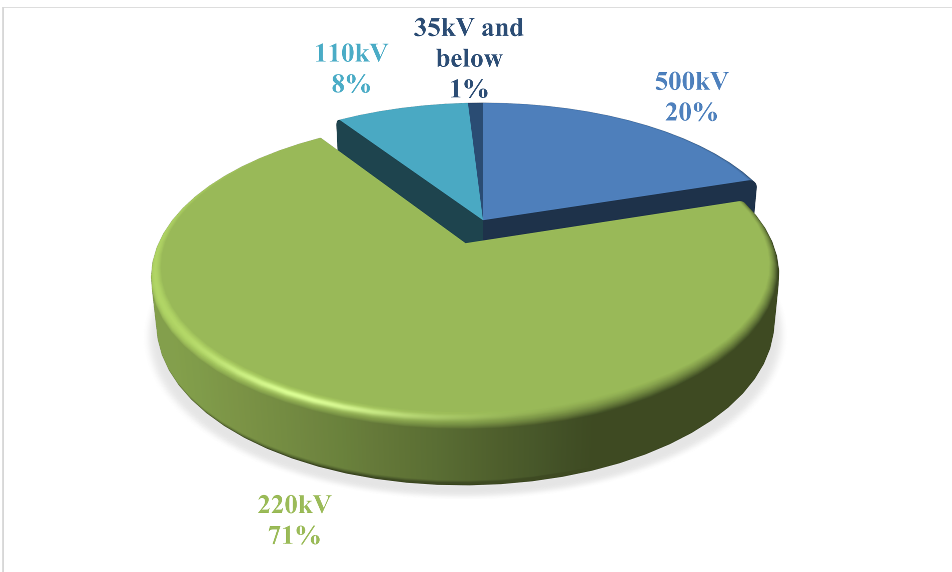

Figure 16 Voltage level in Baotou power grid

5.4 Power Projects Installation Planning

From 2015 to 2020, Baotou electricity grid plans to build two new thermal power plants; they are 1320MW Huadian Tuyou power plant and 700MW Guyang Jinshan power plant. They have a total installed capacity of 2020MW. Also, new energy plants with a total installed capacity of 3152MW are in the plan, including wind power plants of 2802MW and photovoltaic power plants of 350MW.

5.5 Power balance in Baotou Power grid

Table 22 Power Balance in Baotou city from 2015 to 2025,MW

No.	Item	2015	2016	2017	2018	2019	2020	2025
1	Maximum power supply load	6380	7045	7825	8485	9240	9990	14100
2	Maximum power generation load	7089	7828	8694	9428	10267	11100	15667
3	Integrated reserve capacity	1205	1331	1478	1603	1745	1887	2663
4	**Necessary installed capacity**	8294	9159	10173	11031	12012	12987	18330
5	**Grid actual installed capacity**	12840	14850	15880	16200	16500	16800	16800
5.1	Thermal actual installed capacity	8870	10190	10890	10890	10890	10890	10890
5.2	New energy actual installed capacity	3970	4660	4990	5310	5610	5910	5910
5.3	Wind	3425	4065	4345	4615	4865	5115	5115
	Photovoltaic	545	595	645	695	745	795	795
	Hydropower installed capacity	0	0	0	0	0	0	0
6	Available installed capacity at the end of the year (New energy 100%)	11876	13445	14612	15130	15430	15730	15730
	Available installed capacity at the end of the year (New energy 70%)	10684	12047	13115	13537	13747	13957	13957
	Available installed capacity at the end of the year (New energy 50%)	9890	11115	12117	12475	12625	12775	12775
	Available installed capacity at the end of the year (New energy 30%)	9096	10183	11119	11413	11503	11593	11593
	Available installed capacity at the end of the year (No New energy included)	7905	8785	9622	9820	9820	9820	9820
7	Put in production in the same year	2513	2010	1030	320	300	300	0
7.1	Thermal units	0	1320	700	0	0	0	0
7.2	New energy projects	2512.5	689.5	330	320	300	300	0
	Wind	2162.5	639.5	280	270	250	250	0
	Photovoltaic	350	50	50	50	50	50	0
8	Retired units	0	0	0	0	0	0	0
9	Hindered capacity	965	965	1035	1070	1070	1070	1070
10	Power balance (new energy 100%)	3582	4287	4439	4100	3418	2743	-2600

Power balance (new energy 70%)	2390	2889	2942	2507	1735	970	-4373
Power balance (new energy 50%)	1596	1957	1944	1445	613	-212	-5555
Power balance (new energy 30%)	802	1025	946	383	-509	-1394	-6737
Power balance (no new energy included)	-389	-373	-551	-1210	-2192	-3167	-8510

From the results of power balance in Baotou power grid, as show in Table 22, if new energy included in installed capacity by 70% or above, during 2015 ~2020, Baotou power grid would get power surplus at 970MW~4439MW.

If new energy included in installed capacity by 50%, Baotou Power Grid would present power surplus by 613MW~1957MW in 2015 – 2019. But in 2020, the vacancy would show up, and the lack would be 212MW.

If new energy included in installed capacity by 30%, Baotou Power Grid would present power surplus by 383MW~1025MW in 2015 – 2018. But in 2019 and 2020, the vacancy would show up, and the lack would be 509MW and 1394MW respectively.
If new energy were not included in installed capacity, Baotou Power Grid would present power vacancy by 373MW~3167MW in 2015 – 2020.

In 2025, when new energy includes in the installed capacity by different proportion, power vacancy shows up in Baotou electricity grid by 2600MW~8510MW.

6. Economic factors

To resolve the waste management problem in Baotou city, building a new waste to energy plant is necessary. The balance of the treatment capacity and the generation of MSW in Baotou city shown in Figure 18. From 2016 to 2028, two landfill sites and one WTE plant will be operating and 0.13 (in 2016) to 0.34 (in 2028) million tons of MSW in Baotou need to be disposed of. In 2029, the Baotou MSW disposal center will be closed, in 2031, the Donghe landfill sites will be closed, and in 2033, the Pulangte WTE plant will also be closed. Figure 18 shows that a very large amount of MSW needs to be disposed in the next 20 years. Therefore, for this project, a 1500-tons/day-capacity WTE plant is recommended. Based on the technology analysis, a circulating fluidized bed technology is recommended for the project.

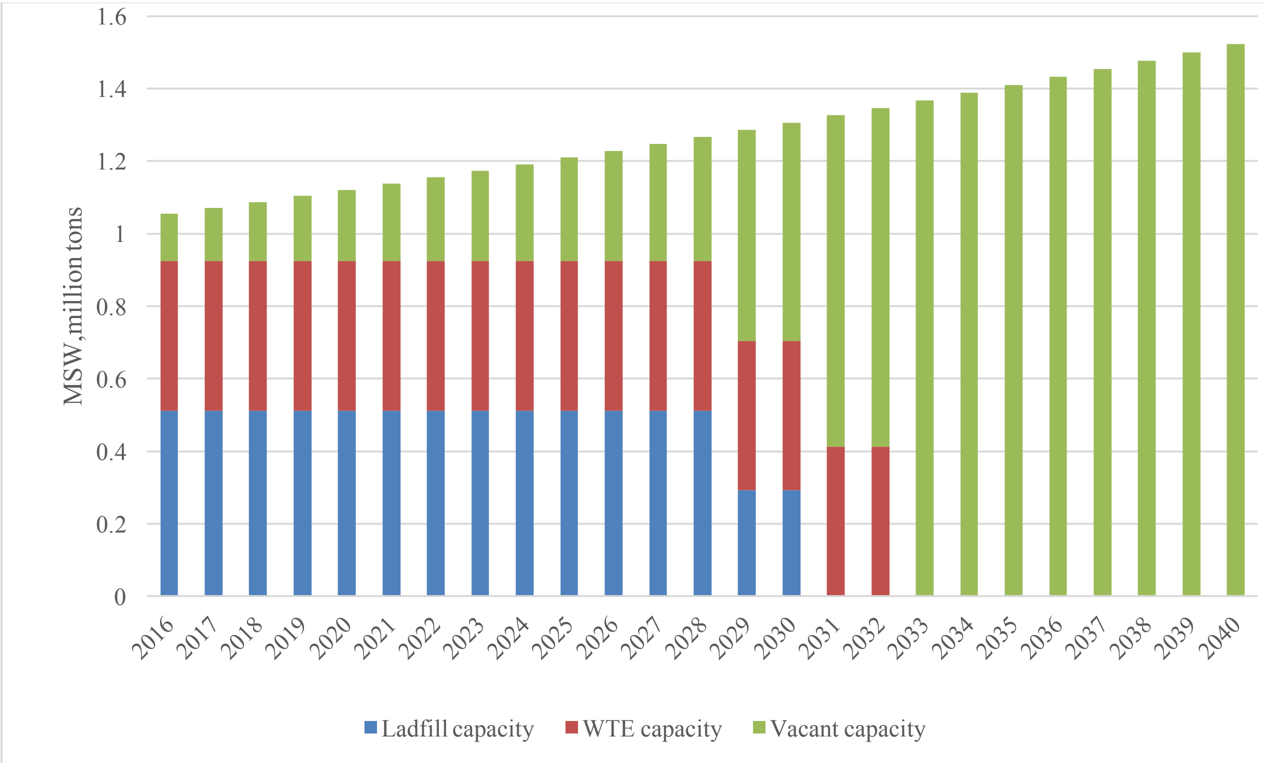

Figure 17 The Balance of the disposal capacity of MSW in Baotou from 2016 to 2040

Based on the above technology and MSW generation analysis, the economic analysis is necessary for a pre-feasibility study. We recommended a WTE plant with the capacity of 1500 tons/day by using CFB incinerator. The operation days are 300 days per year. Generally, a WTE plant can operate 20 years under the concession by the government. Based on the experience from WTE plants in China using domestic equipment and on the basis of the Chang lectures (Jiangguo Chang, 2011), the total investment for Baotou WTE plant is estimated at $80 million dollars ($178/ ton of annual capacity), for purchasing equipment and plant construction. The required bank loan will be $56 million, payable over 15years at 6.5% interest (based on the loan policy in China). The private investment will be $24 million.To carry out a financial analysis of this project, the assumed economic and technical parameters of the Baotou WTE plant are shown in Table 23

Table 23 Economiac and technological parameters of WTE plant in Baotou city

Parameters	Value	
Disposal capacity	1,500	tons/day
Operating days/per year	300	days
Annual disposal capacity	450,000	tons
Total Investment	80	million dollars
Loan ratio	70%	
Loan annual interest rate	6%	
Loan Term	15	years
Construction period	2	
Operation period	20	
Waste subsidies	9.56	$/ton
Income Tax	25%	

6.1 Cost

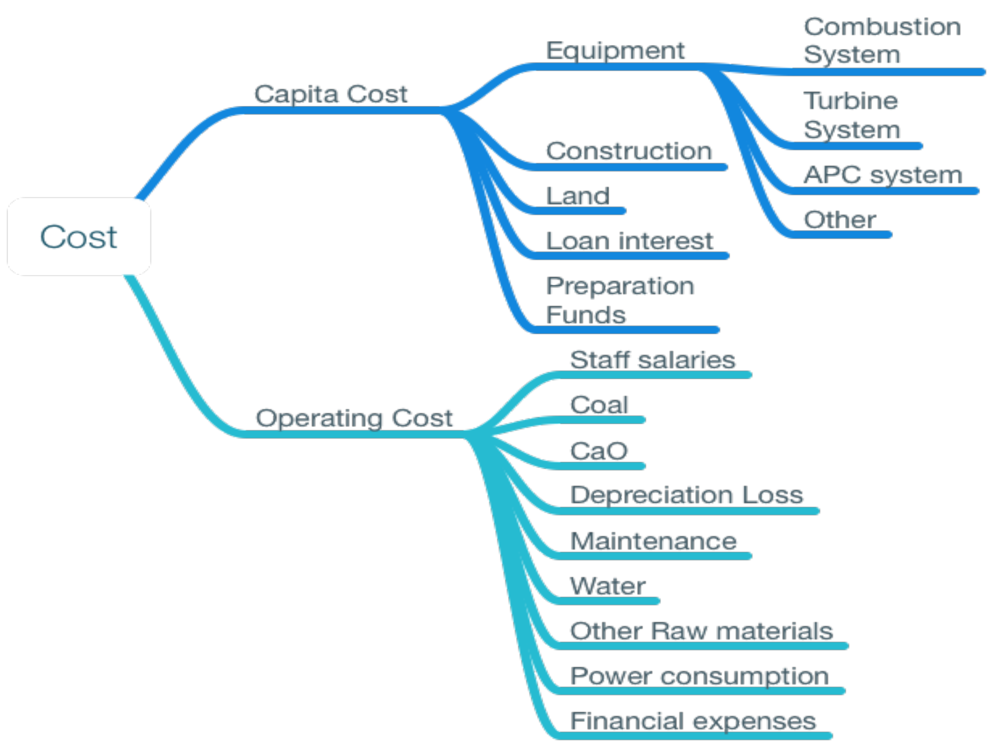

Figure 18 Cost components of a typical WTE plant

The costs of a WTE plant consist of capital costs (CAPEX) and operating costs (OPEX)(Consonni, 2005). The combustion, turbine, air pollution control systems and construction are the major cost on capital costs. Figure 19 shows the list of the capital cost and the operating cost of a typical WTE plant.

6.1.1 Capital Costs

In China, the government can provide a loan at most 80% of the total investment for a WTE project. The main costs of capital costs are equipment purchase, installation and construction cost. China's government offers a series of incentives to promote waste-to-energy technologies development。

Therefore, in recent years, China's WTE technologies got a huge development, such as the CFB technology developed by Zhejiang University and the moving grate technology provided by Tsinghua University. More and more WTE plants choose domestic technologies and equipment. The equipment can get same or more efficiency than the imported equipment with a lower capital cost, as shown in Table 24 (Jianguo Chang, 2011). From this table, the investment for the 1500ton/d-capacity WTE plant by using domestic circulating fluidized bed combustion is between 57.69 to 69.23 million dollars.

Table 24 Investment in a WTE plant in different types of technologies (Calculation using the data from Jiangguo Chang, 2011)

Equipment types	Operating days per year	Investment($/ton)	Disposal capacity(tons)	1500 ton/d Investment(Million Dollars)
Imported Mechanical-grate	330	230.77~256.41	495,000	113.85~126.92
Imported circulating fluidized bed combustion	300	205.13~230.77	450,000	92.30~103.85
Domestic Mechanical-grate	330	153.85~179.49	495,000	76.15~99.85
Domestic circulating fluidized bed combustion	**300**	**128.21~153.85**	**450,000**	**57.69~69.23**

6.1.2 Operating Cost

Considering the LHV of MSW in Baotou city is kind of low and unstable, the author will discuss the following scenarios:

Scenario 1: the MSW will be co-combusted with coal in the furnace.

Scenario 2: Auxiliary fuel will not be used during the combustion process.

Scenario 1:

The main costs for APC system in the project are lime, activated carbon, and urea. Based on the actual consumption of these materials in China's WTE plants, especially in Pulangte WTE plant, the author assumed the value of them should be used in the project, as shown in Table 25.

Table 25 Consumption of Materials in APC system, Scenario 1

Material	Consumption per hour(t/h)	Consumption per day(t/d)	Consumption per year(t/y)
MSW	62.5	1,500	450,000
Ca(OH)2	1.2	24.0	8,640
Urea	0.6	14.0	4,200
Activated Carbon	0.05	1.2	360

The most of operating cost of the WTE plant is from the auxiliary fuel (coal) consumption. The coal consumption should be less than 20% of total fuel mass, and a 20% value will be used for the calculation of the consumption of coal. Therefore, the total coal consumption is equal to 112,500 tons per year. The price of the coal in Baotou city is 92.31 dollars per ton.

The average salaries for the local area are $7,200 per capita per year, and the total labor of the WTE plant is assumed by 100 people. Therefore, the total labor salaries are 720,000 dollars per year. The maintenance charge is 2% of total investment per year, are 1,600,000 dollars per year.

Compared with MG incinerators, CFB produces more fly ash (about 12% of the weight of MSW combusted). The fly ash contains a significant amount of toxic substance and needs to be disposal further. For the project, the fly ash will be sent to the hazardous waste disposal center, and the cost is 10 dollars per ton. The total operating cost for the project will be 15,390724 dollars ($34.20/ton), as shown in Table 26.

Table 26 The operating costs of the WTE plant in Baotou City, Scenario 1

Cost item	Consumption		Price		Cost(dollars)
Coal	112,500.00	tons	92.31	$/t	10,384,875.00
Limestone	8,640.00	tons	80.00	$/t	691,200.00
Urea	4,200.00	tons	130.77	$/t	549,230.77
Activated Carbon	360.00	tons	692.31	$/t	249,230.77
Water	1,743,750.00	tons	0.25	$/t	435,937.50
Salaries	100.00	capita	7,200.00	$/person Year	720,000.00
Maintenance Charge	2%				1,600,000.00
Fly ash disposal	70,000	tons	10.00	$/ton	560,250.00
other					200,000.00
Total					15,390,724.04
Average	34.20	$/t			

Scenario 2:

The most different of the Scenario 2 from Scenario1 is that the project will not use the coal as the auxiliary fuel during the combustion process. The combustion of materials for the APC systems shows in Table 27.

Table 27 Consumption of Materials in APC system, Scenario2

Material	Consumption per hour(t/h)	Consumption per day(t/d)	Consumption per year(t/y)
MSW	62.5	1,500	450,000
Ca(OH)2	1.00	24.0	7,200
Urea	0.6	14.0	4,200
Activated Carbon	0.05	1.2	360

The operating cost for the Scenario 2 shows in table 28. Compared with the operating costs of the Scenario 1 is 33.75 dollars per ton, only 10.77 dollars per ton of Scenario 2. The operating cost is much lower than it in U.S and European WTE plants, which are US$ 32/ton to US$47/ton (WTERT Guidebook). In China, the operating cost of the domestic MG incinerators is from US$16.3/ton to US$32.6/ton, and the domestic CFB incinerators is from US$9.78/ton to US$19.56/to(Xin-Gang, 2016). Low operating cost is an important reason to choose domestic technologies and equipment.

Table 28 The operating costs of the WTE plant in Baotou City, Scenario2

Assumption	Consumption		Price		Cost(dollars)
Limestone	7,200	tons	80	$/t	576,000
Urea	4,200	tons	130.7692308	$/t	549,231
Activated Carbon	360	tons	692.3077	$/t	249,231
Water	1,575,000	tons	0.25	$/t	393,750
Salaries	100	capita	7200	$/person.Year	720,000
Maintenance Charge	2%				1,600,000
other					200,000
Fly ash disposal	56000	tons	10	$/ton	560,000
Total					5,128,212
Average	11.40	$/t			

<u>The auxiliary fuel handling and storage :</u>

Since the Scenario 2 of the project requires coal as the auxiliary fuel, coal storage should be next to the furnace. Coal is transported to the plant by truck, and unloading of it into storage after weighting. The storage of coal should make sure the project operate 3-4 days. The coal storage with an underground coal scuttle, which is equipped with vibration dynamic coal feeder. When the furnace is operating, the coal will be pushed into shredders to be shredded through vibration dynamic coal feeder. And then, the shredded coal will be unloaded into furnace to be combusted with MSW.

6.2 Revenues

6.2.1 Electricity generation

<u>Scenario 1:</u>

Considering the heating value of MSW in Baotou city is 6 MJ/kg and coal is 20MJ/kg (ShenHua Company), they correspond to 1.67 MWh and 5.56 MWh of thermal energy per ton. For a mix of 80% of MSW and 20% coal by weight, one ton mixture fuel will include 1.67Mwh*80% + 5.56MWh*20%= 9 MWh.

Based on the WTERT Guidebook, the heat losses of the furnace are 10%, it means the heat in the superheated steam entering the turbine generator will be 2.25 MWh per ton after the combustion of MSW. And the thermal efficiency of WTE steam turbine is about 28% (WTERT Guidebook), therefore the total power generated 2.25*28%=0.6 MWh of electricity per ton of WSW. Generally, the WTE plant in China will consume about 20% of the total electricity generation.

Based on the parameters and the total annual disposal capacity, the author calculated the annual electricity generation of the WTE plant in Baotou is 283,500 MWh, as shown in Figure 20.

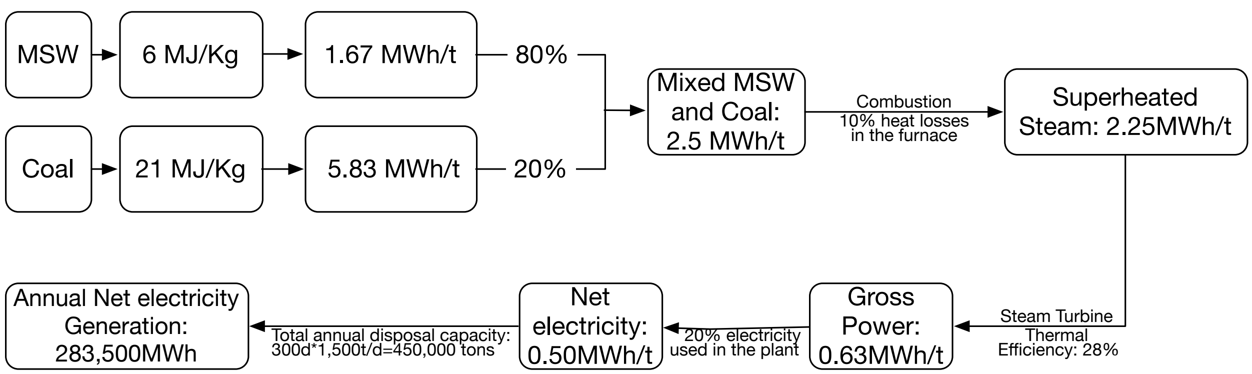

Figure 19 Calculating process of the electricity generation from the combustion of MSW and coal

<u>Scenario 2:</u>

For the Scenario 2, the total net electricity generation is 151,200 MWh, as shown in Figure 21.

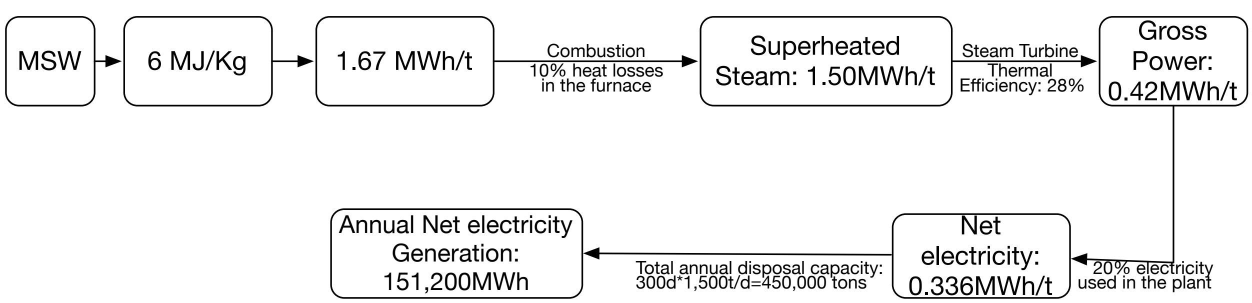

Figure 20 Calculating process of the electricity generation from the combustion of MSW

According to the the NDRC Price (2012), the government will purchase all electricity from WTE plants. The notice requires the incorporated rate of MSW to net electricity is one ton of MSW is equal to 280 kWh of electricity, and it will implement the national benchmark price of 100 dollars per MWh. The remaining electricity will implement the rate for local Coal-fired power generation, 69.23 dollars per MWh used for the project. The gate fee in Baotou city is $9.56 per tons, and the total income form waste subsidies of the WTE plant will be 4,302,000 dollars, as shown in Table. 29. The total revenue of the Scenario 1 is 29,207,632 dollars and the Scenario 2 is 19,300,820 dollars. For the project, the author doesn't calculate the other revenue, such as the metals sell and the bottom ash sell.

Table 29 The mainly income of the WTE plant in Baotou

		Scenario 1					Scenario 2				
	Price	Net Electricity	Generation		Revenue,$		Net Electricity	Generation		Revenue,$	
Electricity Sale	0.28MWh/t: 100 $/MWh	0.50MWh/t	126,000MWh		12,600,000		0.336Wh/t	126,000 MWh		12,600,000	
	Remaining Electricity: 69.23 $/MWh		157,500MWh		10,903,846			25,200MWh		1744615.385	
			Total	283,500MWh	Total	23,503,846		Total	151200 MWh	Total	14,344,615
Gate-fee	9.56 $/t		450000 t		4302000			450000 t		4302000	
Total Revenue		**27,805,846**					**18,646,615**				

6.3 Cost-Benefit Analysis

According to the Regulations of the people's Republic of China on the implementation of the enterprise income tax law, the government will give a tax incentive of “three exemptions and three halves” for the WTE plant. It means the WTE plant will be waived all the income tax for the first three years and a half income tax from 4th to 6th year after it operating. For this pre-feasibility study, we just assumed the revenue from electricity sales and gate fee. The project will loan $44.8 million (80% of total loan) in the first year of construction period and loan $11.2 million (20% of total loan)in the second year.

Based on the cost and revenue analysis, and the assumption parameters of the WTE plant. The operating cash flow analysis of Scenario 1 is shown in Table 30 and Scenario 2 is shown in Table

31. After the 20 years of operation, the project can get a quite high financial payback for both Scenarios.

Table 30 Net cash flow in the WTE plant in Baotou, Scenario 1 (all numbers in million dollars)

Year	Cash inflows	Investment	Loan principal repayment	Loan Interest	Costs	Income tax	Net cash flow	Cumulative net cash flow
1	0.00	12.00	0.00	0.00	0.00	0.00	-12.00	-12.00
2	0.00	12.00	0.00	0.00	0.00	0.00	-12.00	-24.00
3	27.81	0.00	4.18	4.08	15.39	0.00	4.15	-19.85
4	27.81	0.00	4.18	3.81	15.39	0.00	4.43	-15.42
5	27.81	0.00	4.18	3.53	15.39	0.00	4.70	-10.72
6	27.81	0.00	4.18	3.26	15.39	0.64	4.33	-6.40
7	27.81	0.00	4.18	2.99	15.39	0.68	4.56	-1.83
8	27.81	0.00	4.18	2.72	15.39	0.71	4.80	2.97
9	27.81	0.00	4.18	2.45	15.39	1.49	4.29	7.26
10	27.81	0.00	4.18	2.18	15.39	1.56	4.50	11.76
11	27.81	0.00	4.18	1.90	15.39	1.63	4.70	16.46
12	27.81	0.00	4.18	1.63	15.39	1.70	4.91	21.37
13	27.81	0.00	4.18	1.36	15.39	1.76	5.11	26.48
14	27.81	0.00	4.18	1.09	15.39	1.83	5.31	31.79
15	27.81	0.00	4.18	0.82	15.39	1.90	5.52	37.31
16	27.81	0.00	4.18	0.54	15.39	1.97	5.72	43.03
17	27.81	0.00	4.18	0.27	15.39	2.04	5.92	48.95
18	27.81	0.00	0.00	0.00	15.39	2.10	10.31	59.26
19	27.81	0.00	0.00	0.00	15.39	2.10	10.31	69.57
20	27.81	0.00	0.00	0.00	15.39	2.10	10.31	79.88
21	27.81	0.00	0.00	0.00	15.39	2.10	10.31	90.20
22	27.81	0.00	0.00	0.00	15.39	2.10	10.31	100.51

Table 31 Table 29 Net cash flow in the WTE plant in Baotou, Scenario 2 (all numbers in million dollars)

Year	Cash inflows	Investment	Loan principal repayment	Loan Interest	Costs	Income tax	Net cash flow	Cumulative net cash flow
1	0.00	12.00	0.00	0.00	0.00	0.00	-12.00	-12.00
2	0.00	12.00	0.00	0.00	0.00	0.00	-12.00	-24.00
3	18.65	0.00	4.18	4.08	5.13	0.00	5.26	-18.74
4	18.65	0.00	4.18	3.81	5.13	0.00	5.53	-13.21
5	18.65	0.00	4.18	3.53	5.13	0.00	5.80	-7.41
6	18.65	0.00	4.18	3.26	5.13	0.78	5.29	-2.12
7	18.65	0.00	4.18	2.99	5.13	0.82	5.53	3.41
8	18.65	0.00	4.18	2.72	5.13	0.85	5.77	9.18
9	18.65	0.00	4.18	2.45	5.13	1.77	5.12	14.30
10	18.65	0.00	4.18	2.18	5.13	1.84	5.32	19.62

11	18.65	0.00	4.18	1.90	5.13	1.90	5.53	25.15
12	18.65	0.00	4.18	1.63	5.13	1.97	5.73	30.88
13	18.65	0.00	4.18	1.36	5.13	2.04	5.94	36.82
14	18.65	0.00	4.18	1.09	5.13	2.11	6.14	42.96
15	18.65	0.00	4.18	0.82	5.13	2.18	6.34	49.30
16	18.65	0.00	4.18	0.54	5.13	2.24	6.55	55.85
17	18.65	0.00	4.18	0.27	5.13	2.31	6.75	62.60
18	18.65	0.00	0.00	0.00	5.13	2.38	11.14	73.74
19	18.65	0.00	0.00	0.00	5.13	2.38	11.14	84.88
20	18.65	0.00	0.00	0.00	5.13	2.38	11.14	96.02
21	18.65	0.00	0.00	0.00	5.13	2.38	11.14	107.16
22	18.65	0.00	0.00	0.00	5.13	2.38	11.14	118.30

Calculating the net present value(NPV) of the project by the cash inflow and costs data as shown in Table 32. When the discount rate is 5%, 10% and 15%, the project for both Scenarios is acceptable. When the discount rate is 25%, the project cannot get the economic benefit for both Scenarios. And the IRR is 17.93% and 21.19% of Scenario 1 and Scenario 2 separately, as shown Table 33. Calculating the payback period is 6.4 and 5.4 years by the net cash flow and the cumulative net cash flow for Scenario 1 and Scenario 2 separately after the plants operating. It means the owner of the project can get financial payback in a short time.

Table 32 NPV values of the WTE plant in Baotou

	NPV1	NPV2	NPV3	NPV4	NPV5	NPV6
Discount rate	5%	8%	10%	12%	15%	25%
Result of Scenario1 (Million dollars)	42.06	24.35	16.37	10.43	4.14	-5.48
Result of Scenario 2 (Million dollars)	52.39	32.17	22.98	16.08	8.69	-2.95

Table 33 Pack back period and IRR in the WTE plant in Baotou

	S1	S2
Pay-back Period	6.4	5.4
IRR	17.93%	21.19%

Table 34 shows the net profit of the project of Scenario 1. From the first year of the plant operating, the net profit margin is close to 17%, and with interest decreasing the net profit margin is keeping increasing by a stable rate, and will up to 22.70% after the 17th year. And the revenue of the plant is from electricity sales and gate-fee only by assumption. However, other revenues can be considered in the actual WTE plant, such as cinder sales and metal sales.

Table 34 Net Profit analysis of WTE plant in Baotou city, Scenario 1

Year	Income	Costs	Depreciation	Loan Interest	Profit Before Tax	Tax	Net Profit	Net Profit Margin(%)
3	27.81	15.39	4.00	4.08	4.34	0.00	4.34	15.60%
4	27.81	15.39	4.00	3.81	4.61	0.00	4.61	16.57%
5	27.81	15.39	4.00	3.53	4.88	0.00	4.88	17.55%
6	27.81	15.39	4.00	3.26	5.15	0.64	4.51	16.21%
7	27.81	15.39	4.00	2.99	5.42	0.68	4.75	17.07%
8	27.81	15.39	4.00	2.72	5.70	0.71	4.98	17.93%
9	27.81	15.39	4.00	2.45	5.97	1.49	4.48	16.10%
10	27.81	15.39	4.00	2.18	6.24	1.56	4.68	16.83%
11	27.81	15.39	4.00	1.90	6.51	1.63	4.88	17.56%
12	27.81	15.39	4.00	1.63	6.78	1.70	5.09	18.30%
13	27.81	15.39	4.00	1.36	7.06	1.76	5.29	19.03%
14	27.81	15.39	4.00	1.09	7.33	1.83	5.50	19.76%
15	27.81	15.39	4.00	0.82	7.60	1.90	5.70	20.50%
16	27.81	15.39	4.00	0.54	7.87	1.97	5.90	21.23%
17	27.81	15.39	4.00	0.27	8.14	2.04	6.11	21.96%
18	27.81	15.39	4.00	0.00	8.42	2.10	6.31	22.70%
19	27.81	15.39	4.00	0.00	8.42	2.10	6.31	22.70%
20	27.81	15.39	4.00	0.00	8.42	2.10	6.31	22.70%
21	27.81	15.39	4.00	0.00	8.42	2.10	6.31	22.70%
22	27.81	15.39	4.00	0.00	8.42	2.10	6.31	22.70%

Table 35 shows the net profit of the project of Scenario 2. From the first year of the plant operating, the net profit margin is closed to 31.03%, which is much higher than it of the Scenario1, and will up to 38.28% after the 17th year.

Table 35 Net Profit analysis of WTE plant in Baotou city, Scenario 2

Year	Income	Costs	Depreciation	Loan Interest	Profit Before Tax	Tax	Net Profit	Net Profit Margin(%)
3	18.65	5.13	4.00	4.08	5.44	0.00	5.44	29.18%
4	18.65	5.13	4.00	3.81	5.71	0.00	5.71	30.63%
5	18.65	5.13	4.00	3.53	5.98	0.00	5.98	32.09%
6	18.65	5.13	4.00	3.26	6.26	0.78	5.47	29.36%
7	18.65	5.13	4.00	2.99	6.53	0.82	5.71	30.63%
8	18.65	5.13	4.00	2.72	6.80	0.85	5.95	31.91%
9	18.65	5.13	4.00	2.45	7.07	1.77	5.30	28.44%
10	18.65	5.13	4.00	2.18	7.34	1.84	5.51	29.54%
11	18.65	5.13	4.00	1.90	7.62	1.90	5.71	30.63%
12	18.65	5.13	4.00	1.63	7.89	1.97	5.92	31.72%
13	18.65	5.13	4.00	1.36	8.16	2.04	6.12	32.82%
14	18.65	5.13	4.00	1.09	8.43	2.11	6.32	33.91%
15	18.65	5.13	4.00	0.82	8.70	2.18	6.53	35.00%
16	18.65	5.13	4.00	0.54	8.97	2.24	6.73	36.10%
17	18.65	5.13	4.00	0.27	9.25	2.31	6.93	37.19%
18	18.65	5.13	4.00	0.00	9.52	2.38	7.14	38.28%
19	18.65	5.13	4.00	0.00	9.52	2.38	7.14	38.28%
20	18.65	5.13	4.00	0.00	9.52	2.38	7.14	38.28%
21	18.65	5.13	4.00	0.00	9.52	2.38	7.14	38.28%
22	18.65	5.13	4.00	0.00	9.52	2.38	7.14	38.28%

6.4 Financial sensitivity analysis

Financial sensitivity analysis will show the economics effects be changed when some factor changed, such as the MSW generation, electricity price etc.

To analyze the influence of IRR for the uncertain factors in this project such as equipment using hours, electricity price and the project total investment, the single factor sensitivity analysis is considered.

According to the sensitivity study showed in Table 36 and Table 37, this project shows promising economic benefits. Even in the Scenario 1 and Scenario with the worst condition, be it with the lowest gate fee (8.13$/t) and the lowest electricity price (85$/MWh), 10.58% and 13.76%of IRR still be achieved separately. The IRR increases as the gate fee and electricity price rises separately or simultaneously.

Table 36 Sensitivity analysis of the WTE plant by electricity price and gate-fee factors, Scenario 1

IRR		Electricity Price, $/MWh						
		85(-15%)	90(-10%)	95(-5%)	100	105(+5%)	110(+10%)	115(+15%)
Gate fee, $/t	8.13(-15%)	10.58%	12.39%	14.21%	16.04%	17.89%	19.74%	21.60%
	8.60(-10%)	11.19%	13.01%	14.83%	16.67%	18.52%	20.38%	22.24%
	9.08(-5%)	11.81%	13.63%	15.46%	17.30%	19.15%	21.01%	22.88%
	9.56	12.43%	14.25%	16.09%	**17.93%**	19.79%	21.65%	23.51%
	10.04(+5%)	13.05%	14.88%	16.72%	18.57%	20.42%	22.29%	24.15%
	10.52(+10%)	13.67%	15.51%	17.35%	19.20%	21.06%	22.92%	24.79%
	10.99(+15%)	14.30%	16.13%	17.98%	19.83%	21.69%	23.56%	25.43%

Table 37 Sensitivity analysis of the WTE plant by electricity price and gate-fee factors, Scenario 2

IRR		Electricity Price, $/MWh						
		85(-15%)	90(-10%)	95(-5%)	100	105(+5%)	110(+10%)	115(+15%)
Gate fee, $/t	8.13(-15%)	13.76%	15.59%	17.43%	19.28%	21.14%	23.00%	24.87%
	8.60(-10%)	14.38%	16.21%	18.06%	19.92%	21.78%	23.64%	25.51%
	9.08(-5%)	15.00%	16.84%	18.69%	20.55%	22.41%	24.28%	26.15%
	9.56	15.63%	17.47%	19.33%	**21.19%**	23.05%	24.92%	26.78%
	10.04(+5%)	16.26%	18.11%	19.96%	21.82%	23.69%	25.55%	27.42%
	10.52(+10%)	16.89%	18.74%	20.60%	22.46%	24.32%	26.19%	28.06%
	10.99(+15%)	17.52%	19.37%	21.23%	23.10%	24.96%	26.83%	28.69%

The IRR changes oppositely as the loan rate changes for both Scenarios. When the capital investment increases by 15%, and the loan interest rate increases dramatically by 25%, the IRR of Scenario 1 and Scenario 2 remain 11.57% and15.13% separately, as shown in Table 38 and Table 39.

Table 38 Sensitivity analysis of the WTE plant by Loan interest and Capital investment, Scenario 1

IRR		Capital Investment, million dollars						
		68(-15%)	72(-10%)	76(-5%)	80	84(+5%)	88(+10%)	92(+15%)
Loan interest	5.85%(-10%)	22.79%	21.52%	20.27%	19.04%	17.83%	16.64%	15.49%
	6.18%(-5%)	22.29%	21.00%	19.73%	18.49%	17.26%	16.07%	14.91%
	6.50%	21.79%	20.48%	19.20%	**17.93%**	16.70%	15.50%	14.33%
	6.83%(+5%)	21.29%	19.96%	18.66%	17.39%	16.14%	14.94%	13.76%
	7.15%(+10%)	20.79%	19.44%	18.13%	16.84%	15.59%	14.38%	13.20%
	7.48%(+15%)	20.29%	18.93%	17.60%	16.30%	15.05%	13.83%	12.65%
	7.80%(+20%)	19.79%	18.41%	17.07%	15.77%	14.50%	13.28%	12.11%
	8.13%(+25%)	19.29%	17.90%	16.55%	15.24%	13.97%	12.75%	11.57%

Table 39 Sensitivity analysis of the WTE plant by Loan interest and Capital investment, Scenario 2

IRR		Capital Investment, million dollars						
		68(-15%)	72(-10%)	76(-5%)	80	84(+5%)	88(+10%)	92(+15%)
Loan interest	5.4%(-%10)	25.42%	24.38%	23.35%	22.34%	21.33%	20.34%	19.37%
	5.7%(-5%)	24.91%	23.85%	22.80%	21.76%	20.74%	19.74%	18.75%
	6.00%	24.40%	23.31%	22.24%	**21.19%**	20.15%	19.13%	18.13%
	6.3%(+5%)	23.89%	22.78%	21.69%	20.61%	19.56%	18.53%	17.52%
	6.6%(+10%)	23.37%	22.24%	21.13%	20.04%	18.97%	17.93%	16.91%
	6.9%(+15%)	22.86%	21.71%	20.58%	19.47%	18.39%	17.34%	16.31%
	7.2%(+20%)	22.34%	21.18%	20.03%	18.91%	17.82%	16.75%	15.72%
	7.5%(+25%)	21.83%	20.64%	19.48%	18.35%	17.24%	16.17%	15.13%

The normal operating days for a WTE plant equipped with CFB incinerator in a year are 300 days. Table 40 shows the value of IRR with the operating days and operating cost changed for Scenario 1 of the project. When the operating days decrease by 10% to 270 days per year and the operating cost increased by 20%, the IRR will be 1.09%; it will bring a financial risk for the project. Compared with it of Scenario 1, the IRR of Scenario 2 is more stable when the operating cost and days changed. Even when the operating days is 240 days per year, and the operating cost is 7.70 million dollars per year, the IRR remain positive as 8.96%, as shown in Table 41.

Table 40 Sensitivity analysis of the WTE plant by Operating days and Operating cost Scenario 1

IRR		Operating Cost, million dollars per year						
		13.85(-10%)	15.39	16.93(+10%)	18.47(+20%)	20.01(+30%)	21.55(+40%)	23.09(+50%)
Operating days, day	240(-20%)	6.34%	1.95%	-2.58%	-7.51%	-13.39%	-	-
	255(-15%)	10.30%	5.92%	1.52%	-3.04%	-8.03%	-14.05%	-
	270(-10%)	14.31%	9.88%	5.49%	1.09%	-3.49%	-8.55%	-14.74%
	285(-5%)	18.38%	13.88%	9.45%	5.06%	0.65%	-3.96%	-9.09%
	300	22.48%	**17.94%**	13.44%	9.02%	4.64%	0.22%	-4.43%
	315(+5%)	26.60%	22.04%	17.50%	13.01%	8.59%	4.21%	-0.22%
	330(+10%)	30.70%	26.16%	21.59%	17.06%	12.58%	8.17%	3.79%
	345(+15%)	34.77%	30.26%	25.71%	21.15%	16.62%	12.15%	7.74%

Table 41 Sensitivity analysis of the WTE plant by Operating days and Operating cost Scenario 2

IRR		Operating Cost, million dollars per year						
		4.6(-10%)	5.13	5.64(+10%)	6.16(+20%)	6.67(+30%)	7.18(+40%)	7.70(+50%)
Operating days, day	240(-20%)	17.87%	16.37%	14.87%	13.38%	11.90%	10.43%	8.96%
	255(-15%)	19.07%	17.57%	16.06%	14.57%	13.08%	11.60%	10.13%
	270(-10%)	20.28%	18.77%	17.26%	15.76%	14.27%	12.78%	11.30%
	285(-5%)	21.49%	19.97%	18.46%	16.96%	15.46%	13.97%	12.48%
	300	22.70%	**21.18%**	19.67%	18.16%	16.65%	15.15%	13.66%
	315(+5%)	23.91%	22.39%	20.87%	19.36%	17.85%	16.35%	14.85%
	330(+10%)	25.12%	23.60%	22.08%	20.57%	19.05%	17.54%	16.04%
	345(+15%)	26.33%	24.81%	23.29%	21.77%	20.26%	18.75%	17.24%

7.Conclusions

The Baotou MSW disposal center will be closed by 2029, the Donghe landfill sites will be closed by 2031, and the Pulangte WTE plant will be closed by 2023. An immense amount of MSW needs to be disposed of in next 20 years. Therefore, building a new WTE plant in Baotou is necessary and it is an urgent task for the local government.

With incentives and support provided by the natonal government, China is rapidly becoming the largest WTE market all over the world. Moving-grate furnaces are used widely in developed countries and China; however, after the experience of WTE plants operation, CFB furnaces have also been developed in China. Compared with the imported MG technologies, domestic CFB technologies can get a higher thermal efficiency for low heating value and high moisture MSW with a lower capital cost and operating cost.

The generating capacity of the Baotou Power Grid must be increased by at least 400 MW by 2020. Therefore, the power to be generated by the WTE plant, estimated at about 20 MW, will be welcome.

Building a 1500 ton/day WTE plant based on CFB technology in Baotou city will alleviate the problem of expected closures of existing landfills. The investment of the project was estimated at US$80 million; 56 million dollars will come from a loan with 6.5% interest provided by the local bank and 24 million dollars will be provided by private investors. The government will pay for the gate fee of US$9.56 per ton and purchase the power generated by the WTE at the price of $100 per MWh.

Due to the high moisture and low heating value of MSW in Baotou, co-combustion coal and MSW was also considered for the project. Based on the comparison between co-combustion of MSW with coal (Scenario 1) and combustion of MSW solely (Scenatio 2), the latter will result in a higher net profit. The respective IRR is 17.93% (Scenario 1) and 21.19% for Scenario 2 separately. The payback periods are 6.4 years (Scenario 1) and 5.4 years for Scenario 2 separately.

The project will bring to both the private investors and the government a high financial benefit and result in several environmental benefits for the city of Baotou.

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Appendix 1: Policies encouraging WTE projects in China

No.	Time	Policy File Name	Abstract
1	May 1997	Temporary Regulations on the Basic Construction Projects of New Energy	Specific provisions on construction projects of new energy
2	1998	Notification on approval of new energy construction projects	Includes waste to energy in new energy, and provides a lot of preferential policies to support waste to energy
3	Jan. 1999	Notification from the Planning Commission and the Ministry of science and technology on further supporting the development of renewable energy	gives clear norms on the aspects of project setting up, financial support, grid combination preferential and pricing method, in order to accelerate the development of renewable energy **priority of basic construction loans** 2% financial discount for renewable energy project loans **Acquisition of all power** the power grid would share the part that is higher than the average price
4	May. 2000	Municipal solid waste disposal and pollution control technology policy	Specified garbage disposal technology and pollution treatment technology in detail.
5	Sep. 2002	Opinions on promoting the industrialization of urban sewage and garbage treatment	1) Guarantee the operating expenses and investment payback, achieve market-oriented operation of waste collection, transportation, treatment and recycling 2) For investment in urban sewage and garbage disposal facilities, the project capital should not be less than 20% of the total investment, and operating period not more than 30 years 3) Government gives necessary policy support to municipal solid waste treatment enterprises and projects constructions, including: discounted power supply for waste treatment; allocation of project construction land for new urban garbage treatment facilities 4) **operating cost compensation policy** Governments should compensate the cost of the construction of waste collection and transportation facilities and garbage disposal fees

6	2002	Notification on the implementation of the municipal solid waste disposal charging system to promote the industrialization of garbage disposal	For waste treatment facilities that are in the construction for supplement waste treatment capacity, with the approval of the city government, household garbage treatment fee is allowed to support the construction. But the construction must complete and operation within three years .
7	Jul. 2004	Decision of the State Council on the reform of investment system	Allowing accesses for social capital to enter the infrastructure, public utilities and other industries and fields within laws and regulations permission.
8	Mar. 2004	No. 126th Document from the Ministry of construction of the people's Republic of China	Defined franchise period no more than 30 years
9	2005	Industrial structure adjustment Guidance Catalogue	Government supports the Reduction, Recycling, Harmless Treatment and Comprehensive Utilization of Urban Garbage and Other Solid Waste Project
10	2005	people's Republic of China law of Renewable energy	1) the nation encourages and supports power generation by renewable energy and its combination with the power grid 2) enterprises on the power grid should sign contracts with those renewable energy power generation companies have legally obtained administrative license or submitted for the record, provide easy accesses to grid combination, and acquire their full generated power 3) Power price should be decided according to local conditions based on economic and reasonable principle, and be published.
11	2006	Trial management of renewable energy power prices and cost sharing	1) the subsidy price standard is 0.1 dollar per kilowatt hour (equivalent to 0.65 yuan). Power generation projects enjoy the subsidy for 15 years from the date of production at the price of 0.25yuan/kWh 2) the mixed fuel power generation projects consume conventional energy of more than 20% shall be deemed as conventional energy power generation projects and don't enjoy the subsidies
12	Jan. 2006	Regulations on the administration of renewable energy power generation	For large and medium-sized renewable energy projects, direct accesses to the power grid for hydropower, wind power and biomass power shall be invested by the power grid enterprises

13	May 2010	Notification on printing and distributing "the technical guidelines for the domestic refuse treatment"	Incineration facilities relate to less land use, rapid stabilizing, effective waste reduction, easy odor control and useful waste incineration heat.
14	Apr. 2011	Notification on Further Strengthening the work of municipal solid waste disposal	By 2015, the city garbage harmless treatment rate reaches higher than 80%. Each province builds more than one model city for garbage classification. 50% city achieves kitchen garbage classified collection. Municipal solid waste resource utilization ratio reaches 30%, and important cities plan to reach 50%. Establish improved urban household garbage disposal supervision system. Promotion for waste product recycling, waste incineration for power generation, biological treatment and other solid waste resource utilization.
15	Apr. 2012	Notification of the national garbage disposal facilities construction plan for the 12th Five-Year plan	By 2015, the country's urban domestic waste incineration treatment facilities capacity reaches more than 35% of the total capacity of harmless treatment, of which the eastern region reaches more than 48%.