Thematic Summary Report
First DRAFT VERSION

May 2022

CHINA
Integrated Waste Management
NAMA Support Project
Optimization of Chinese Anaerobic Digestion (AD) Plants for Restaurant/Kitchen Waste

GOPA Infra

UPM

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1 Introduction

The China Integrated Waste Management Project is a NAMA (NAMA=Nationally Appropriate Mitigation Action) Support Project (NSP), which is financed by the NAMA Facility (a joint initiative of the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU), UK's Department for Business, Energy and Industrial Strategy (BEIS), Danish Ministry of Energy, Utilities and Climate (EFKM), Danish Ministry of Foreign Affairs (MFA) and European Commission). The NSP aims to accelerate sustainable low-carbon development of the waste management sector in China, demonstrated by the example of five municipalities, namely Suzhou (Jiangsu Province), Taian (Shandong Province), Xi'an (Shaanxi Province), Lanzhou (Gansu Province) and Bengbu (Anhui Province), and develop integrated waste management (IWM) systems which can be operated as good business cases. The overarching goal of this project is to induce a transformational change in China's waste management practice, converting it from simple collection-disposal models to an integrated approach with improved corresponding physical infrastructure and governance aspects.

The task of technical assistance aims to provide consulting advice on planning support with integration of BAT and BEP solutions, logistic optimization, optimization and integration of existing facilities, monitoring of the system's functionality and efficiency, solutions to improve financial sustainability, and cross-sectoral synergy improvement.

According to the United Nations Food and Agricultural Organization (FAO), 1.6 billion tons of food is lost and wasted globally every year, inflicting severe environmental and socio-economic damage. Poor management of food waste causes the loss of natural resources, human health issues, pollution of rivers and seas, the generation of methane emissions from dumps and landfills, and a missed opportunity to recover valuable energy, organic matter, nutrients, and water contained in the food waste. To illustrate the scale of the environmental impact, managing food waste sustainably could reduce greenhouse gas emissions by up to 518 million tons, equivalent to taking all the cars off the road in the European Union.

With the acceleration of urbanization in China and the improvement of people's living standards, food waste (including household food waste, restaurant food waste, and other food waste) has become a large part of urban waste. In the urban waste structure, food waste accounts for about 50%. In 2018, the quantity of collected and transported domestic garbage was about 228 million tons; about 110 million tons of food waste were produced. It is estimated that by 2025, China's food waste growth will reach about 130 million tons. In 2020, the quantity of collected and transported domestic garbage was about 235 million tons. Currently, the main treatment methods are incineration and landfill.

In the continuous promotion of waste classification, food waste recycling and resource reuse will increase. Regarding recycling and resource reuse of food waste, anaerobic digestion, composting, and incineration could be the main process options. In Fig.1, the structure of the MSW separated treatment system in China was proposed by Chinese scholars. Based on the cost-benefits analyses, anaerobic digestion enabling renewable energy generation, nutrient recovery, and building of soil organic matter, essential for mitigating climate change, sustainable growth, and industrialization, is becoming more and more attractive.

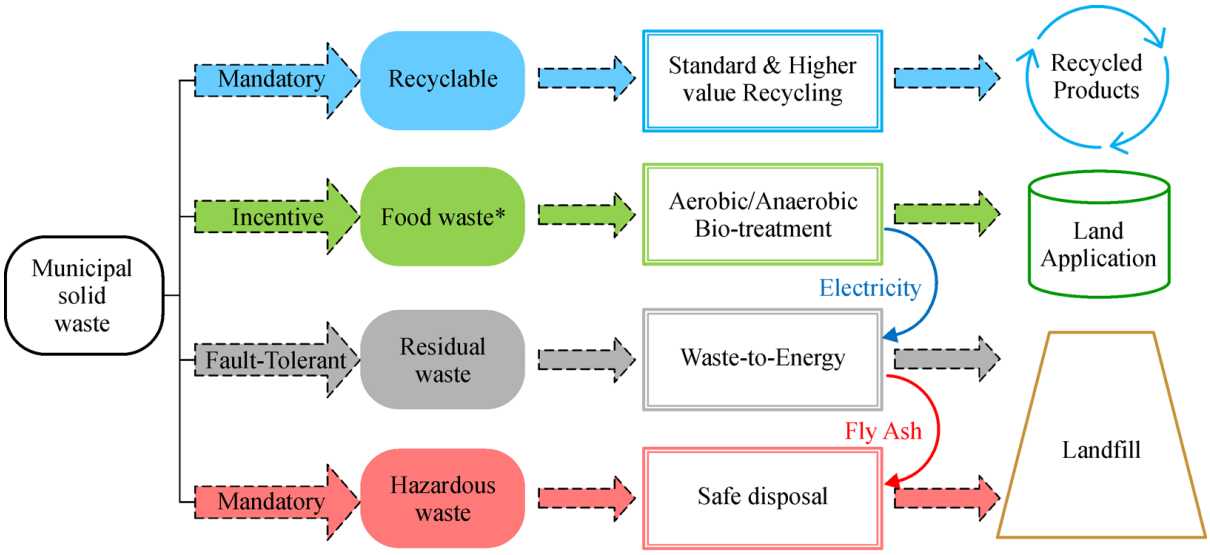

Figure 1: Structure of MSW separated treatment system in China [J. Liu, 2020]

In the five IWM-NAMA pilot municipalities, the local authorities selected anaerobic digestion technology as the primary treatment process for food waste.

2 Chinese AD plants for restaurant/ kitchen waste treatment

Food waste disposal in China officially began during the 12th Five-Year Plan period (2011-2015). Various national policies, laws, regulations, and local policies were approved. During the 12th Five-Year Plan period, the National Development and Reform Commission (NDRC), the Ministry of Finance, and the Ministry of Housing and Construction announced five groups of pilot cities (districts), for a total of 100, for the treatment of food waste in the 32 provincial administrative regions respectively in July 2011, October 2012, July 2013, July 2014, and May 2015. It shows that the development of the food waste treatment industry is gradually accelerating.

The changes to the legal and regulatory framework as well as the development of the food waste treatment industry demonstrate the continuous focus of China's authorities on the waste sector, which also emphasizes the timeliness and importance of the NAMA Support Project (NSP) to assist the waste sector's transformation towards low-carbon and carbon capture & utilization solutions. For this reason, five pilot cities of Suzhou, Tai'an, Lanzhou, Bengbu, and Xi'an were jointly selected with Chinese partners. The locations of these five cities are pointed out on the following map.

Figure 2: Locations of five selected pilot cities

Table 1: List of food waste treatment plants in the project cities

No.	City	Project Name	Operation status	Main process	Capacity	Remarks
1	Lanzhou	Lanzhou Chinai R&KW treatment plant (300t/d)	operation in 2011	Mesophilic/thermophilic anaerobic digestion	Capacity: 350t/d R&KW	Gansu Chinai
2	Bengbu	R&KW treatment plant (100t/d)	operation in 2020	Mesophilic anaerobic digestion	Design capacity is 100 t/d for R&KW	
3	Xi'an	Xian Welle R&KW Treatment Plant (Baxingtan) (200 t/d)	operated with full load since Dec 2018	Mesophilic anaerobic digestion	design capacity is 200 tons/d for R&KW, 20t/d for waste oil	Xi'an Welle
4	Xi'an	Xian Gaoling R&KW Treatment Plant	Commissioning in Jan 2021	Mesophilic anaerobic digestion	design capacity is 500 tons/d	Wuxi Masheng
5	Xi'an	Xian Lantian R&KW Treatment Plant	operation in April, 2021	wet mesophilic anaerobic digestion	design capacity is 500 tons/d, 2*1.5MW electricity Generators	Everbright
6	Xi'an	Xian Huyi R&KW Treatment Plant	Under construction	Mesophilic anaerobic digestion	design capacity is 300 tons/d for restaurant waste, 200 tons/d for kitchen waste, and 20t/d for waste oil	CECEP
7	Suzhou	Huayijie R&KW Treatment Plant (High-Tech) (200+20 t/d)		Mesophilic anaerobic digestion		

No.	City	Project Name	Operation status	Main process	Capacity	Remarks
8	Suzhou	Huayan food waste and greenery waste treatment	operation in 2019	Mesophilic anaerobic digestion	Located In the Suzhou Industrial Park; (R&KW:300t/d, leachate: 200t/d, greenery waste: 100t/d)	
9	Suzhou	Suzhou Jiejing R&KW Treatment Plant (Qizishan) (350t/d, actual 400t/d)	The 1st phase in operation in 2010; 2nd phase in operation in 2013	Mesophilic anaerobic digestion	located at the Vein Industrial Park in Wuzhong district, Suzhou; The 1st phase for 100 t/d capacity, and the 2nd phase for 250 t/d capacity	
10	Tai'an	R&KW and sludge treatment plant (102t/d) Upscaling is planned	operation in Oct 2015	Mesophilic anaerobic digestion	The 1st phase for 50 t/d R&KW, 50t/d excess sludge; and the 2nd phase for upscaling to 200 t/d R&KW, 90t/d sludge, and 10t/d faecal sludge	Shandong Tianren

Examples of the AD plants were visited during the assignment; the following information was collected:

CITY 1: Lanzhou kitchen waste treatment plant

Lanzhou is the capital of Gansu province and is located in Northwest China (36° 03′ N, 103° 40′ E).

- Project description

  Lanzhou kitchen waste recycling treatment plant operated by Gansu Chinai bioenergy System Co., Ltd is a franchise project with a franchising period of 30 years. The project is in Hanjiahe Industrial Estate, Xiguoyuan Town, Qilihe District, Lanzhou. The construction land area is 43 acres, with a treatment capacity of 300 t/d and a total investment of CNY 160 million (20.35 million Euro). The project started construction in September 2009, and the trial operation was created on March 24, 2011.
- R&KW Treatment Process in Lanzhou

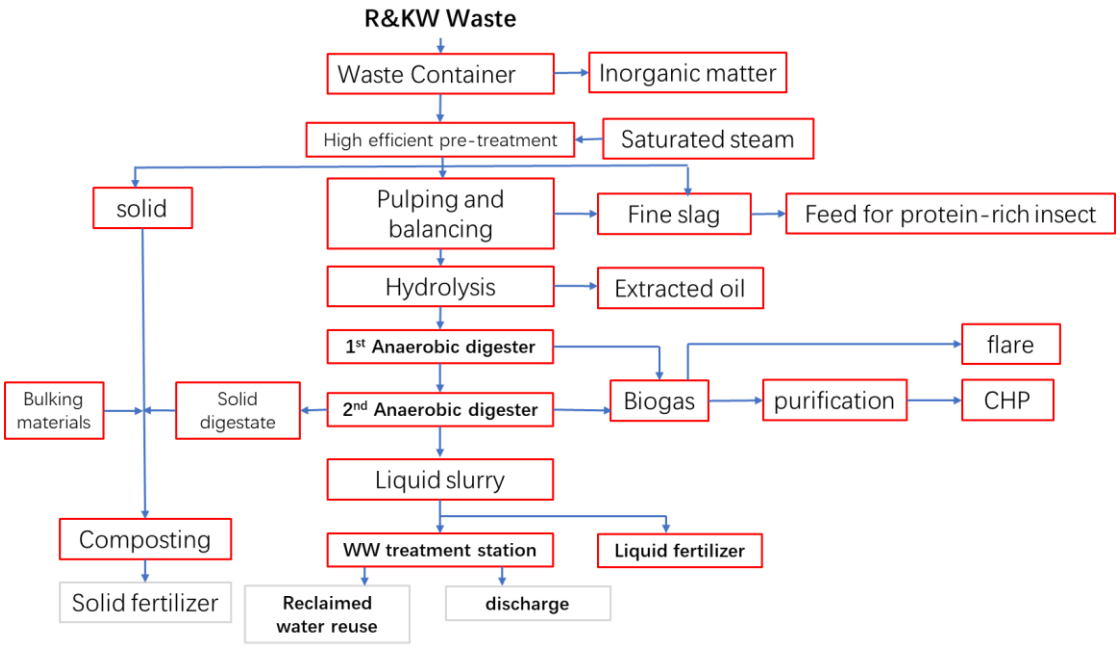

Figure 3: Flow chart of Lanzhou Chinai restaurant & kitchen waste treatment plant

Capacity: 300t/d, treatment process: pre-treatment (solid/liquid separation) + organic solid is transported to composting plant to make fertilizer + liquid to anaerobic digestion + biogas boiler.

This plant has been operated since 2011. The equipment is quite old but still in operation.

According to the collected data, the average daily waste was more than 300 tons and over design capacity. The specific biogas production fluctuated considerably, and methane gas contents (45%) seem relatively low, which can be analyzed with the operators based on the more detailed information to find optimization solutions.

Table 2 : Characters of the AD treatment system in the Lanzhou kitchen waste recycling treatment plant

No	Item	Specification	Remarks
1	Pre-treatment	Solid/liquid separation, oil extraction, Hydrolytic acidification	
2	Fermentation temperature range	Two phase digestion 1st phase digestion is thermophilic digestion with 55°C 2nd phase digestion	
3	Stirring/mixing	stirring system	
4	Support bodies between stages	pump	
5	Sediment/float separation in fermentation		No data
6	Hydraulic Retention Time	15 days for 1st phase digestion No data for 2nd phase digestion	
7	Facilities for the control of the process environment		No data
8	Phase separation	Solid/liquid separator	
9	Post-treatment procedures	Part of the biogas slurry is used as liquid fertilizer and applied to alkaline soil. Part of the biogas slurry adopts two-level A/O and is discharged into the urban sewer network after treatment	but the sewer network has not yet been completed, and the biogas slurry has not entered the A/O system
10	Biogas treatment and utilization	Electricity production (ca 2 MW)	

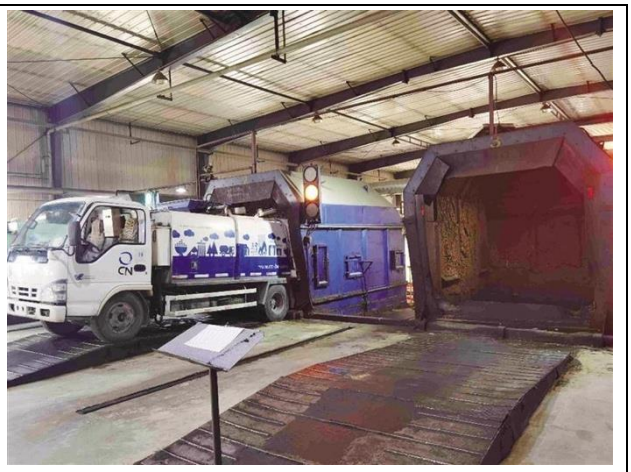

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Figure 4: Pictures of Lanzhou Chinai R&KW treatment plant

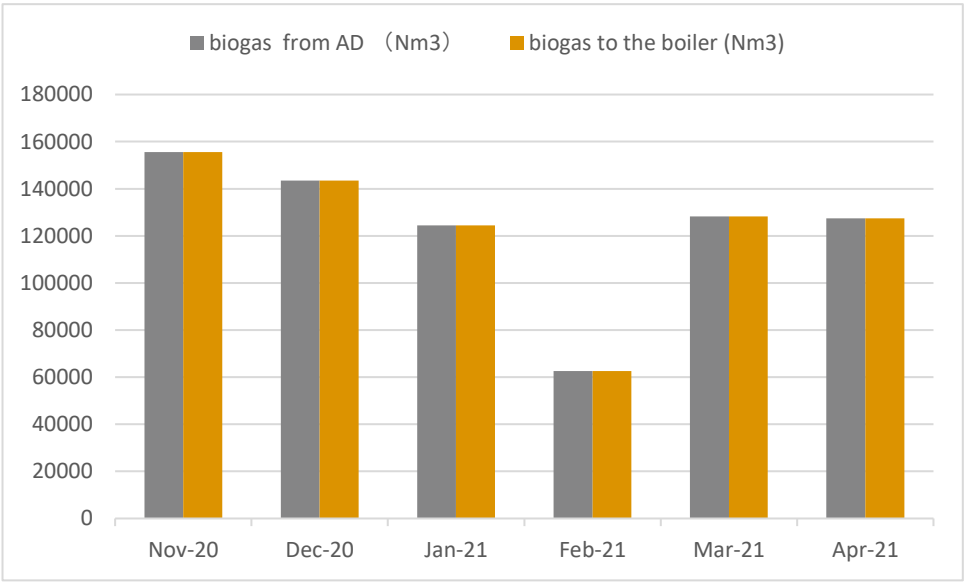

Figure 5: Monthly biogas production and utilization of Lanzhou Kitchen Waste Treatment Plant in 2020 and 2021

- Primary data (input quantities, output, energy consumption, produced methane quantities, residues from AD process)

  The project can now process more than 100,000 t/y of restaurant waste, with an annual biogas output of 5.475 million m3 (the biogas output is 5,000-7,000m3 per day during site visit), yearly heat output of 158,775 MJ, and an estimated annual electricity generation of 10.95 million kWh (current biogas power generation is for captive use only). 5,000 t/y of industrial grease and 13,000 t/y of organic fertilizer can be produced.

Summary of the findings

1. System optimization such as solid organic matter addition, longer HRT, and C/N ratio adjustment for highly efficient biogas production is recommended.
2. The efficient utilization of biogas such as CHP adoption, biogas upgrading, and a more efficient boiler.
3. To set up a state-of-the-art treatment of biogenic waste from households, an extension of the food waste treatment with a similar capacity as the ChiNai facility should be pursued. Since the source separation of food waste will have an impact on both the calorific value and the volume of waste

to be incinerated, a feasibility study on the source segregation potential of biogenic wastes from households and on the overall effect of increased source separation of recyclables and biogenic waste should be carried out.

A restaurant/kitchen waste treatment facility manages the remaining MSW (between 300-350 tons/day), composting approximately 100-150 tons/day. Aside from compost (6,800 tons/year) and liquid organic fertilizer (30,000 tons/year), this facility produces biodiesel (5,000 tons/year) and biogas (about 70m^3 per ton of waste).

CITY 2: Bengbu kitchen waste treatment plant

Bengbu is one of the cities of Anhui province and is located in the East of China (32° 43′ N, 116° 45′ E).

- Description of the direct neighborhood

  Bengbu is located in the north of Anhui Province, with a latitude of 32°43' to 33°30' N and a longitude of 116°45' to 118°04'E. It is bordered by Suzhou City, Suixi County, Lingbi County, and Qixian County in the north, with Huainan City and Fengyang County in the south. It is adjacent to Mingguang City and Sihong County of Jiangsu Province and bordered by Mengcheng County and Fengtai County in the west. The Jinpu Railway passes through the north and south from the center, and the Huai River flows through the southern part from west to east. Most of the jurisdiction is at the south end of the Huaibei Plain. It is the intersection of the Beijing-Shanghai Railway and Huainan Railway, called the "Throat of Huning," with a total area of 5,950.72 square kilometers.

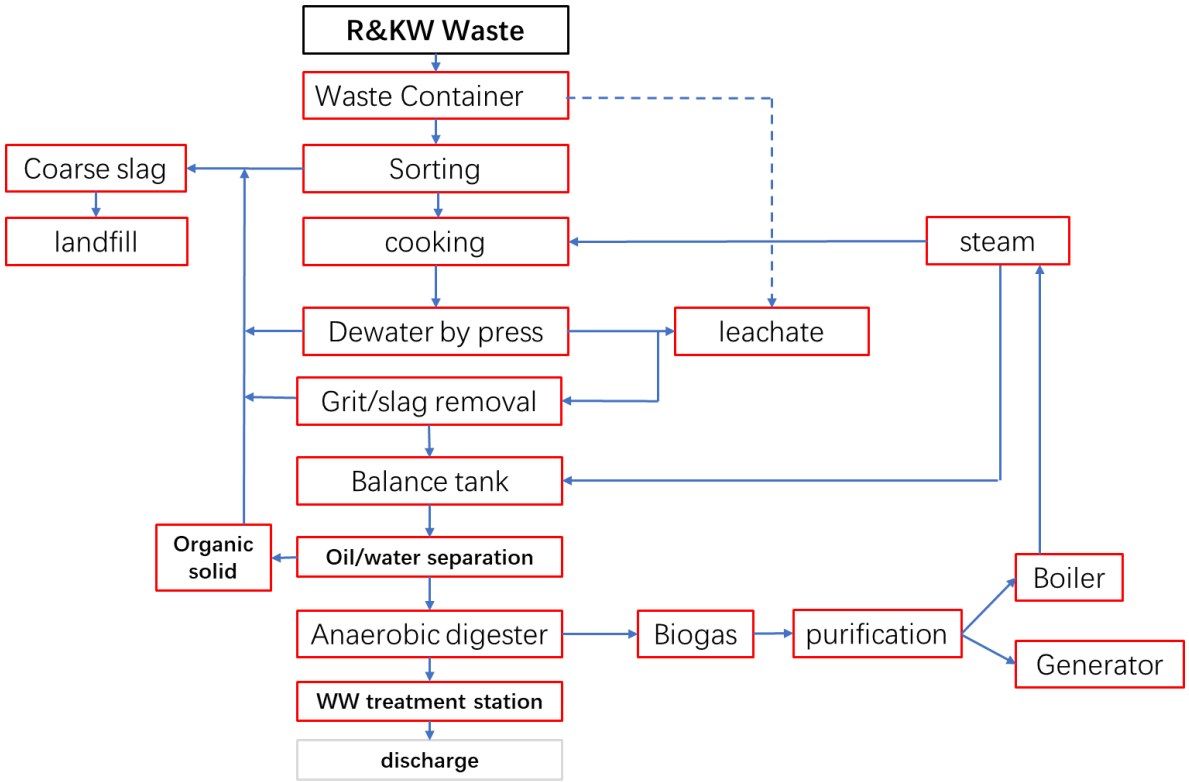

Figure 6: Flow chart of Bengbu restaurant & kitchen waste treatment plant

The city government of Bengbu will build a restaurant food waste treatment facility. The planned investment in the project is 110 million yuan. It will be located in the area of a landfill site, covering about 36 acres with the technology of "dry anaerobic fermentation + biogas cogeneration + organic fertilizer produced by biogas residue." It can process 36,500 tons of restaurant waste every year. The project design has been completed, and the bidding for construction work is ongoing. After completing the

restaurant waste treatment plant, Bengbu plans to gradually implement separate classification, collection, and treatment of restaurant kitchen wastes.

Capacity: 100t/d restaurant waste + 30 t/d of crop stalks

Table 3: Characters of the AD treatment system for the Bengbu kitchen waste recycling treatment plant

No	Item	Specification	Remarks
1	Pre-treatment	sorting-cooking and heating-pressing-heating the slurry (65-70°C)-three-phase separation	
2	Fermentation temperature range	Mesophilic digestion (38℃)	
3	Stirring/mixing	stirring system	
4	Support bodies between stages	pump	
5	Sediment/float separation in fermentation	The coarse slag is sent and burned in the incineration plant. Fine slag is treated in the sludge drying and incineration plant	No data
6	Hydraulic Retention Time	30	
7	Facilities for the control of the process environment		No data
8	Phase separation	Solid/liquid separator	
9	Post-treatment procedures	The biogas residue is 8-10 tons/d (80% moisture content) and sent to the sludge drying and incineration plant (320t/d) for drying and incineration. The biogas slurry is ca 110t/d, the secondary A/O+NF is used, 95% of the water is discharged into the sewage sewer network, and 5% of the concentrated liquid is sent to the sludge drying and incineration plant for treatment.	
10	Biogas treatment and utilization		

Figure 7: Pictures of Bengbu R&KW treatment plant

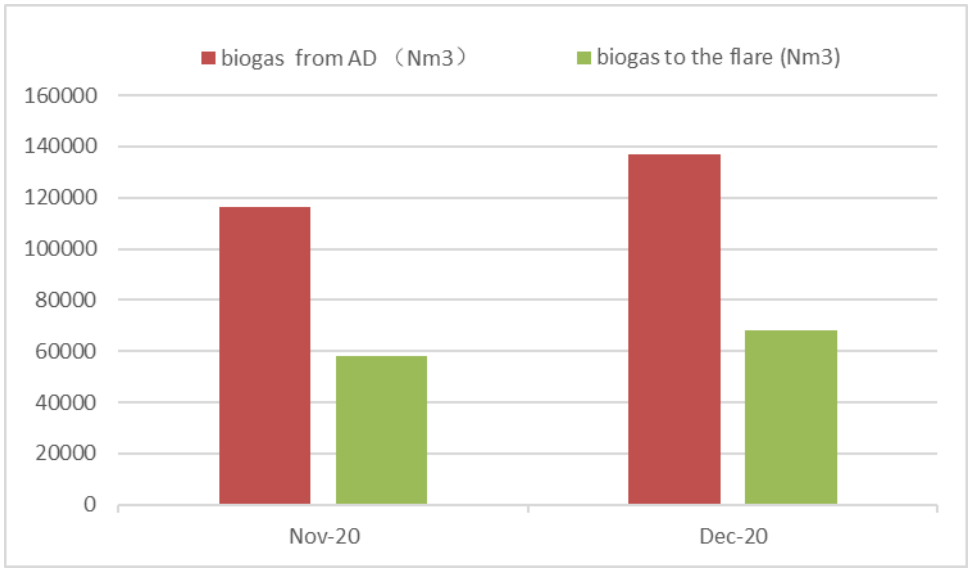

Figure 8: Monthly biogas production and utilization of Bengbu Kitchen Waste Treatment Plant in 2020

CITY 3: Xian kitchen waste treatment plant

Xi'an, historically known as Chang'an, is located in the Guanzhong Basin in the middle region of the Yellow River. It is between 107.40 to 109.49 degrees east longitude and 33.42 to 34.45 degrees north latitude. It borders the Wei River and the Loess Plateau north and the Qinling Mountains south. The east is bounded by the Ling river and the Bayuan Mountain and connected with Huaxian, Weinan, Shangzhou, and Luonan County. The west is bounded by Taibai Mountain and Qinghua Loess Platform, connecting with Meixian and Taibai County. The south reaches the main ridge of North Qinling Mountain and is bordered by Foping, Ningshan, and Lishui County. The north reaches the Wei River, northeast across the Weihe River, neighboring Xianyang City, Yangling District, Sanyuan, Fuyang, Xingping, Wugong, Fufeng, and Fuping County /City. It crosses 204 kilometers from east to west and 116 kilometers from north to south.

According to the local “Management Measures of MSW Classification” in Xi’an, kitchen waste refers to solid food, eggshells, fruit peels, cores, tea residue, etc., from households, and perishable organic waste such as fruits, vegetables, and aquatics produced in agricultural markets. Xi'an hasn’t conducted the classification and statistics of kitchen waste by now, but Xi’an performs classification in some pilot communities and units. According to the experience of the environmental sanitation department, the amount of kitchen waste collection and transportation accounts for 30-40% of the total MSW, which is

about 3,000 tons/day. Therefore, several kitchen waste treatment plants will be built in different districts.

CASE 3-1: Xian Welle Kitchen Waste Treatment Plant (Baxingtan)
A Resource Utilization and Bio-safety Treatment Project (Phase I) of the Kitchen Wastes in Xi'an has been built; the project is located at the Baxintan Village in the west of Fuyin Highway, with an area of about 50.5 mu (33700 m^2). The capacity of the plant for the kitchen waste is **200t/d**, the size of the used cooking oil treatment facility is **20t/d**, and the annual biogas output reaches 5,410,000 m^3, with the yearly on-grid electrical energy delivery of 48,000,000 kWh. The total investment in the project is about RMB 190,000,000; the primary materials treated include food waste, flour residues, vegetables, animal and vegetable oil, and the meets and bones, etc., generated by restaurants, hotels, government departments, public institutions, and school canteens in the city. The treatment process technology flow chart shows that mainly anaerobic methods to generate biogas are used. This first restaurant waste treatment plant was built for Xi'an in 2018 and has been in operation with a full load since 2019. The facility adopts the pre-treatment technology of "organic separation + solid-liquid separation + oil-water separation" and wet medium temperature anaerobic fermentation treatment technology. The solid AD residue (separated from the digestate) is dehydrated and then landfilled. The biogas slurry (liquid digestate) is treated with "MBR+ nanofiltration," covering an area of 50 acres with a total investment of 190 million yuan.

According to the plan, to be completed by 2025, Xi'an is building three more restaurant waste treatment plants. These food waste treatment facilities would have a total treatment capacity of 800 tons/day. By 2030, the total treatment capacity will reach 1,000 tons/day.

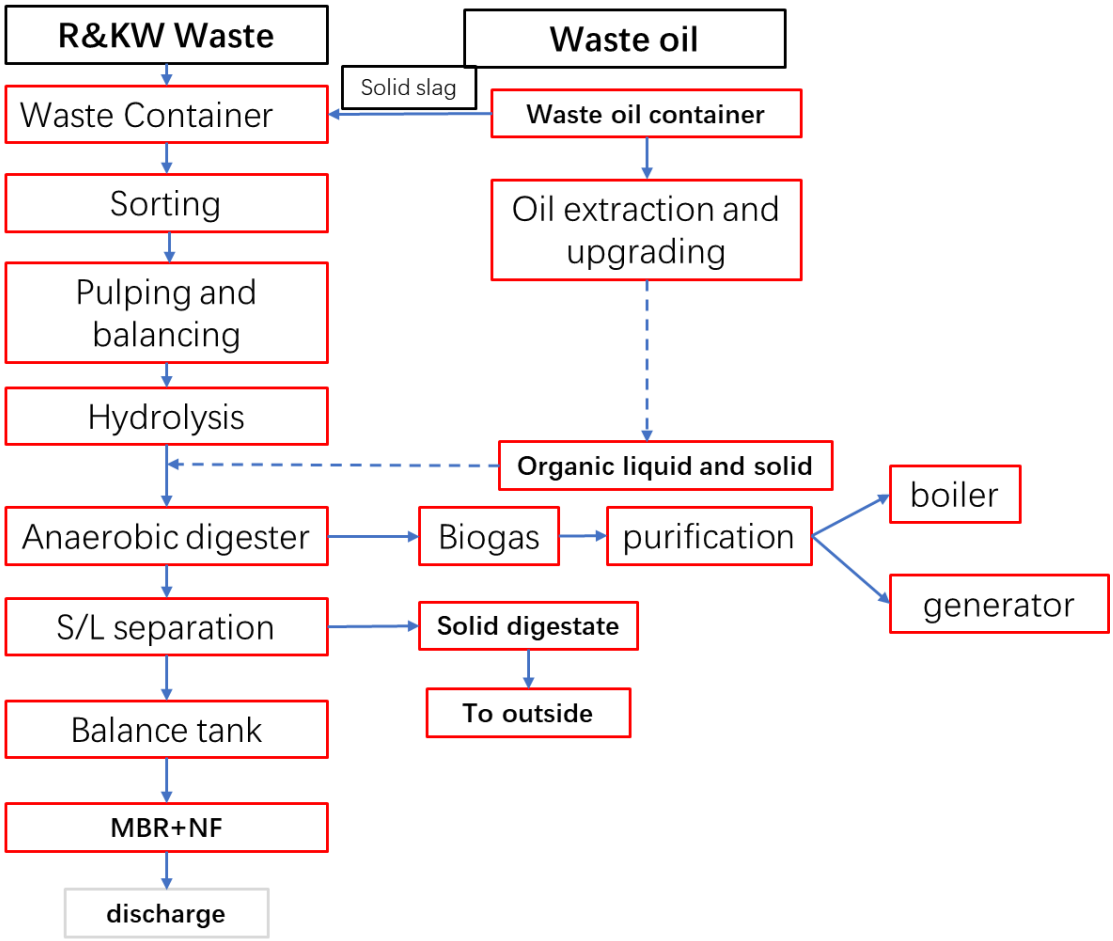

Figure 9: Flow chart of Baxingtan restaurant & kitchen waste treatment plant in Xi'an

Table 4: Characters of the AD treatment system in Xi'an kitchen waste recycling treatment plant operated by Xi'an Welle Environmental Protection Technology Co., Ltd.

No	Item	Specification	Remarks
1	Pre-treatment	organic separation (including crushing and screening) + solid-liquid separation + oil-water separation	
2	Fermentation temperature range	mesophilic	
3	Stirring/mixing	Mixer in the CSTR	
4	Support bodies between stages	pump	
5	Sediment/float separation in fermentation	The agitator is designed with "auxiliary blade" below the design liquid level, and large-diameter slag discharge ports are evenly distributed at the same height. When the surface scum crusting is serious, the surface scum is broken through the "auxiliary blade" by reducing the liquid level to the height of "auxiliary blade", and the slag discharge port is opened for slag discharge at the same time	
6	Hydraulic Retention Time	10 – 30 days	
7	Facilities for the control of the process environment	The agitator can ensure the uniform distribution of effective materials in the reactor, avoid stratification and fully contact with microorganisms, so as to ensure the complete effective reaction and biogas production. The temperature is controlled at 35 ~ 37 ℃, the solid content is about 6 ~ 8%, and enters the anaerobic system. Liquid phase CODcr = about 100000 ~ 150000 mg/L	
8	Phase separation	Solid/liquid separator	
9	Post-treatment procedures	Digester solid residues are dehydrated and then landfilled; Digester liquid residues are treated by "balance tank+ MBR+ nanofiltration", then flows to Xi'an 6th WWTP	
10	Odor control	The odor is collected and sent to the deodorization system for treatment. After reaching the standard, it is discharged through a 15m exhaust funnel	
11	Biogas treatment and utilization	Collection and storage + purification + boiler heating + self-use of power generation + feed into the power grid	

Figure 10: Pictures of the Welle R&KW treatment plant, Xi'an

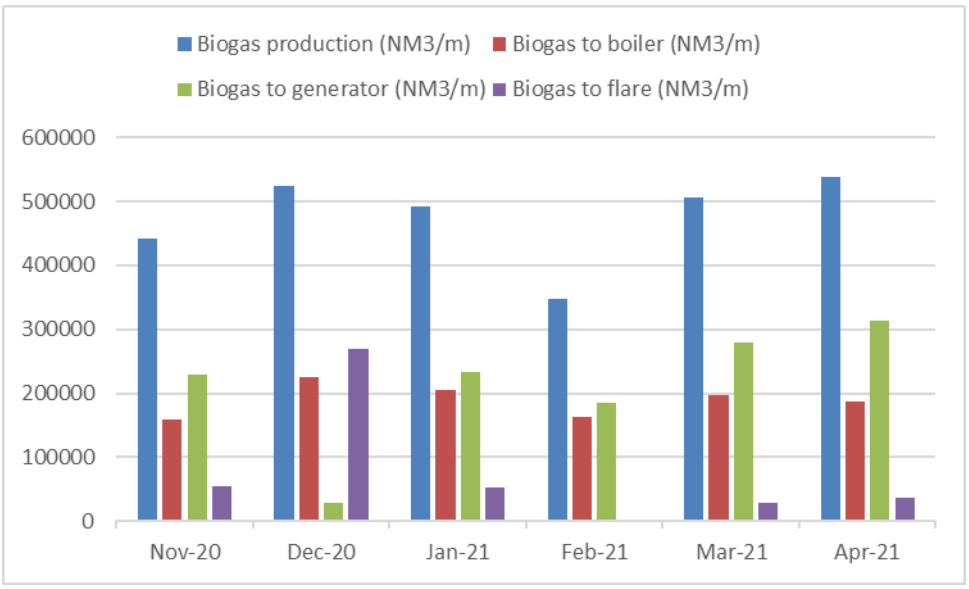

Figure 11: Monthly biogas production and utilization of Xi'an Kitchen Waste Treatment Plant (Baxingtan) in 2020 and 2021

Case 3-2: Lantian R&KW Treatment Plant

Xi'an Lantian kitchen waste treatment plant is located east of Xi'an Lantian domestic waste incineration cogeneration plant, covering an area of 35.81 mu. The treatment capacity is 300t/d of restaurant waste and 200t/d of kitchen waste, including two sets of 1560kw biogas electricity generators.

(1) Main treatment technology route: pre-treatment + wet mesophilic anaerobic digestion;
(2) The technical route of restaurant waste pre-treatment: feeding + sorting pulping + sand removal + high-temperature cooking + oil-water separation;
(3) Technical route of kitchen waste pre-treatment: feeding + manual sorting + crushing + screening + pressing;
(4) Technical route of oil purification and utilization: preparation of "crude oil" process;
(5) Technical route of biogas treatment and utilization: collection and storage + purification + boiler heating + power generation and self-use + surplus power on the Internet;
(6) Technical route of AD residue treatment: after centrifugal dehydration, it is combined with the residual sludge from the digestate post-treatment and transported to Xi'an Lantian domestic waste incineration plant;

(7) Biogas slurry treatment technology route: coagulation air flotation + high efficiency oil removal + membrane bioreactor (MBR) + nanofiltration + reverse osmosis;
(8) The technical route of concentrated liquid treatment: pre-treatment + evaporation + reverse osmosis, and the concentrated liquid is sprayed back to the incinerator of the incinerator;
(9) Deodorization technology route: "chemical deodorization + biological deodorization + activated carbon adsorption deodorization" point source deodorization process, "chemical deodorization + biological deodorization" non-point source deodorization process. The food waste unloading area is sprayed with "natural plant liquid" for deodorization.

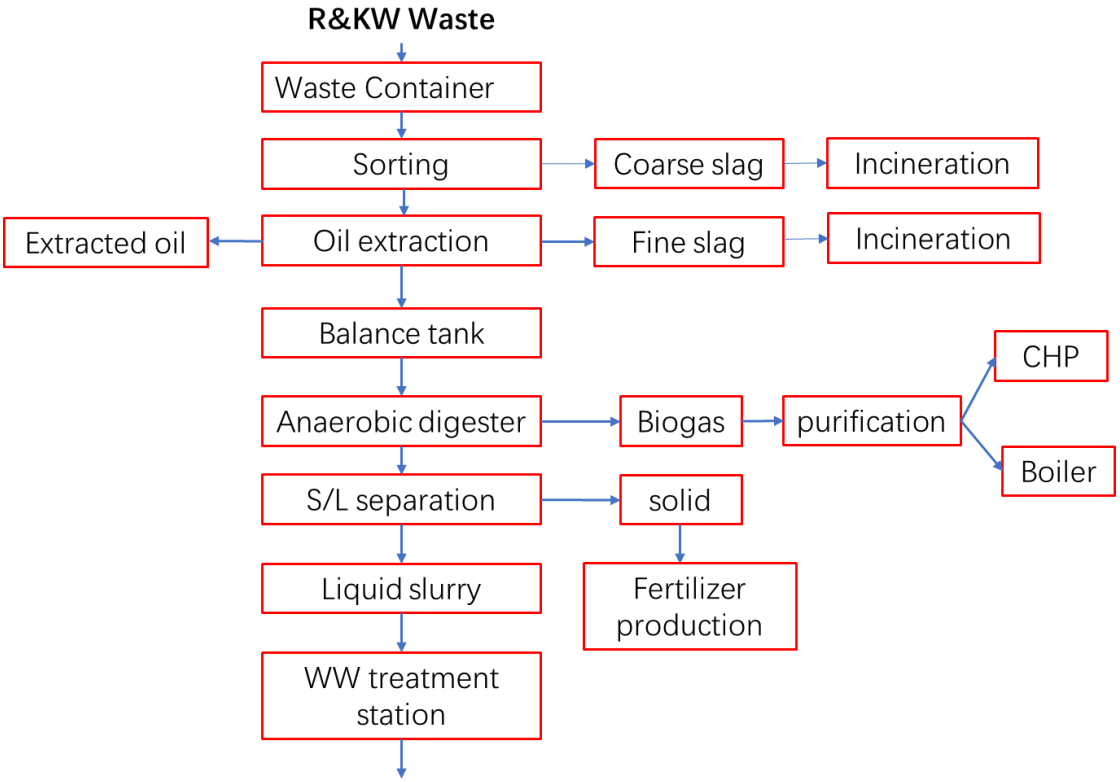

Figure 12: Flow chart of Lantian restaurant & kitchen waste treatment plant in Xi'an

Table 5: Characters of the AD treatment system of the kitchen waste recycling treatment plant in the Huyi District of Xi'an city

No	Item	Specification	Remarks
1	Pre-treatment	large material sorting - fine sorting - pulping - heating oil extraction	
2	Fermentation temperature range	Mesophilic digestion	
3	Stirring/mixing	stirring system	
4	Support bodies between stages	pump	
5	Sediment/float separation in fermentation		No data
6	Hydraulic Retention Time		No data
7	Facilities for the control of the process environment		No data
8	Phase separation	Solid/liquid separator	
9	Post-treatment procedures	Digester solid residues to incineration plant for incineration; three-stage process for slurry treatment.	
10	Biogas treatment and utilization	Biogas pre-treatment and power generation after entering the generator - Generator with	

No	Item	Specification	Remarks
		waste heat boiler - steam is used for slurry heating (80-90℃) to extract oil. The plant has two sets with 1,560kW per set. The current biogas output is 30,000m3/d, except for heating in the plant; the rest is burned to the flare.	

Figure 13: Pictures of the Lantian R&KW treatment plant, Xi'an

Case 3-3: Huyi R&KW Treatment Plant

It is still in the commissioning phase. The plant is designed to treat 300t/d restaurant waste, 200t/d household kitchen waste, and 20t/d wasted cooking oil.

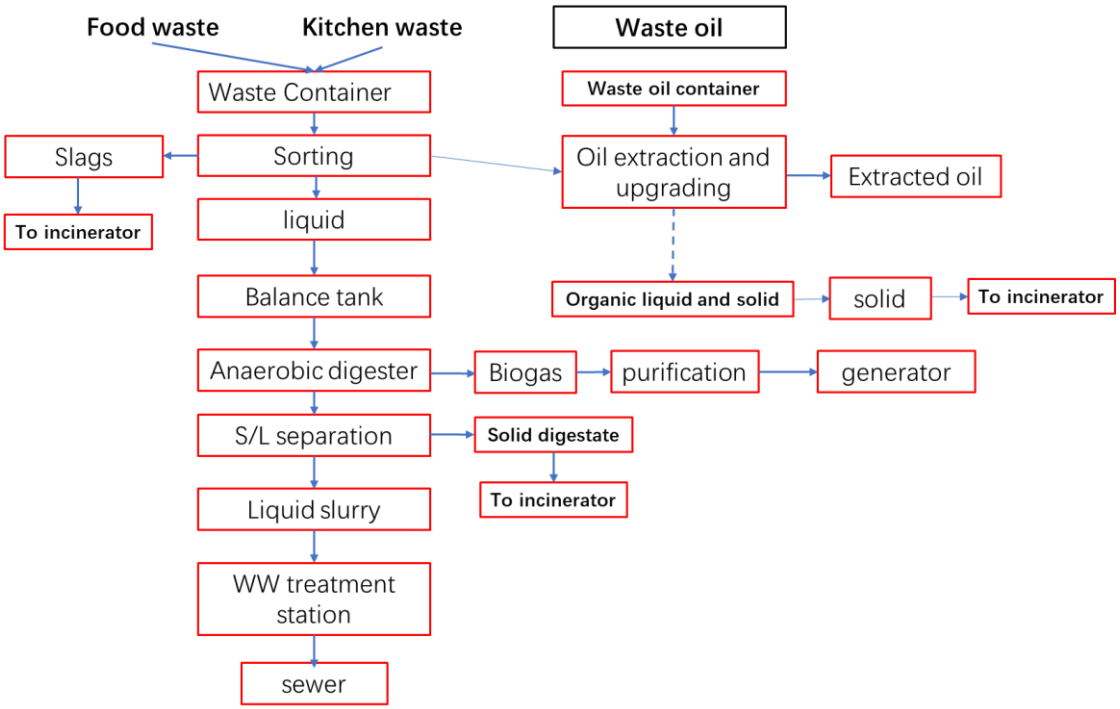

Figure 14: Flow chart of Huyi restaurant & kitchen waste treatment plant in Xi'an

Table 6: Characters of the AD treatment system of the kitchen waste recycling treatment plant in the Huyi District of Xi'an city

No	Item	Specification	Remarks
1	Pre-treatment	large material sorting - fine sorting – pulping - heating oil extraction	
2	Fermentation temperature range	Mesophilic digestion	
3	Stirring/mixing	stirring system	
4	Support bodies between stages	pump	
5	Sediment/float separation in fermentation		No data
6	Hydraulic Retention Time		No data
7	Facilities for the control of the process environment		No data
8	Phase separation	Solid/liquid separator	
9	Post-treatment procedures	Digester solid residues to incineration plant for incineration; three-stage process for slurry treatment.	
10	Biogas treatment and utilization	biogas pre-treatment and power generation after entering the generator - Generator with waste heat boiler - steam is used for slurry heating (80-90℃) to extract oil. The plant has two sets with 1,560kW per set. The current biogas output is 30,000m3/d, except for heating in the plant, the rest is burned to the flare.	

Figure 15: Pictures of Huyi R&KW treatment plant, Xi'an

Case 3-4: Gaoling R&KW Treatment Plant

The plant is located in the middle of the core area of the Gaoling circular economy industrial park; the treatment project of restaurant & kitchen waste in the Gaoling district covers a total area of 60 mu (40000 m2), with a total investment of 318 million RMB. The designed treatment capacity is 500 tons per day. The R&KW collection area covers Gaoling District, the international port area, Yanliang District, Lintong district, and the aviation base. After the completion of the project, 182500 tons of restaurant & kitchen waste will be treated annually, 3285 tons of crude oil will be produced annually, and 5 million kWh of electricity generated from biogas will be sent to the grid.

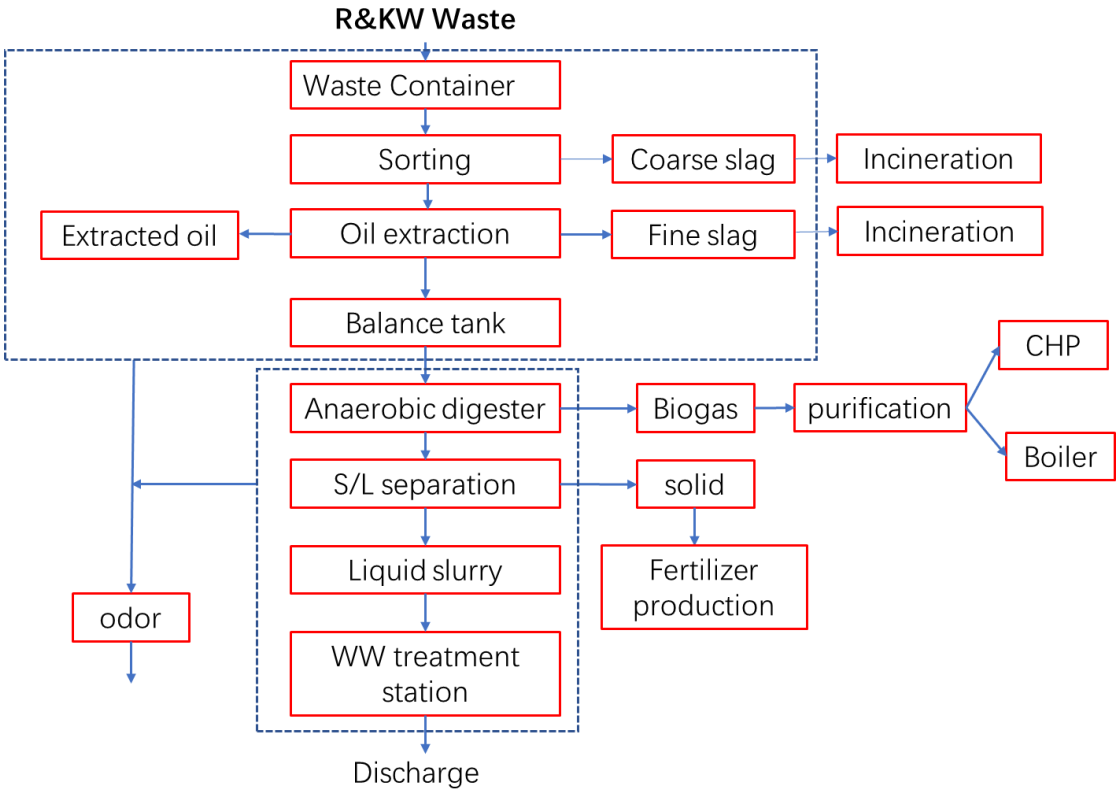

Figure 16: **Flow chart of Gaolin restaurant & kitchen waste treatment plant in Xi'an**

Table 7: **Characters of the AD treatment system of the kitchen waste recycling treatment plant in the Gaolin district of Xi'an city**

No	Item	Specification	Remarks
1	Pre-treatment	Large material separation - three-phase separation – slurry - heating oil extraction	
2	Fermentation temperature range	Mesophilic digestion	
3	Stirring/mixing	stirring system	
4	Support bodies between stages	pump	
5	Sediment/float separation in fermentation		No data
6	Hydraulic Retention Time		No data
7	Facilities for the control of the process environment		No data
8	Phase separation	Three-phase separation fine slag (80% moisture content), after drying to 10% moisture content, will be sent to compost. Biogas slurry is by steam for recovery of NH4HCO3, then A/O – MBR - sewer network.	
9	Post-treatment procedures	Digester solid residues are dehydrated and then landfilled; Digester liquid residues are	

No	Item	Specification	Remarks
		treated by “MBR+ nanofiltration”, then discharged	
10	Biogas treatment and utilization	Biogas (30,000 m3/d) will be sent into 2 (6t/h) steam boilers + 1MW internal combustion engine generator with flue gas waste heat boiler.	

Figure 17: Pictures of Gaoling R&KW treatment plant, Xi’an

Summary of the findings

1. Biogas production
   System optimization such as solid organic matter addition, longer HRT, and C/N ratio adjustment for highly efficient biogas production is recommended.
2. The efficient utilization of biogas such as CHP adoption, biogas upgrading, and a more efficient boiler.
3. To set up a state-of-the-art treatment of biogenic waste from households, an extension of the food waste treatment with a similar capacity as the ChiNai facility should be pursued. Since the source separation of food waste will have an impact on both the calorific value and the volume of waste to be incinerated, a feasibility study on the source segregation potential of biogenic wastes from households and on the overall effect of increased source separation of recyclables and biogenic waste should be carried out.

CITY 4: Suzhou Kitchen Waste Treatment Plant

Suzhou is located in the middle of the Yangtze River Delta and southeast of Jiangsu Province, with a longitude of 119°55′-121°20′E and a latitude of 30°47′-32°02′N. It is east of Shanghai, south of Zhejiang, west of Taihu Lake, and north of the Yangtze River. Its total area is 8657.32 square kilometers, of which the urban area is 4,652.84 square kilometers. Suzhou has numerous rivers and lakes with low-lying terrain. The majority of Taihu Lake is located in Suzhou. The area of rivers, lakes, and intertidal zones accounts for 36.6% of the city's land area, which characterizes Suzhou as a famous water township in southern China. Suzhou has a subtropical monsoon maritime climate with an average temperature of 16.9 °C and a precipitation volume of 1745.5 mm in 2017. Suzhou has distinct seasons, mild climate, abundant rainfall, fertile land, and advantageous natural conditions.

The key implementation scope of the National Appropriate Mitigation Actions (NAMA) project in Suzhou is the five districts under the jurisdiction of the former city (i.e., Gusu District, High-Tech District, Wuzhong District, Xiangcheng District, and Suzhou Industrial Park), covering 4044 square kilometers

and 4.2276 million people.

Case 4-1: Huayijie Restaurant Waste Treatment Plant (High-Tech Zone)
The project is located in the Hushuguan town of the High-tech Zone, with a total treatment scale of 600 tons and an area of 56.35 mu. The overall process adopts the advanced technical scheme of "pre-treatment + anaerobic biogas digestion + composting."

The disposal scale of phase I of the project is 220 tons/day (including 200 tons/day of kitchen waste and 20 tons/day of waste oil). The investment in phase I is 180 million yuan. After treatment, industrial oil, clean energy biogas, and organic fertilizer can be obtained, turning waste into valuable products and achieving resource utilization.

The second phase of the project plans to increase the processing capacity of 400 tons/day of kitchen waste in the existing project site, including kitchen waste (including kitchen waste generated after waste classification collection), fruit and vegetable waste in farmers' markets, garden waste, etc. Implementing the phase II project can guarantee the end resource utilization and disposal of kitchen waste in the High-tech Zone.

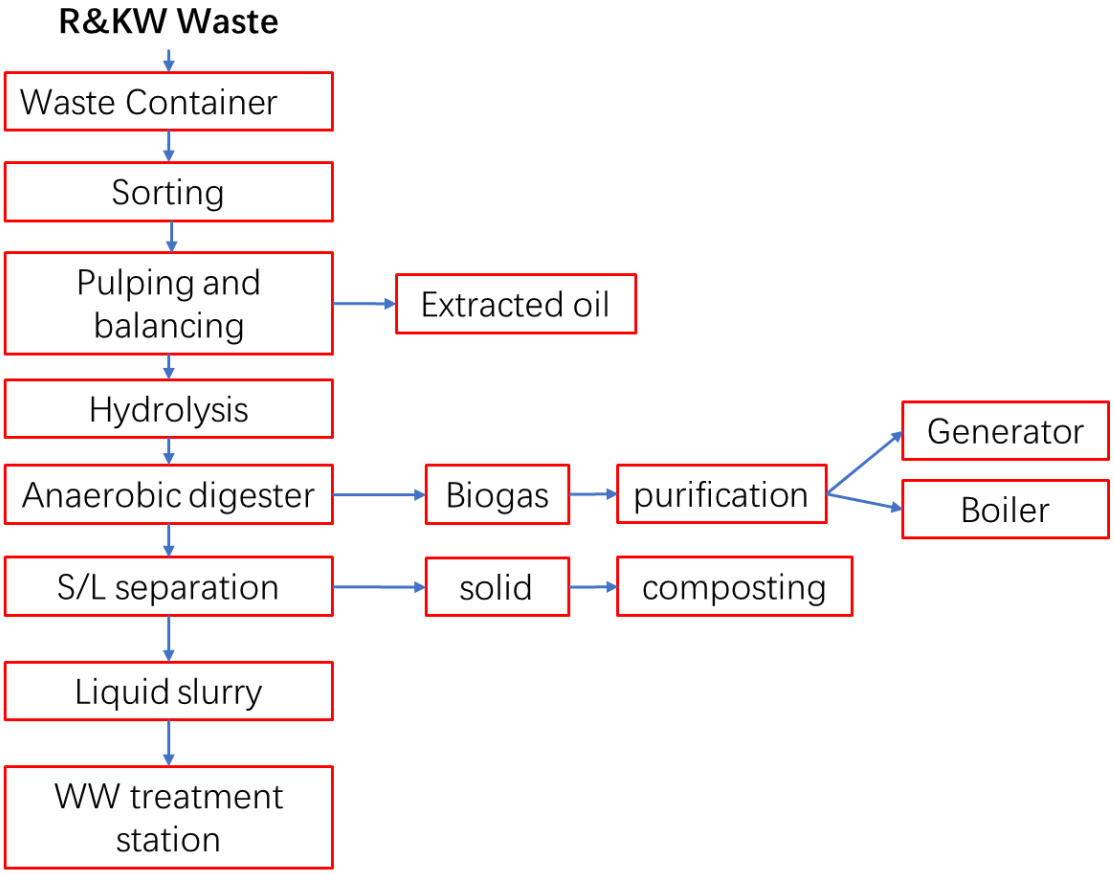

Figure 18: **Flow chart of Huayijie restaurant & kitchen waste treatment plant in High-Tech zone, Suzhou**

Table 8: **Characters of the AD treatment system of the kitchen waste recycling treatment plant in the High-Tech zone of Suzhou city**

No	Item	Specification	Remarks
1	Pre-treatment	Solid/liquid separation, oil extraction, Hydrolytic acidification	
2	Fermentation temperature range	mesophilic	

No	Item	Specification	Remarks
3	Stirring/mixing	stirring system	
4	Support bodies between stages	pump	
5	Sediment/float separation in fermentation		No data
6	Hydraulic Retention Time		No data
7	Facilities for the control of the process environment		No data

No	Item	Specification	Remarks
8	Phase separation	Solid/liquid separator	
9	Post-treatment procedures	Digester solid residues are dehydrated and then landfilled; Digester liquid residues are treated by “MBR+ nanofiltration”, then discharged	
10	Biogas treatment and utilization		No data

Figure 19: Pictures of Huayijie R&KW treatment plant, Suzhou

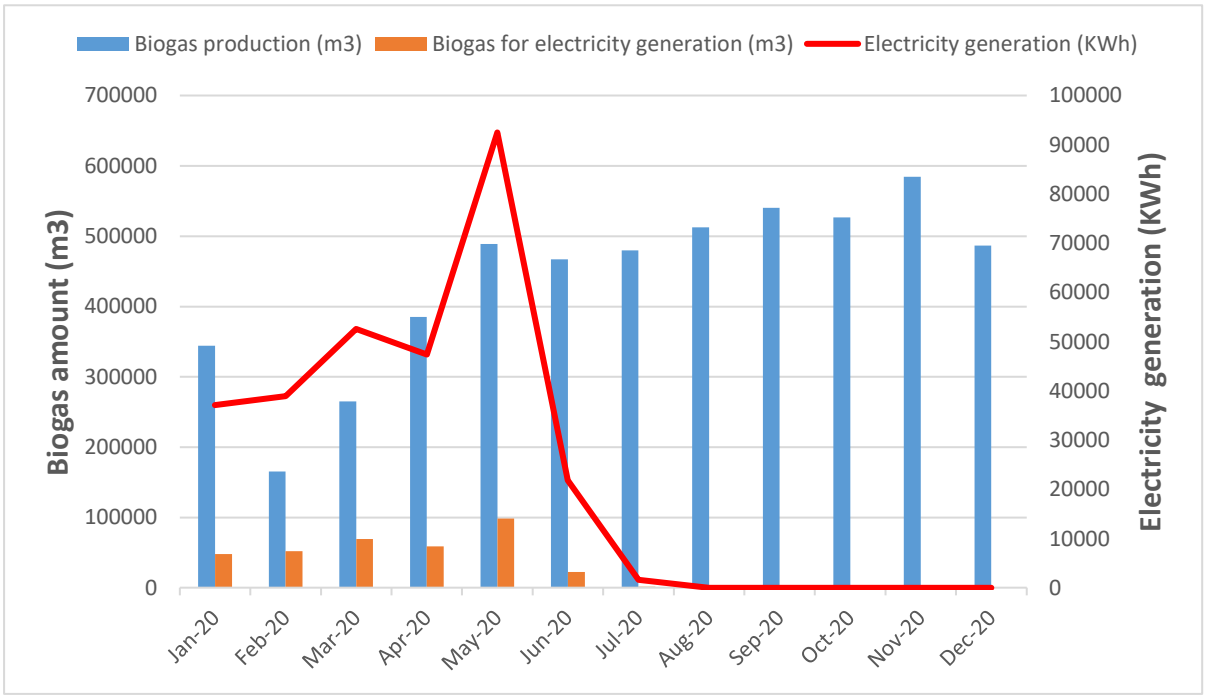

Figure 20: Monthly biogas production and utilization of Huayijie R&KW treatment plant in 2020

Case 4-2: Huayan Restaurant Waste Treatment Plant (Industrial Park)

The project deals with kitchen waste, greening waste branches, landfill leachate, expired food, and other organic wastes collected in the industrial park. The scale of the phase I project is 500 tons/day. Among them, the disposal scale of kitchen waste is 300 tons/day, landscaping waste is 100 tons/day, and landfill leachate is 100 tons/day.

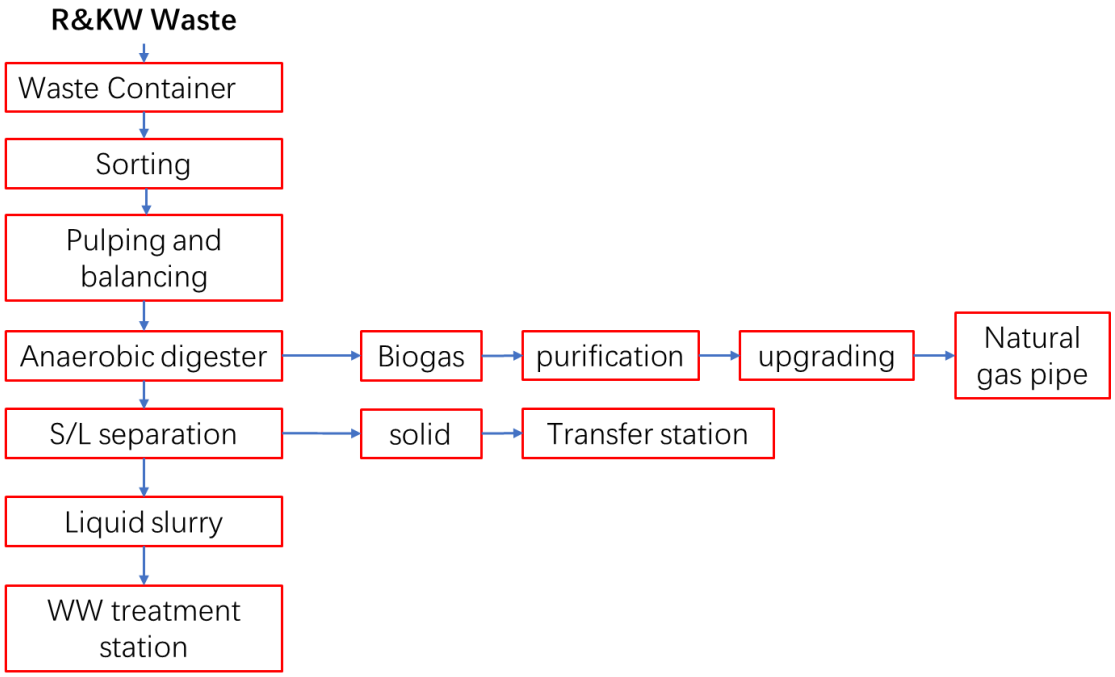

Figure 21: **Flow chart of Huayan restaurant & kitchen waste treatment plant in Industrial Park, Suzhou**

Table 9: **Characters of the AD treatment system in Suzhou Huayan kitchen waste recycling treatment plant operated by Huayan environmental industry development (Suzhou) Co., Ltd.**

No	Item	Specification	Remarks
1	Pre-treatment	organic separation (including crushing and screening) + solid-liquid separation + oil-water separation	
2	Fermentation temperature range	Mesophilic/thermophilic digestion	Overloaded using thermophilic digestion
3	Stirring/mixing	Mixer in the CSTR	
4	Support bodies between stages	pump	
5	Sediment/float separation in fermentation	The agitator is designed with "auxiliary blade" below the design liquid level, and large-diameter slag discharge ports are evenly distributed at the same height. When the surface scum crusting is serious, the surface scum is broken through the "auxiliary blade" by reducing the liquid level to the height of "auxiliary blade", and the slag discharge port is opened for slag discharge at the same time	
6	Hydraulic Retention Time	10 – 30 days	
7	Facilities for the control of the process environment	The agitator can ensure the uniform distribution of effective materials in the reactor, avoid stratification and fully contact with microorganisms, so as to ensure the complete effective reaction and biogas production. The temperature is controlled at 35 ~ 37 ℃, the solid content is about 6 ~ 8%, and enters the anaerobic system. Liquid phase CODcr = about 100000 ~ 150000 mg/L	
8	Phase separation	Solid/liquid separator	

No	Item	Specification	Remarks
9	Post-treatment procedures	Digester solid residues are dehydrated and then transfer station; Digester liquid residues are treated by “balance tank+ flocculation + hydrolysis+ 2 stage AO + sedimentation + floating”, then discharge	
10	Odor control	The odor is collected and sent to the deodorization system (water washing + alkali washing + oxidation + water washing + biological unit) for treatment. After reaching the standard, it is discharged through a 15m exhaust funnel	
11	Biogas treatment and utilization	Collection and storage + purification + upgrading + feed into the natural gas grid	

Figure 22: Pictures of Huayan R&KW treatment plant, Suzhou

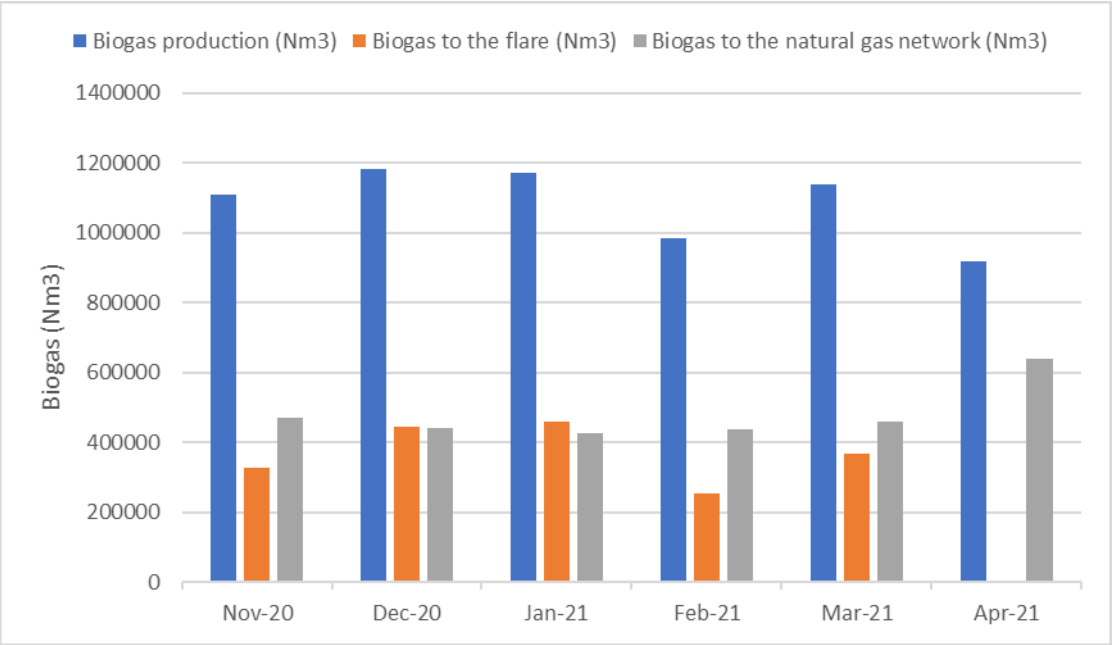

Figure 23: **Monthly biogas production and utilization of Huayan Kitchen Waste Treatment Plant (Baxingtan) in 2020 and 2021 in Industrial Park, Suzhou**

Case 4-3: Restaurant Waste Treatment Plant (Qizishan)
The Suzhou Restaurant Waste Treatment Project is located at the Vein Industrial Park in Wuzhong District; Jiangsu Clean Environment Co., Ltd. manages and operates.

The total designed capacity of the project is 350 tons/day, and the annual treatment capacity is about 130,000 tons. The project was constructed in two phases. The first phase project was established at the end of 2007, with an area of 26,643 m^2. It was completed at the end of 2009 and officially put into operation on August 1st, 2010, with a designed daily treatment capacity of 100 tons. The project's second phase was started in 2011 with a designed capacity of 250 tons/day. The project's second phase has a total investment of 61.95 million RMB. The newly added plant area is 3,224 square meters.

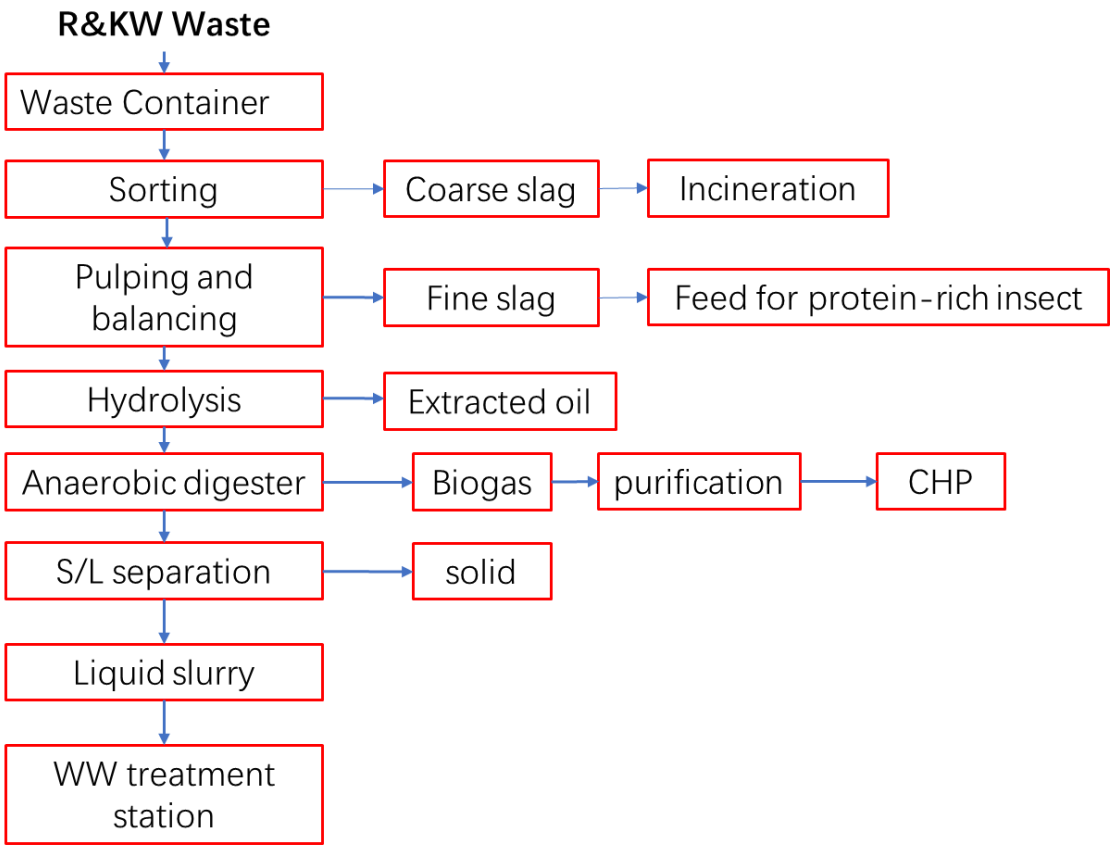

Figure 24: **Flow chart of Qizishan restaurant & kitchen waste treatment plant in Wuzhong District, Suzhou**

In May 2013, the trial operation was completed and put into production. The plant mainly adopts the technology of "hot humid hydrolysis + anaerobic fermentation in high to medium temperature." Jiangsu independently develops the core equipment for sorting, hot humid hydrolysis, and anaerobic fermentation.

The process flows are shown in the figure above. The collected restaurant waste enters the treatment workshop, and impurities are sorted out. Oil and the solids are separated, and the waste oil is refined to make biodiesel. The generated wastewater is treated through anaerobic fermentation. The generated biogas is used for the boiler's combustion to generate steam, and the steam is used as a heat source for waste oil refining.

In December 2013, the average daily restaurant waste entering the plant was about 350 tons, of which 300 tons went into the anaerobic digestion system. The degradation rate of organic matter was about 90%, and the average daily biogas production was 16000-17000 cubic meters. The methane content was about 55% used in biogas boilers and generator sets. It performed resource recycling with a daily average net oil extraction of 6 tons, mainly used to produce biodiesel and plant asphalt.

Approximately 350 tons MSW/day are treated at a restaurant/kitchen waste treatment facility, which uses an anaerobic digestion (AD) treatment (wet fermentation) to produce 10,000 m^3 biogas/day. Seventy-four farmers' market waste treatment facilities, covering 70 markets (approximately 1/3 of all markets), also treat 100 tons of waste/day. Five hundred recycling stations are additionally scattered across the municipality. However, only data from 74 is retrieved. The overall MSW system resembles the one in Xi'an,

though the waste streams from farmers' markets are designated for composting and should contribute to higher recycling rates. To compare: Suzhou's recycling rate is slightly underperforming than Xi'an's. This could also be attributed to the lack of data collection.

Expired food, including beef, fish, and shrimps, is daily delivered to the Kitchen Waste Disposal Facility at the Organic Waste Disposal Plant, where they are turned into biogas and organic fertilizers after processing. The 4-hectare plant, run by Huayan Environmental Development (Suzhou) Co Ltd., a subsidiary of China-Singapore Suzhou Industrial Park Development Co Ltd.'s public service arm CS Public Utilities, boasts advanced equipment and technologies to break down and recycle biodegradable waste. It partly came into service in February 2019, with a designed capacity of dealing with 90,000 tons of kitchen waste, 30,000 tons of filtrate, and 30,000 tons of landscape material per year.

Table 10: Characters of the AD treatment system of Qizishan kitchen waste recycling treatment plant in the Suzhou city

No	Item	Specification	Remarks
1	Pre-treatment	Solid/liquid separation, oil extraction, Hydrolytic acidification	
2	Fermentation temperature range	mesophilic	
3	Stirring/mixing	stirring system	
4	Support bodies between stages	pump	
5	Sediment/float separation in fermentation		No data
6	Hydraulic Retention Time		No data
7	Facilities for the control of the process environment		No data
8	Phase separation	Solid/liquid separator	
9	Post-treatment procedures	Digester solid residues are dehydrated and then landfilled; Digester liquid residues are treated by "MBR+ nanofiltration", then discharged	

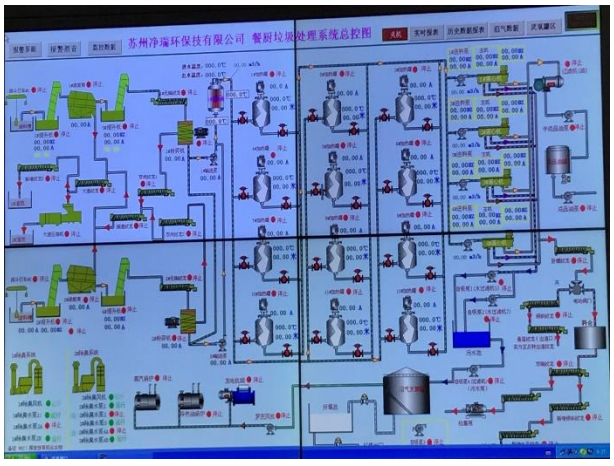

Figure 25: Pictures of Qizishan R&KW treatment plant, Suzhou

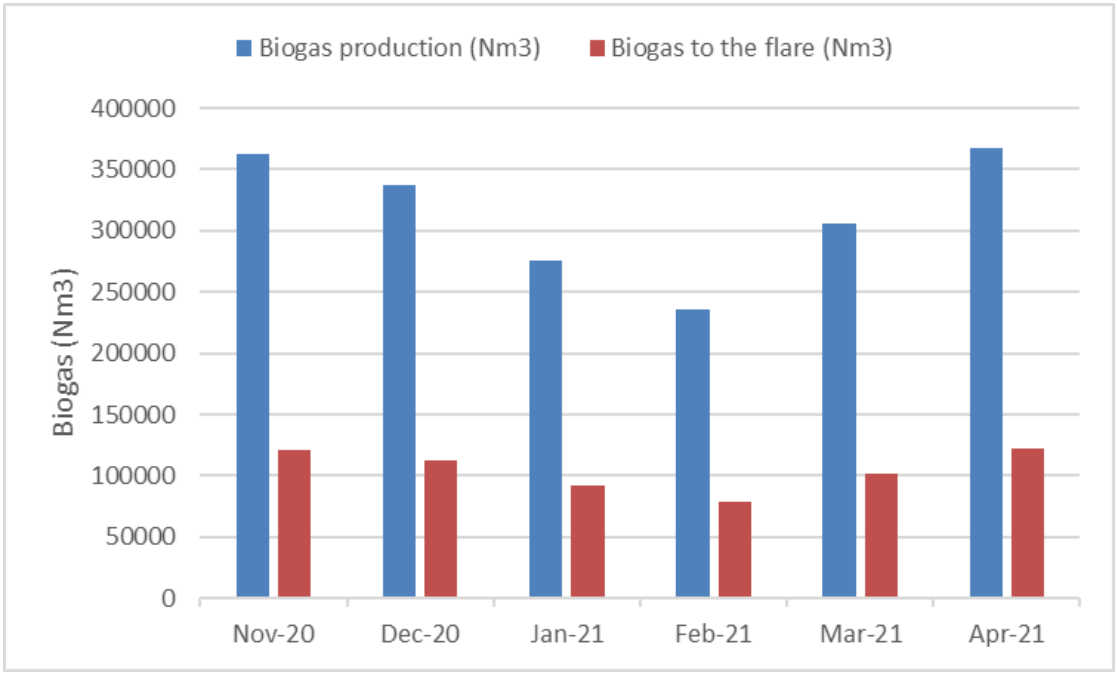

Figure 26: **Monthly biogas production and utilization of Qizishan Kitchen Waste Treatment Plant (Baxingtan) in 2020 and 2021 in Suzhou**

CITY 5: Tai'an Kitchen Waste Treatment Plant
102 t/d(including 87 t/d of restaurant waste, 10 t/d of sludge, 5t/d of animal excrements)

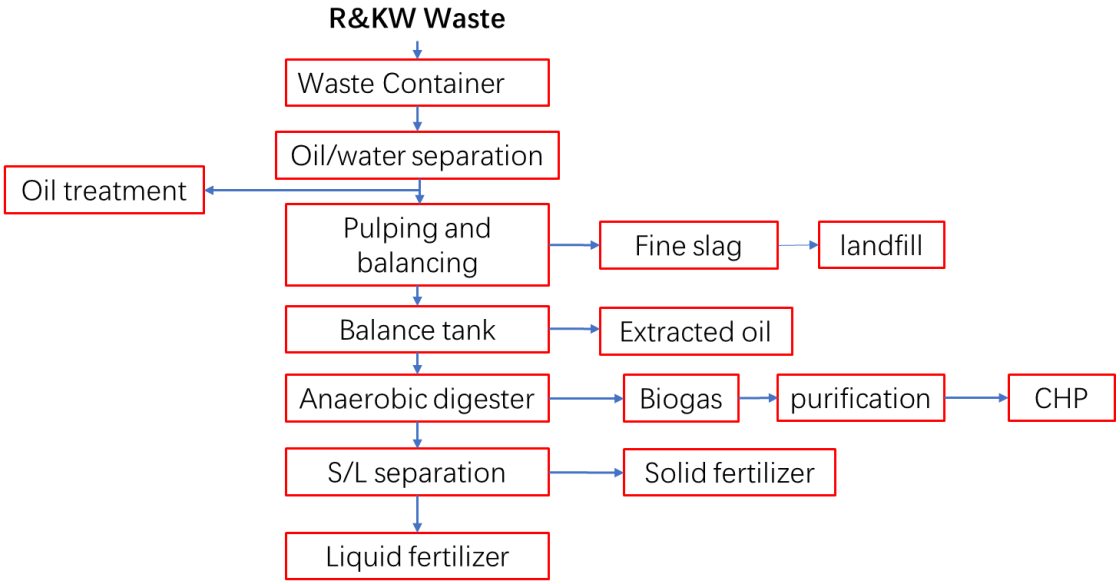

Figure 27: **Flow chart of Tai'an restaurant & kitchen waste treatment plant**

Table 11: **Characters of the AD treatment system in the Tai'an kitchen waste recycling treatment plant**

No	Item	Specification	Remarks
1	Pre-treatment	Solid/liquid separation, oil extraction, Hydrolytic acidification	
2	Fermentation temperature range	mesophilic	
3	Stirring/mixing	stirring system	
4	Support bodies between stages	pump	
5	Sediment/float separation in fermentation		No data

No	Item	Specification	Remarks
6	Hydraulic Retention Time		No data
7	Facilities for the control of the process environment		No data
8	Phase separation	Solid/liquid separator	
9	Post-treatment procedures	Digester solid residues are dehydrated and then landfilled; Digester liquid residues are treated by “MBR+ nanofiltration”, then discharged	

Figure 28: Pictures of Taian R&KW treatment plant

3 Comparison to European Facilities

3.1 Germany

In 2018, about 9.7 million tons of biogenic municipal waste were generated in Germany. This mainly includes organic and green waste from households, municipal green maintenance and industry, and food waste. Around 1,000 composting plants and 100 pure biowaste fermentation plants have recycled this waste (UBA 2010). More than half of the organic waste was composted, whereby the energy contained cannot be used. Therefore, the aim is to increase the proportion of fermentation with biogas production in suitable biowaste.

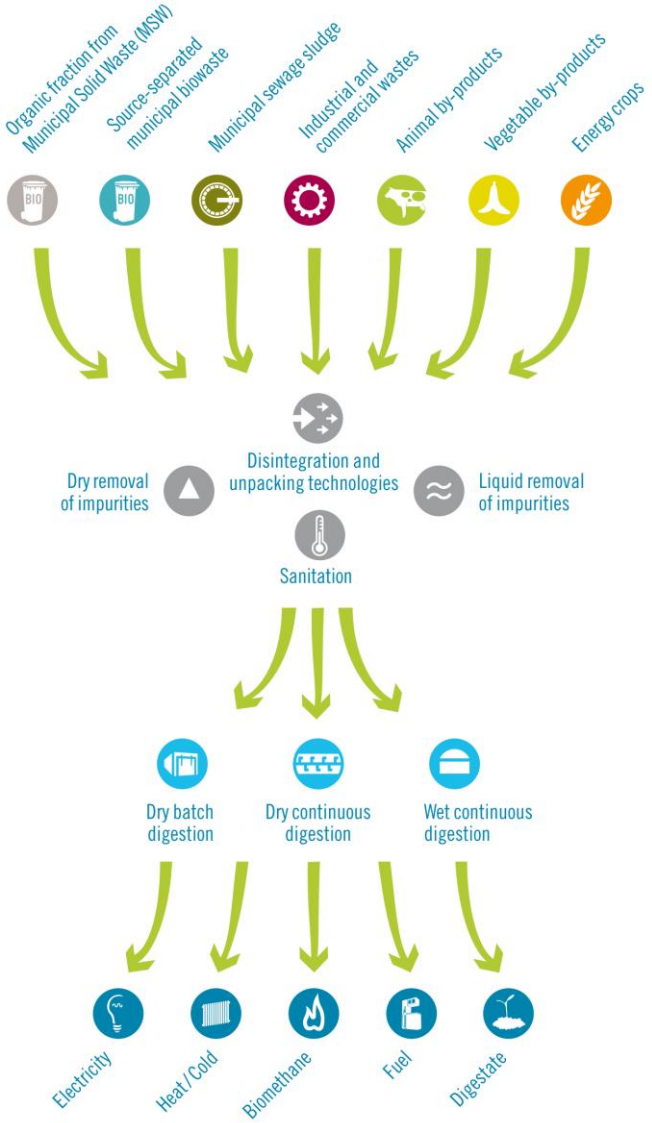

Figure 29: The production of energy and fertilizer from biowaste

Source: GIZ / German Biogas association

In the project "Current Development and Perspectives of the Biogas production from manure and biowaste" FKZ 37EV17 104 0 supported by the Institute for Biogas, Circular Economy and Energy, the German Biomass Research Center and the Witzenhausen Institute, and the Thuringian State Institute for Agriculture current barriers to the expansion of biogas production from biowaste and manure as well as solutions for removal of these barriers have been identified.

In 2016, approximately 20% and 1% of the total of Germany's organic or green waste to biogas fermented. Thus, through the more consistent implementation of separate collection and retrofitting of fermentation stages in composting plants, there is still significant potential for the provision of renewable energy.

Table 12: Anaerobic digestion of biowaste in biogas treatment facilities

	Situation in 2016	Potential for 2030
Percentage of digestion in 2016	Around 35% /5% of the collected and around 20% / 1% of the available Bio- / green waste	
Number of Bio-gas digestors in 2016	86 facilities (bio- and green waste)	
Electricity production in 2016	0.3TWh$_{el}$/a (bio-and green waste) 0.4TWh$_{el}$/a (commercial bio-waste)	
Additional potential until 2030		Around 4.7 mio Mg/a * 1.0TWh$_{el}$/a

*100% of separately collected biowaste but not used for digestion yet; 40% of not yet separated bio-waste.

With unchanged funding law and regulatory framework conditions, a stagnation of digestion of bio-waste must be assumed. A decline is also conceivable. For dismantling, existing barriers were measured in the project developed and evaluated in terms of their impact, which, on the one hand, to secure the plant inventory and contribute to the development of the biogas production from biowaste can contribute.

3.2 Switzerland

In Switzerland, some 1.3 million tons of biogenic waste are generated annually. 740000 tons are processed in the country's 333 composting and anaerobic digestion plants, each with an annual capacity of over 100 tons/year. In comparison, 300000 tons are reckoned to be recycled in private gardens and on neighborhood compost heaps. Nevertheless, a further 250000 tons or so still find their way into the municipal solid waste (MSW) incinerators along with the regular domestic refuse.

Biogenic wastes help produce electricity, heat, and fertilizer. During the last ten years, industrial and agricultural waste production from electricity, heat, and biogas with biogenic waste from farms and industrial factories has increased six-fold. Due to the increasing interest in biomass for energy and heat production and to ensure that other sectors that need this resource are not disadvantaged, four federal agencies concerned developed a common biomass-use strategy for biomass usage. This strategy is based on the cascade classification for the use of biomass. The production of high-value-added products such as food and construction materials should remain a top priority. Synergies should be checked and applied consequently. For example, waste and by-products from the food industry can be used for animal feed. The wastage from animal husbandry can be used for energy production in biogas plants. Also, other organic wastes can be used for digestion and the production of fertilizer for agriculture. The energy produced in biogas plants can support the digestion process and heating required by industry.

There is still room for waste management structures to be optimized locally. For example, much regionalization would be possible for the collection of biowaste. Further measures can also be taken for the standardization of the collection systems. And finally, to further increase the efficiency of bio-waste management, it will be necessary to act on product design and improve social and environmental criteria along the life cycle of food and related services.

4 Measures to strengthen the biowaste fermentation

1. Promotion of regional studies on system optimization
   Subsidization of studies to optimize the disposal system at the regional level. Effects of the measure would be that a large part of the public services (waste management operators) deals with the system optimization, and a certain amount would implement those concepts.

2. Knowledge management and public relations
   They subsidize advisory and exchange measures, i.e., excursions, workshops, and counseling centers. Effects of the action would be that the implementation by the public services would lead to an accurate knowledge transfer for citizens and decision-makers.

3. Best Practice Guide and Benchmarking:
   Creation of a best practice guide that knowledge management for decision-makers supports. Effects of the measure would be
   - Already existing experience with the construction and the operation of biowaste fermentation plants is collected and passed on.
   - Based on a benchmarking of exploitation concepts can be used by decision-makers
   - identify the right solution for your situation.

4. Implementation of the separate collection obligation and definition of high quality
   Monitoring tool: Waste analysis about a target value of the organic matter in household waste, which has to be defined. Definition of high quality: "Fermentation with subsequent material use of the digestate."
   Effects of the measure would be a significant increase in collected biowaste and significantly increased nutrient circulation.

5. Uniform enforcement of regulations regarding air pollution:
   Guarantee of consistent implementation of the provisions by the authorities.
   Effects of the measure would be that plants that are not up to date with the technology have to work massive retrofits.

6. Investment and innovation promotion
   Subsidization of fermentation plants and the implementation of innovative concepts for biogas use.
   Effects of the measure
   - Increasing the benefits of investing in fermentation plants
   - State-of-the-art plant concepts with innovative biogas use concepts beyond electricity generation

Conservation measures of the plant stock

1. Amendment on air pollution regulations:
   Before setting TOC limits, mandatory monitoring for TOC and, if applicable, methane is carried out to define the appropriate limit and target values.

2. Application of liquid digestate:
   The liquid phase application from a solid-liquid separation of biowaste digestate on grassland areas and multi-edged field fodder surfaces will be used and declared admissible. Thus, a uniform national regulation can be achieved to have planning reliability.