Comparison of 3 different methods of food waste treatments in terms of Economy & CO_2 generation

[Among Bio-gas production by AD, Drying, and WTE(Waste to Energy) by drying with dried food waste]

Gaia Corp.(Mar. 2017)

Summary

Recently food waste is considered as an important & new type of energy source.

Therefore to review 3 different ways of food waste treatment that currently adapted in the food waste treatment business fields and find the best way in terms of economy & environment(by CO_2 Generation) is valuable to do.

@ AD :

Since a decade or more, AD(=Anaerobic Digestion, or Methanization, or Bio-Gas Production) is done with many steps of process, such as collection of food waste, trucking to intermediate process sites where crushing & squeezing food waste to process AD directly or to separate into solid parts(72% moisture content) & leachate(90% moisture content) so that solid parts to be used for low quality level of fertilizer(compost) and leachate to be used for AD.

@ Drying :

Drying food wastes at the places where food wastes are generated, such as at home, at condominiums, at restaurants, and at food factories has been recommended to delete collection/transportation/crushing/separation of food waste so that lots of cost saving as well as to recycle relatively fresh food wastes for better results. Drying can be done by heats from electricity or gas.

@ WTE(Waste To Energy) :

Drying food wastes at the places where food wastes are created is same as just DRYING system but to use dried food wastes of which calorific value is quite high as 4,200 – 6,500 kcal/kg(=18,000 – 27,000 MJ/kg) depends on food wastes, countries and also very cleaner(no heavy metals, much less harmful gases) than coal makes the cost of food waste treatment very low.

Therefore to mix drying technology and energizing dried food waste as a fuel to dry food waste would be considered the best way in terms of economy and environmentally as well.

Energizing of AD is currently used popularly nowadays, however lots of pre-process of food wastes treatment for AD, such as collection/transportation/crushing/separation of food waste and slow micro-organism's activity to digest food waste as well as to treat leftover waste water & sludge would cost a lot with much of bad odor creation and frequent operation stops by scum, it is required complicated operation skills so it would be big obstacles to perform AD process.

Compared with AD, Drying is quite simple as long as dryers are well made.

To dry, energy is required normally at around 800 kcal/kg of food waste (based on 85% moisture content) considering efficiency of heating, which is ca 0.93kWh/kg(of food waste), so either electricity or gas can be heat sources depends price of electricity and gas at each place.

Naturally dryers for electricity or gas based heating must be well made without creating bad odor, noise, and etc.

WTE(Waste To Energy) is a kind of Drying but to use dried food waste as a fuel.

The way to use dried food waste is to combust dried food waste to heat thermal oil, as electricity dryers heat thermal oil, and dry food wastes.

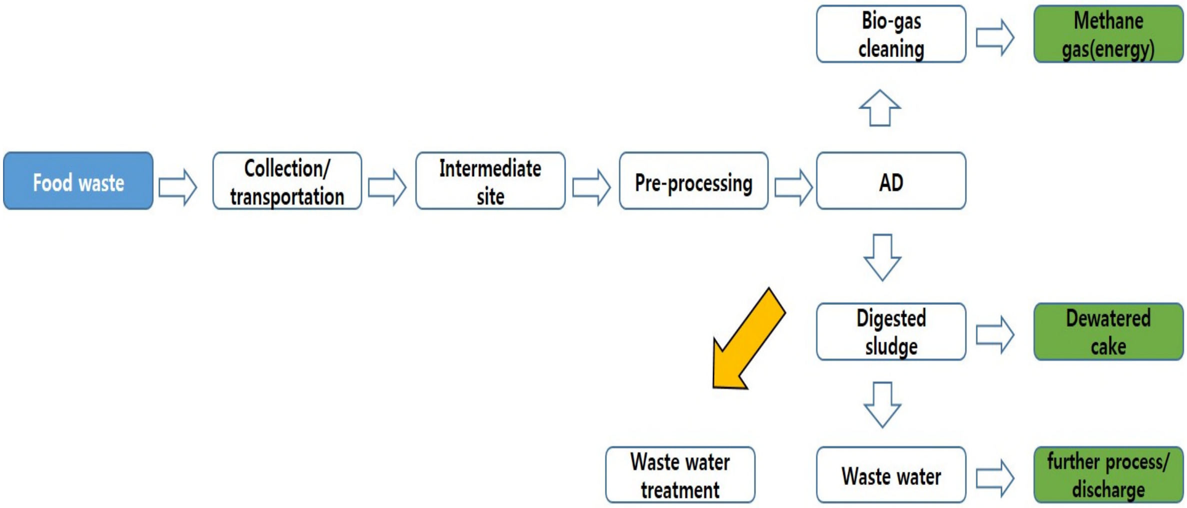
As long as dryers are combined with the boiler that heat thermal oil by dried food waste are well made, this would be the best way in terms of cost saving and environment because normally at AD and just Drying, lebt over food waste, such as digested sludge or dried food waste, would have to be treated another process for either into fertilizer(compost) or landfill.

A. AD(Anaerobic Digestion, or Methanization, or Bio-gas production) with food wastes

In general, AD is done with food waste or leachate of food waste or pig's manure, or sewage sludge but here we investigate process, operation cost, and leftover material's treatment for AD with food waste only.

(1) Process of AD

Fig. 1 shows how AD is done, which shows proper steps of the process as follows[1)].



(1-1) food waste collection & transportation from each place where food wastes are generated as at home, condominiums, restaurants, and food factories to intermediate sites.

(1-2) At intermediate site, sorting out scraps of food wastes, such as plastics, metals, etc. and crushing food waste and start to process AD.

(1-3) AD : digestion, de-nitrogen, de-phosphate, etc. with chemicals, and others

(1-4) Gas cleaning(de-sulfur), storage, transportation, etc.

(1-5) Digested sludge treatment : dewatering with belt-press and to landfill

(1-6) Waste water transportation to sewer for further treatment : to control C/N ratio, temp., etc.

(1-7) De-Odor : chemical aromatic, fans/blower

In general, there are much of plastics, metals, bones, and other scraps when food wastes are collected, so these create many problems of process of food waste inside the intermediate sites as well as to stop operation of AD facilities during to AD process.

As Micro-organisms are working to process AD, very highly skilled technicians are required to operate the AD facility and manuals are not properly applied due to unexpected changes of micro-organism's activities practically.

(2) Problems of AD

(2-1) High cost to build AD facility

Korean central government has paid ca U$ 660 mil. for 22 AD sites until 2012 since 2008 based on a law to promote AD technologies and plans to build additional 28 AD sites until 2020.

However, total no. of AD sites in Korea as of the end of 2015 including private or local government's support, is 88 sites which consists of 20 sites food waste, 6 sites for pig's manure, 32 sites for sewage sludge, and mixed sites of 30 sites, thus 3.1 times than Korean central government's plan.

Table 1. Building cost of some important AD sites in Korea[2].

Facility	Operating date	Installation cost	Capacity	Installation cost Per ton(fw)
Seoul Dongdaemun	2010	U$56.3 mil.	98 ton/day	U$574,500/ton
Busan Saenggok	2005	U$10.0 mil.	200 ton/day	U$49,764/ton
Daegu Sangni	2013	U$75.6 mil.	300 ton/day	U$251,818/ton
Namyang-ju Byeollae	2013	U$54.3 mil.	31 ton/day	U$1,752,757/ton
Goyang	2014	U$62.9 mil.	260 ton/day	U$242,021/ton

Out of above important examples, proved as failure at Dongdaemun site and Namyang-ju sites (LH bought existed failed site) as well as Busan Saenggok(too old) are extra-ordinary high in building cost, we deletd them to calculate building cost of AD site, so we applied only the other 2 sites, of which average building cost is U$ 245,000/ton.

This cost of U$ 245,000/ton is around 12.5 % higher than Korean standard waste treatment site's building cost in 2017(U$ 218,000/ton),

This cost is average 2.5 times more expensive than 2017 standard for animal feed site and 2.3 times more expensive than Korean stand cost for fertilizer site building cost.[3]

(2-2) High Operation cost

Out of 23 AD sites (6 food waste, 6 food waste leachate only, 11 mixed wastes) in 2014 operation cost per ton of wastes are as follows

@ capacity over 100 ton/day : U$ 54.5/ton

@ capacity under 100 ton/day : U$ 98.2/ton

Above figures are less than U$ 100.1/ton which was record of 2012 for the site bigger than 200 ton/day which was reported by Korean National Parliament.

Above figures of 2014 is much higher than U$ 57.7/ton(1.7 times) for animal feed by drying and fertilizing by U$ 49.2/ton(1.6 times)[4, 5)].

One of the reasons why higher operation cost might be by sub-contract job from local government to private companies

In addition to above operation cost at the AD sites, the cost up to arrival of AD sites from the collection stage of the food waste should be added to calculate the correct cost of AD sites because without collection/transportation steps, no AD operation is possible.

Above additional costs before AD operation is different from urban area(U$ 49.2/ton) and from rural area(U$ 50.2/ton) and quantity of food waste from urban area is 73.8% while from rural area is 26.2%, so average cost before AD sites is U$ 49.5/ton.

Therefore real AD operation cost is U$ 147.7/ton.

(2-3) Technical problems to operate AD facility

Practical elements to operate AD facility are rate of bio-gas generation, temperature, density of digestion tank, organic acid, minerals, ammonia, scum, and etc., therefore there should be well prepared manual even though the manual is not perfect to meet each different situation.

Important aspects of operation effecting elements are as follows

@ Size of food waste or quantity of food waste being loaded into AD tank influence conveyer's transportation, food waste's reservation hopper's availability, freezing in winter time, etc

@ Crusher, separator, separating filter(under 10 mm), etc. are required to guarantee constant loading, especially any kind of blocking of the pipes must be considered.

@ Stirring of food waste inside food waste's reservation tank

@ At the outside of AD tank, water catching system being required when the AD tanks to be cleaned

@ Chimneys for boiler's exhaust and gas generator's chimney must be separately installed

@ Scum cleaning system at AD tank is absolutely required for proper staying time of food waste at digestion tank.

@ When density of sludge is increased, stirring being difficult, so proper motor to be installed.

@ Checking windows are required because by sensors only, there would be errors.

@ Many drains valves are required for condensed water & pipes of bio-gas generation

@ At de-sulfuring system, there should be a system for anti-pipe blocking for winter because it is quite frozen

@ Gas detectors for bio-gas and boiler are required

@ De-odor system for everywhere at AD site is required

@ Noise problems for vibration & blower/ID fans must be well prepared

(2-4) Low rate generation of Bio-Gas and its Value

In Korea, Bio-gas generation with food waste is reported as 77.5m^3/ton(food waste) and in 2015, actual bio-gas generation from the food waste AD plant is average 72m^3/ton(f/w) [1,6)].

This quantity is quite lower than that of European (mainly Germany : 120m^3/ton) AD site's bio-gas generation, however most of German AD sites receive complete corn tree itself rather than food waste, therefore naturally, raw material as corn tree has much more organics to be able to generate more bio-gas, thus to compare German bio-gas generation from AD sites with Korean AD sites is not proper[6,7)].

Also out of 10 Korean AD site's average content of Methane gas from bio-gas is 64.4±1.1% (Mean±S.E., n=12)[8)].

With this data, we can calculate power(=electricity) production from AD site as follows

@Bio-gas generation

- 72m^3 bio-gas/ton(fw) x 64.4% CH_4/bio-gas x 8,550 kcal/m^3.CH_4 = 396,446.4 kcal/ton(fw)
  ※ LHV of Methane gas is 8,550 kcal/m^3

@ Power generation with gas generator

- 396,446.4 kcal/ton x 34%/860 kcal/kWh = 156.7 kWh/ton(fw)

  ※ Efficiency of gas generator is 28 -40%, so we applied 34 % as average.[1)]

@ Income with power from bio-gas

- 156.7 kWh/ton(fw) x U$ 0.082/kWh(average SMP price in Feb. 2017 in Korea) = U$ 12.85/ton(fw)

  ※ The cost of gas generator & gas cleaning, etc. are not included.

This means that out of 1 ton of food waste, we have income of U$ 12.85 while operation cost of AD plant is U$ 147.7/ton(fw).

Therefore we lose 134.85/ton(fw) by AD(Methanization)

(2-5) Load of final wastes, (Waste water) increase

Out of 104 AD sites in 2015, Korean government found out that increase of waste water is more than increase of food waste compared with 2014.

This means that AD sites added water to food waste in order to meet acceptable level of BOD/COD for sewage/waste water treatment sites[11)].

Therefore bigger waste water treatment system for AD plants is required to generate Methane gas properly and also digested sludge must be treated or recycled after AD plants.

B. Drying with heat from electricity or gas(LNG/LPG)

Moisture content of food wastes from each home, restaurants, and food factories is seasonally different as well as from urban area or rural area as 81.% & 76.2 % respectively, so average we calculate is 82.1% in Korea.

Therefore food waste which is mostly water is recommended to treat at the places where food wastes being created instead of collection from each place and transport to intermediate treating sites in order to save cost and also to treat before heavily spoiled[4, 12)].

This will minimize odor problem as well as better results for recycling purposes after treatment.

To meet these purposes, DRYING food waste at the place of food wastes being created as soon as food wastes being created is absolutely required.

B-1 Drying with electricity(by electric heators)

In order to dry high content moisture of food wastes, there are many steps to process, such as heating system with electric heaters, piping system to transport vaporized moisture, condenser to cool down vaporize water in a short time as heat exchanger, control system to control operation time by automation, directions of impellers, cooling time, automatic sensors to stop operation when drying is finished, safety system, de-odor, pipe cleaning system to prevent scales inside the pipes, and etc.

Fig. 2. Flow diagram of food waste dryer by thermo-oil heating by electricity

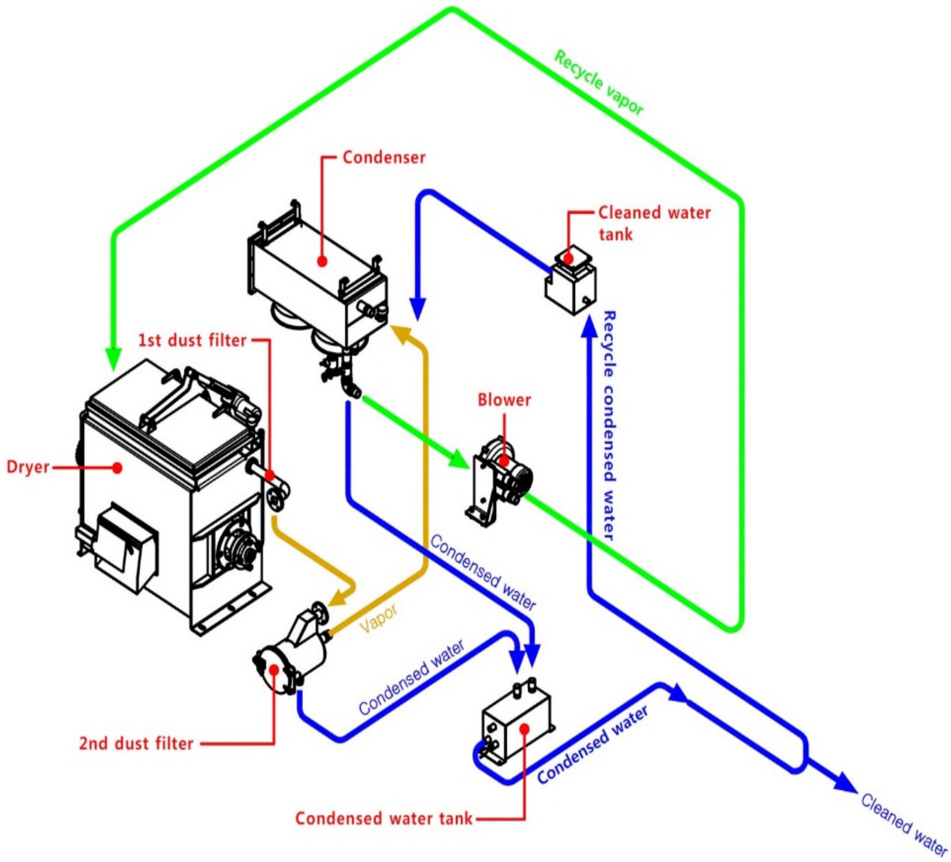


Fig. 3. Dryer with electric heaters

B-2 Drying with gas(LNG or LPG) energy(motor/blower/fan/control panel to be operated by electricity)

Fig 4 : Flow diagram of food waste dryer by thermo-oil heate by gas

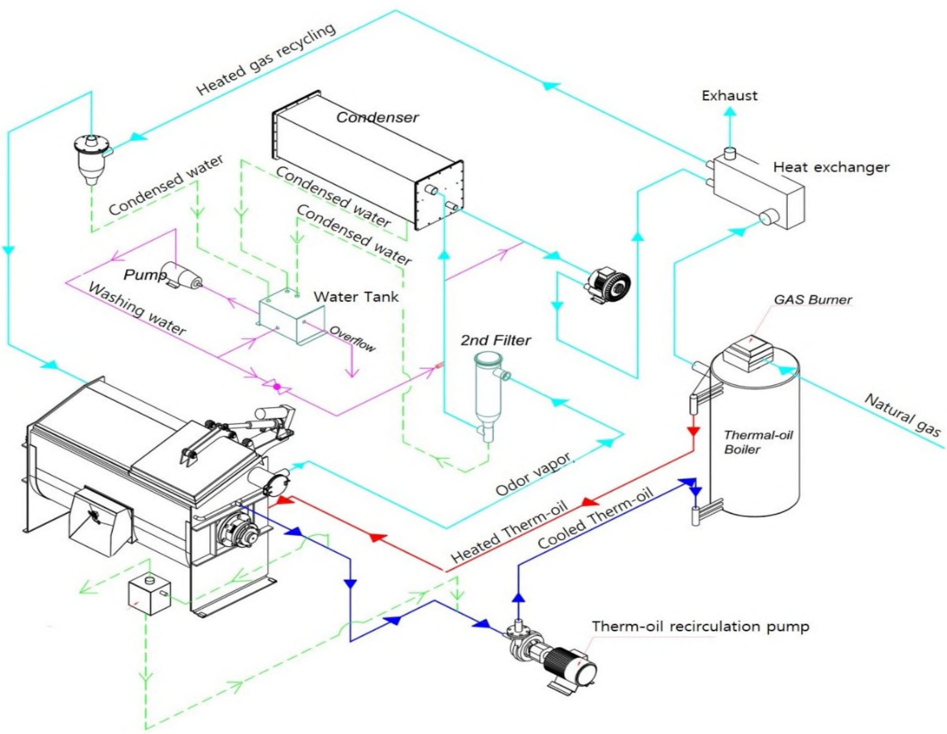


Fig 5 : Dryer with gas heating system

B-3 Drying process

Drying is done as follows

Moisture inside food waste is heated by thermal oil that is heated by electricity (thru heaters) or gas at around 170'C and then vaporized.

Vaporize moisture is transported by blowers/fans thru piping system thru 1st & 2nd filters.

Condensed water from the vaporized moisture being discharged to drain while uncondensed moisture, which has high potential energy as more than 650 kcal/kg being returned to drying chamber to reuse to dry food waste to increase efficiency of energy consumption.

Reuse of uncondensed moisture can prevent odor problem during the drying process as well.

This system is completed closed loop so that no odor comes out at ate.

Drying capability depends on heating area to meet food wastes very closely.

B-4 Operation cost

(1) General information

By many experiments with real food waste of average 85% moisture content in Korea, we got following data of energy consumption & operation cost

cf 1. Energy consumption consists of (i) operation mechanics, such as motor/blower/fan/control panel
(ii) heat consumption to dry either by electric heat with heaters or gas to be burnt.

Therefore electricity driven dryers need only electricity to dry while gas driver dryers need gas for heat and electricity for operation mechanics.

cf 2. Energy(electricity and gas) consumption is different from each model deperdant on :
(i) drying capacity : bigger models consume less energy due to higher efficiency

(ii) more function consumes more energy
※ Smart Dryer : computer, scale, internet, RFID function, automatic discharge, etc. need more electricity

(2) Average operation cost(per 1ton of food waste)

As of Feb. 2017(in Korea)

Model		Energy consumption		Operation cost per 1 ton of food waste
		Electricity(@ U$ 0.082/kWh)	**Gas(LNG : U$ 0.51/Nm^3)**	
Electricity driven dryers	GC-100	840kWh(= U$ 65.60)		U$ 68.88
	GS-100HD (Smart dryer)	1,020kWh(= U$ 12.30)		U$ 83.64
	GC-1200	780kWh(= U$ 63.96)		U$ 63.96
Gas Driven dryers	GG-100	140kWh(=U$ 11.48)	110Nm^3(= U$ 56.10)	U$ 63.58
	GG-100HD (Smart dryer)	190kWh(= U$ 15.58)	130Nm^3(= U$ 66.30)	U$ 81.88
	GG-1200	37kWh(= U$ 3.03)	105Nm(= U$ 53.55)	U$ 56.58

B-5 Final product after drying

Dried food waste is average 19.3wt % of original food waste (average moisture content is 8.7±0.47%), thus dried food waste can be used as fertilizer (compost) or animal feed.

However, by Seoul City's report, practically only 1.7% of food waste is utilized as compost because there is very few people/company who would like to use dried food waste as compost or animal feed due originally it is a WASTE[11)].

Therefore to use dried food waste as a fuel or fuel source directly or indirectly is very much required and recommended.

C. WTE(Waste To Energy)

Concept of WTE is to dry food waste with dried food waste as a heat source that combusts in thermal oil boiler.

Calorific value of dried food waste is quite different depends on original food wastes, i.e. food waste with much of meat or oil would be higher calorific value after drying while vegetable/fruit content's food waste's dried product has lower calorific value.

Therefore calorific value of dried food waste is quite different from season, country, etc.

However, LHV(Low Calorific Value) of dried food waste is min. 4,000 kcal/kg up to 6,500 kcal/kg of dried food waste.

Quantity of dried food waste from the original food waste also depends on moisture content of food waste, such as in Korea average 82.1% in this case quantity of dried food waste becomes ca 20 % of original food waste(for the reference, its LHV is ca 4,400 kcal/kg) and in France, average 75% of moisture content, dried food waste becomes 27 % with 6,500 kcal/kg

Therefore, average quantity of dried food waste with its LHV is not less than requiring energy to apply WTE.

C-1 WTE's flow chart

Fig. 6 shows how WTE is processing

Fig. 7 (Video of WTE are to be seen at http://www.gaia21.co.kr/src/bbs/board.php?bo_table=sub0301&wr_id=43)

C-2 Energy consumption of WTE

@ Requiring quantity of dried food waste : 180 kg/ton(f/w) in Korea

- In France, 120kg/ton(fw) is expected due to lower moisture content of original food waste but higher LHV of dried food waste
- Requiring electricity to drive motor/blower/fan/control panel : 120kWh/ton(fw)

C-3 Operation cost

@ Dried food waste : "0" (no cost)

@ Electricity : U$ 0.082/kWh x 48kWh/ton(fw) = U$ 3.94/ton(fw)

Total Operation Cost : U$ 3.94/ton(fw)

C-4 Final product

Leftover the whole WTE process would be follows

@ Ash of dried food waste : ca 22 kg/ton(fw) to be landfilled at U$ 1 (U$ 45.45/ton x 22kg)

@ All the dried food waste is combustible except some kinds of scraps, such as metal, glass or ceramics which should not be included in food waste so we do not count none combustible materials in dried food waste.

Summary of Operation cost among 3 different ways of food waste treatments.

[based or dryer model No. GC/GG/WTE-1200(1.2 ton/day capacity)]

<table>
<tr><th colspan="2"></th><th>Net Operation cost</th></tr>
<tr><td colspan="2">Bio-Gas</td><td>U$ 134.85/ton(fw)</td></tr>
<tr><td rowspan="2">Drying</td><td>BY Electricity</td><td>U$ 63.96/ton(fw)</td></tr>
<tr><td>By Gas</td><td>U$ 56.58/ton(fw)</td></tr>
<tr><td colspan="2">WTE</td><td>U$ 3.94/ton(fw)</td></tr>
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2. Comparison of CO_2 generation among AD, Drying, and WTE

(1) Anaerobic digestion(AD)

In order to calculate correct distance to transfer food waste, we need to check urban area and rural area from each home, restaurant, or mart to the intermediate sites.

Among the data we collected for the last decade in Korea, we got the result as described at Table 3(Source : Ministry of Environment in Korea).

Table 3. Transportation distance of food waste.

(Mean±S.E., n=3)

Items	Food waste from Urban area			Food waste from rural area		
Residence type	House	Condo.	Restaurant	House	Condo	Restaurant
Transport distance (km/truck·cycle)	42.3	38.1	41.0	59.2	50.5	48.1
Collection vehicle (truck)	54	54	53	41	41	42
Number of collection (cycle/year)	11,336	12,948	11,648	9,880	9,984	10,244
Collection(ton/year)	2,151,208			748,536		
Transport distance (km/ton)	12.04	12.38	11.77	32.04	27.62	27.65
Average(km/ton)	12.1±0.1			29.1±1.3		

Urban area's average distance to transport food waste is 12.1 +/- 0.1 km while rural area is 29.1 +/-1.3 km per ton, so we made average for whole Korea as 20.6 km but 73.8 % of food waste comes from urban area while from rural area is 26.2 %.

Therefore we make average distance of food waste in Korea as 16.6 km/ton(fw) and Table 4 shows how much of CO_2 being created by transportation according to IPPC's guide Line of CO_2 generation(Ministry of Environment of Korea made a format to calculate CO_2 generation by IPPC's guide Line and this format is now applied world-wide).

Table 4. CO_2 generation during AD(Methanization or Bio-Gasification).

Process	CO_2 Emission factor	CO_2 Emission
Collection vehicle	88.07 kg CO_2-e/ton·km	1,461.9 kg CO_2-e/ton(100%, 16.6 km)
Anaerobic digestion	50.2 kg CO_2-e/ton	50.2 kg CO_2-e/ton(100%)
Sewage treatment	244.7 kg CO_2-e/ton	244.7 kg CO_2-e/ton(100%)
Total		1,756.8 kg CO_2-e/ton

In other words, by AD process of food waste, 1,756.8 kg CO_2-e/ton(fw) is generated.

(2) Drying with electric heating system

Food waste treatment by drying with energy from electricity generate 501.0kg/CO_2-e/ton(fw) as shown in Table 5.

Table 5. CO_2 generation by electric heat drying.

Process	CO_2 Emission factor	CO_2 Emission
Dryer(Electricity)	370.7 kg CO_2-e/ton	370.7 kg CO_2-e/ton(100%)
Collection of dried food waste by vehicle	88.07 kg CO_2-e/ton·km	63.4 kg CO_2-e/ton(18%, 4 km)
Incineration of dried food waste	371.8 kg CO_2-e/ton	66.9 kg CO_2-e/ton(18%)
Total		501.0 kg CO_2-e/ton

We applied CO_2 generation with electric energy as following numerical formula.

E = electricity consumption × 1/(1-r) × EF

EF : exhaust coefficient 0.454 kg CO_2-e/kWh

r : loss rate of electricity 0.0448.

Therefore, CO_2 generation by electric heat together with CO_2 generation to landfill the dried food waste, which is 18 % of original food waste is 498.7 kg CO_2-e/ton(fw), which is just 29% of AD.

(1) Drying with gas(LNG)

Food waste treatment by Drying by gas as a fuel source would generate 402.3 kg CO_2-e/ton(fw) as shown at Table 6.

Table 6. CO_2 generation by gas(LNG) as a heat source together with landfill of leftover dried food

waste(18 % of original food waste.

Process	CO_2 Emission factor	CO_2 Emission
Dryer(LNG)	272.0 kg CO_2-e/ton	272.0 kg CO_2-e/ton(100%)
Collection of dried food waste by vehicle	88.07 kg CO_2-e/ton·km	63.4 kg CO_2-e/ton(18%, 4 km)
Incineration of dried food waste	371.8 kg CO_2-e/ton	66.9 kg CO_2-e/ton(18%)
Total		402.3 kg CO_2-e/ton

CO_2 generation from gas(LNG) per 1 m^3 "E" is applied as follows.

$$E = 0.955 \text{ kg} \times 0.637 \text{ Ton C/kg of LNG} \times 44 \text{ kg } CO_2/12 \text{ kg C}$$

$$= 2.23 \text{ kg } CO_2$$

Food waste treatment by gas including leftover (18 % of original food waste), the dried food waste's landfill would generate 402.3 kg CO_2-e/ton(fw), which is just 23 & that of AD.

(2) WTE(Waste To Energy)

Food treatment at the place where food wastes are generated, such as wastes from home, restaurant, food factory, etc. and use dried food waste as a heat source to dry food waste, we call this system as WTE that food waste being dried by its(food waste's) dried product would generate 187.0 kg CO_2-e/ton(fw) which including landfill of ash from food waste as shown at Table 7.

Table 7. CO_2 generation with WTE.

Process	CO_2 Emission factor	CO_2 Emission
Dryer(Solid fuel)	71 kg CO_2-e/ton	71 kg CO_2-e/ton(100%)
Pelletizing	162.0 kg CO_2-e/ton·km	29.2 kg CO_2-e/ton(18%)
Combustion	371.8 kg CO_2-e/ton	66.9 kg CO_2-e/ton(18%)
Landfill	992.6 kg CO_2-e/ton	19.9 kg CO_2-e/ton(2%)
Total		187.0 kg CO_2-e/ton

This amount of CO_2 generation 187.0 kg CO_2-e/ton(fw) is just 11 % of that of AD.

Summary of CO_2 generation & Operation Cost among AD, Drying, and WTE

		CO_2 generation/ton(fw)	CO_2 INDEX	Operation Cost	PRICE INDEX
AD		1,756.8 kg CO_2-e/ton(fw)	100	U$ 134.85/ton(fw)	100
Drying	by electricity	501.0 kg CO_2-e/ton(fw)	29	U$ 63.96/ton(fw)	47
	by Gas	402.3 kg CO_2-e/ton(fw)	23	U$ 56.58/ton(fw)	42
	WTE	187.0 kg CO_2-e/ton(fw)	11	U$ 3.94/ton(fw)	3

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