APPLICATION OF CIRCULATING FLUIDIZED BED (CFB) TO A WASTE TO ENERGY (WTE) PLANT IN HONG KONG

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EXECUTIVE SUMMARY

The objective of this study was to analyze the current waste situation in Hong Kong, and discuss the pre-feasibility of implementing a waste to energy plant in Hong Kong.

Hong Kong, one of China's most developed regions, has a population of 7.3 million and generated 5.74 million tons (0.79 tons per capital) of municipal solid waste (MSW) in 2015, with an annual increase of roughly 2% in the last few years. Hong Kong is faced with a scarcity of land and three of Hong Kong's largest landfills, including the South East New Territories Landfill (SENT), are expected to be full by the end of 2019.

The technology of Circulating Fluid Bed (CFB) for energy recovery from MSW (waste to energy or WTE) is an alternative to the moving grate combustion technology. First, it would reduce the volume of MSW by up to 90% through combustion, solving the most urgent problem of land scarcity. Second, energy would be recovered and then be used for electricity generation, thus reducing the consumption of non-renewable coals. Third, emission of methane, a potent greenhouse gas and a normal phenomenon in landfills, would be prevented.

The Bubbling Fluidized Bed (BFB) and Circulating Fluidized Bed (CFB) boiler, were analyzed and compared in this study. In addition, the final site and transportation method were examined during this study. Possible ways to increase public acceptance of WTE in Hong Kong are also discussed.

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I would like to thank my advisor Professor Nickolas J. Themelis for his invaluable support and guidance during this research. I would also like to thank my mother, Taiyi Duan, for her continuous encouragement and support throughout my academic career.

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1.1 Current Waste Management in Hong Kong

The amount of waste generation in Hong Kong has exceeded early projections. When the three-landfill strategy was implemented in 1993, the amount of waste processed daily by landfills was expected to increase from 12,500 tons per day in 1989, to 14,000 tons per day in 1997 and 16,700 tons per day in 2001. However, the three strategic landfills already received 16,000 tons of waste per day by 1997. The landfill sites have filled up faster than anticipated. If this trend continues, the landfills will not be lasting until 2020 as they were designed for.

For decades, China was the world's largest importer of waste. In 2016, China took 51% of the 15 million tons of plastic recyclables exported globally[1]. Hong Kong has no internal market for plastic waste, therefore, it is exporting most of the imported and locally collected plastic wastes. According to world news, until last year, Hong Kong exported over 90% of the imported and collected recyclables to mainland China[2]. As a cosmopolitan metropolis, Hong Kong boasts glittering skyscrapers, seamless transportation and billion-dollar infrastructure projects, but it also struggling with the waste disposal problem. The main reason why it is hard for the local government to deal with the recyclable stream is that Hong Kong has not the land needed to develop an effective recycling industry, in the meantime, it has done little to develop alternatives to landfilling.

As of January 1, 2018, China effectively banned imports of 24 types of unprocessed rubbish from other countries. China's ban on importing waste means cutting down the main channel of waste disposal in countries such as EU, U.S, UK, etc. Faced with this challenge, many different ideas have emerged, the European Union was planning to levy a

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[1] The world is scrambling now that China is refusing to be a trash dumping ground, Reporting by Farah Master; additional reporting by Chermaine Lee and Wyman Ma; Editing by Philip McClellan, Jan 31, 2018, web source: https://www.reuters.com/article/us-hongkong-rubbish/hong-kong-drowning-in-waste-as-china-rubbish-ban-takes-toll-id USKBN1FK0J4

[2] Hong Kong drowning in waste as China rubbish ban takes toll, Reporting by Farah Master; additional reporting by Chermaine Lee and Wyman Ma; Editing by Philip McClellan, Jan 31, 2018, web source: https://www.reuters.com/article/us-hongkong-rubbish/hong-kong-drowning-in-waste-as-china-rubbish-ban-takes-toll-id USKBN1FK0J4

tax on plastics usage, the U.K. was looking to divert some of its trash to Southeast Asia, and the U.S. asked China to lift its ban. However, none of those suggestions are long-term solutions to the new global problems in waste management.

The objective of this study was to characterize and quantify Hong Kong's plastic waste and to assess the potential technologies for Hong Kong's waste. Two technologies, Bubbling Fluidized Bed (BFB) and Circulating Fluidized Bed (CFB), were compared and analyzed in this paper.

1.2 Population and Economic Level of Hong Kong

Hong Kong is an autonomous territory on the eastern side of the Pearl River estuary in East Asia, on the south of the Chinese province of Guangdong, and east of the former Portuguese colony and special administrative region of Macau. It is strategically located at the mouth of the Pearl River delta in Southern China. All major cities in East and Southeast Asia, such as Beijing, Shanghai, Tokyo, Seoul and Singapore are within a few hours' flight. With a population of 7.3 million (Source from: World Bank 2016[3]), Hong Kong residents occupy a territory of 1,104 square kilometers, Hong Kong is the fourth-most densely populated region in the world. Moreover, this bustling city also features lush green hillsides, secluded beaches, leisurely rural landscape and rocky coastline[4].

As a highly competitive financial and commercial center, Hong Kong remains one of the most resilient economies in the world, with a GDP of USD 321 billion (USD 43,000 per capita) in 2016, which is comparable to the most developed economies. Hong Kong's economic freedom score is 90.2 (Figure 1).

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[3] Hong Kong SAR, CHINA, Population, total, web source: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=HK

[4] Introducing Hong Kong, Nov 15, 2018, web source: https://www.hketolondon.gov.hk/intro/hksar.htm

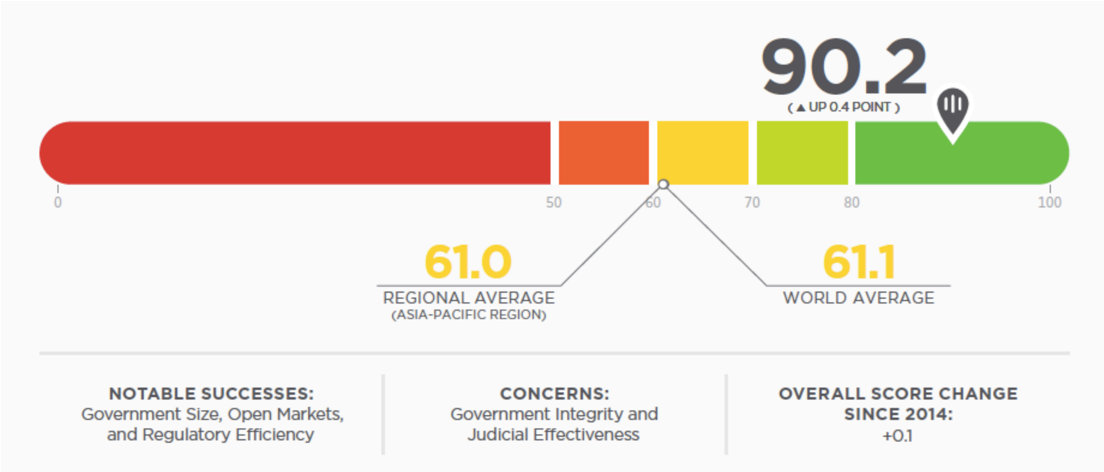

Figure 1: "Economic Freedom Score" of Hong Kong in 2018

(Source: Miller 2018)

2. SOLID WASTE IN HONG KONG

2.1 Definition of Various Types of Solid Waste in HK

Table 1 shows the detail data for annual solid waste went to landfills in Hong Kong from 2004 to 2016. Compared with the other two types of waste (overall construction waste and special waste), municipal solid waste is the largest part of landfilling in Hong Kong. The rate of landfill MSW increased every year from 2004 to 2016 when 3.8 million tons were landfilled (10,350 tons per day), corresponding to about 68% the total MSW generated (Figure 2).

The construction waste in this Table includes waste collected from construction and demolition activities, but does not include materials that are transported to public fill areas for land reclamation and formation. The overall construction waste received at landfills includes construction waste and concrete batching plants on construction sites and cement plaster or mortar manufacturing plants, outside construction sites. The solid waste generated by construction activities is a serious concern in Hong Kong. In addition to its environmental impact, construction waste also puts tremendous pressure on MSW sites.

Based on Table 1 and Figure 2, the percentage of overall construction waste is 29%, which is the second largest part in Hong Kong's waste system. In order to control this, Hong Kong government implemented a series of construction waste management (CWM) policies. According to the "polluter pays" principle, the Hong Kong government implemented the Construction Waste Disposal Charging Scheme (CWDCS) in 2006. On the basis of CWDCS, a levy of HK$125 (US$16) per ton of construction waste is disposed of in a landfill. However, the levy will be HK$100 (US$13) per ton if the waste has first been processed at off-site sorting facilities. Further, waste will be charged at just HK$27 (US$3.5) per ton if it consists of inert materials which are accepted by Public Fill Reception Facilities.[5] This policy plays a very positive role in Hong Kong, the total amount of the construction waste has suddenly decreased from 2393 thousand tons (6556 tons per day) in 2005 to 1506 thousand tons (4,125 tons per day) in 2006.

Special waste in Table 1 includes animal carcasses, abattoir waste, condemned goods, waterworks and sewage treatment sludge, sewage works screening, livestock waste, clinical waste and chemical waste delivered to landfills. Special waste represents only 4% of the total amount landfilled in 2016.

Table 1: Annual solid waste disposed of at Hong Kong landfills

Unit: Thousand Tons

Type	2004	2005	2006	2009	2010	2011	2012	2013	2014	2015	2016

[5] Construction Waste - Hong Kong Style, Dr. Wilson W.S. Lu, Aug 15, 2013, web source: https://waste-management-world.com/a/construction-waste-hong-kong-style

MSW:	3399	3423	3387	3271	3603	3284	3386	3485	3570	3708	3778
(1) Domestic	2569	2492	2421	2195	2239	2180	2294	2321	2343	2359	2332
(2) Commercial	611	692	753	846	858	861	825	879	936	1023	1106
(3) Industrial	219	239	213	230	229	242	267	285	292	326	339
Overall construction W	2407	2393	1506	1139	1308	1216	1256	1311	1439	1533	1613
Special waste	591	637	597	454	408	413	411	428	414	271	204
Total	6389	6453	5489	4864	5320	4912	5053	5224	5424	5512	5595

(Source: Hong Kong Environmental Protection Department, Web Source: www.epd.gov.hk)

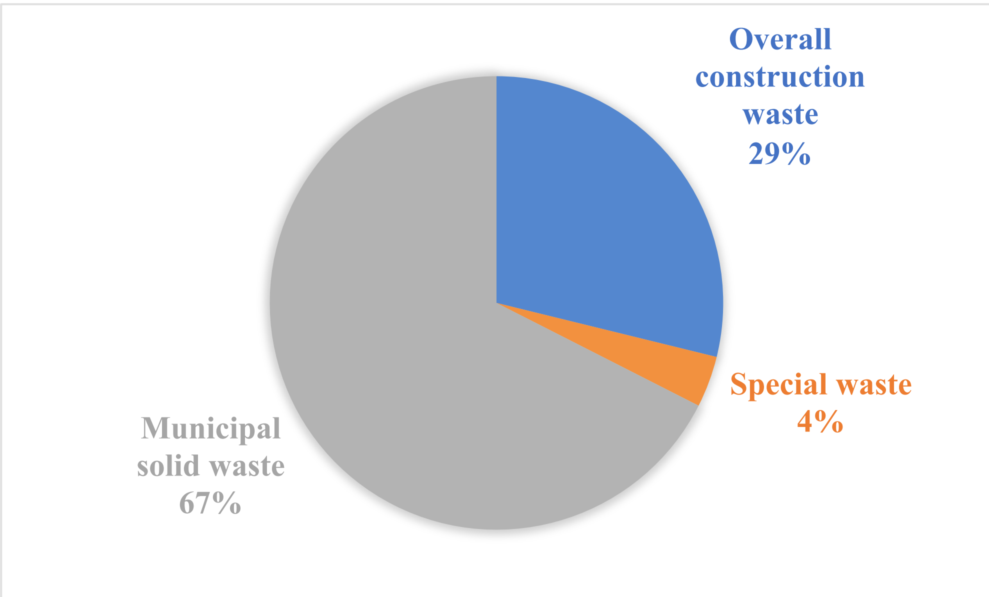

Figure 2: Distribution of Hong Kong solid waste in 2016

2.2 Municipal Solid Waste in HK

2.2.1 Definition of MSW

Domestic, commercial and industrial wastes are collectively referred to as municipal solid waste (MSW) in HK. Domestic solid waste, which comes from households and public areas, including waste collected from residential buildings, litter bins, streets, marine areas and country parks; Commercial solid waste, which comes from shops, restaurants, hotels, offices and markets in private housing estates; Industrial solid waste, which is generated by all industrial activities, but does not include construction and demolition waste, chemical waste or other special waste.[6]

Table 2 was calculated based on Table 1. In 2016, the quantity of MSW delivered to landfill was 3.78 million tons, an increase of 0.24% compared with 2015. The major component of MSW is domestic waste. The quantity of it was 2.33 million tons in 2016, which represented a decrease of 1.89% as compared to 2015. Commercial waste is the second largest component of MSW, the amount of disposed was 1.11 million tons, an increase of 1.69% compared to 2015. The smallest component of material landfilled is industrial waste. It amounted to 0.3 million tons waste in 2016, an increase of 0.21% compared with 2015.

The relatively stable domestic waste disposal rate in recent years is generally consistent with population growth. In general, the commercial waste generation rate is related to the level of consumption activity. Therefore, the increasing of commercial waste quantity in 2016 may be partly attributable to the relatively active local economy.

Table 2: Percentage of MSW Landfills in HK from 2004 to 2016

6 Municipal Solid Waste, GovHK, December 2017. Web source: https://www.gov.hk/en/residents/environment/waste/msw.htm

Type	2004	2005	2006	2009	2010	2011	2012	2013	2014	2015	2016
Domestic	75.58%	72.82%	71.49%	67.11%	62.15%	66.40%	67.75%	66.61%	65.61%	63.63%	61.74%
Commercial	17.97%	20.21%	22.22%	25.87%	23.82%	26.23%	24.36%	25.22%	26.22%	27.59%	29.28%
Industrial	6.45%	6.97%	6.28%	7.02%	6.35%	7.37%	7.89%	8.17%	8.17%	8.78%	8.99%

2.2.2 Composition of Landfilled MSW in HK

According to the Hong Kong government official site, the amount of each type of annual MSW going to landfill is shown in Table 3. Waste concrete delivered to landfill as industrial waste since 2007 was re-classified as “overall construction waste”. Its corresponding quantity has been deducted from municipal solid waste. Other wastes in Table 3 include bulky items and other miscellaneous materials.

The total disposal rate of post-recycled MSW in Hong Kong increased from 3.4 million tons in 2004 to 3.6 million tons in 2015. The corresponding disposal rate of MSW increased roughly by 2%-3% annually.

Table 3: Composition of Hong Kong MSW delivered to landfills

Unit: Thousand tons

Composition	2004	2005	2006	2009	2010	2011	2012	2013	2014	2015
Paper	872	884	879	753	732	705	697	666	702	824
Plastics	653	637	624	622	708	618	668	681	736	797
Rattan/Wood	125	127	119	119	108	116	139	144	126	145
Metals	77	87	79	62	64	66	87	65	76	86
Glass	123	127	112	117	136	101	106	129	104	134
Textile	92	101	127	92	85	79	107	99	107	112
Putrescible	1298	1304	1334	1356	1339	1458	1415	1529	1517	1430
Others	159	156	114	150	154	139	176	173	203	180
Total	3399	3423	3387	3271	3327	3283	3396	3485	3570	3708

(Source: Environmental Protection Department, Web Source: www.epd.gov.hk)

The composition of landfilled MSW shown in Figure 3 was calculated from data in Table 3. In 2015, Figure 3 shows that paper, plastics and putrescibles are the main compositions of MSW in Hong Kong, with the proportion of 22.2%, 21.5% and 38.6%, respectively. There are also some other minority compositions such as wood, metals, glass, textile, and other waste which in total account for 17.7%.

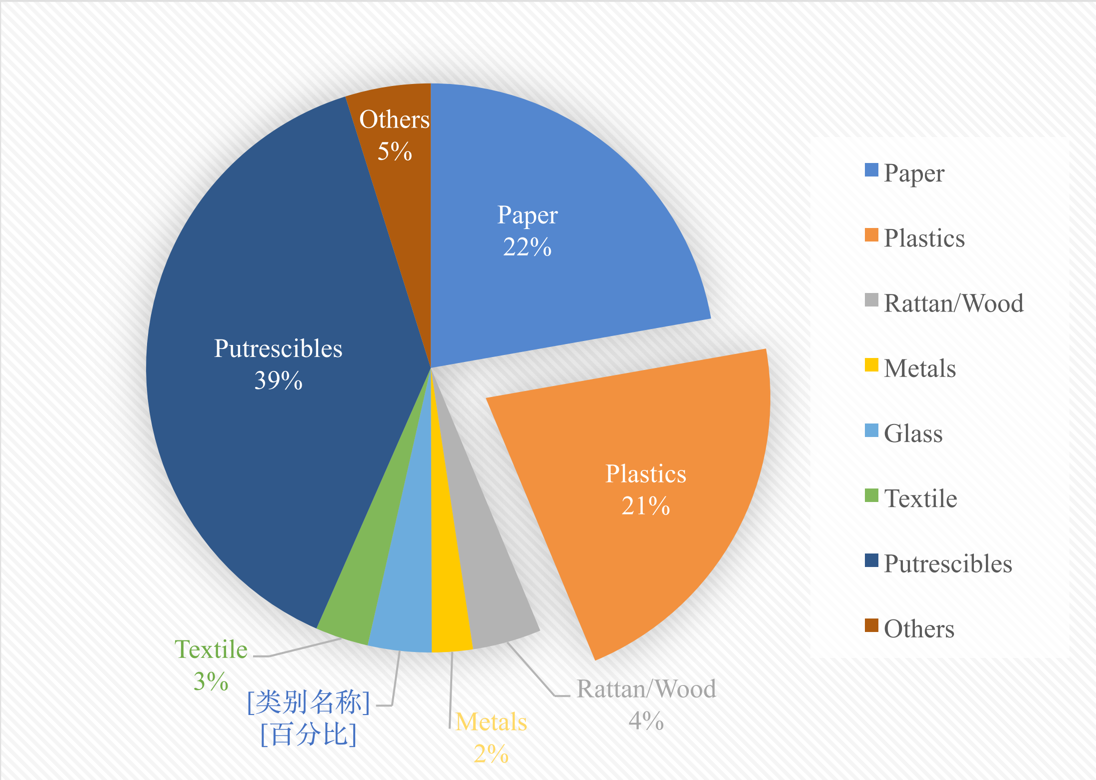

Figure 3: Distribution of each composition of Landfilled MSW in 2015

2.2.3 Recycled and Non-recycled Materials in Hong Kong

In Hong Kong, private buildings are responsible for recycling their own wastes, while in the public areas, garbage bins were set up by the government to collect the recyclable wastes. Tables 4 and 5 show the recyclable and non-recyclable materials in Hong Kong.

Table 4: Description of Recyclable Materials in HK

Material Type	Recyclable Materials	Collection Points
Waste Paper	newspapers, books and magazines, office papers, cardboard (corrugated fiberboard)	• Collector/Recycler • Recycling Organizations and Collection Points • Waste Separation Bin • Community Green Stations
Metals	iron / aluminum cans (clean), cook wares, milk powder cans, food containers	• Collector/Recycler（Ferrous Metals, Non-Ferrous Metals) • Waste Separation Bin • Community Green Stations
Plastics	beverage plastic bottles, personal care product plastic bottles	• Collector/Recycler • Recycling Organizations and

		Collection Points • Waste Separation Bin • Community Recycling Network • Community Green Stations
Rubber	rubber tire	• Collector/Recycler
Electrical Appliances	Small Electrical Appliances: e.g. cooker, toaster, oven, hair-dryer, vacuum cleaner, electric fan, Iron, mobile phone, telephone, camera, recorder, MP3 player, electronic dictionary, notebook, computer, printer, DVD/cassette tape player, hi-fi, etc. Large Electrical Appliances: e.g. air conditioner, refrigerator, washing machine, television etc.	• Collector/Recycler (Computer Products, Electrical Appliances) • Recycling Organizations and Collection Points (Computer Products, Electrical Appliances) • Community Recycling Network • E-waste Collection Hotline and Collection Service • Community Green Stations
Rechargeable Batteries	All rechargeable batteries, including general purpose and small electronic devices	• Rechargeable Battery • Collection Point • Community Green Stations
Fluorescent Lamp	compact fluorescent lamps, other fluorescent lamps (including straight tubes and round tubes), high intensity discharge (HID) lamps	• Fluorescent Lamp • Collection Point • Community Green Stations
Clothes	clothes, accessories, textile (clean)	• Collector/Recycler • Recycling Organizations and Collection Points (Clothes, Accessories) • Clothes Recycling Bank
Glass	Clean glass bottles: e.g. beer/wine glass bottles, beverage glass bottles, cooking oil/seasoning/sauce glass jar, etc.	• Collector/Recycler • Recycling Organizations and Collection Points • Community Recycling Network • Community Green Stations
Furniture	Household, institution/commercial	• Recycling Organizations and Collection Points
Food	dried food, canned food	• Recycling Organizations and Collection Points
Others	food waste, restaurant waste (oil, grease trap), toner cartridge, wood, PVC Banner	• Collector/Recycler • Recycling Organizations and Collection Points

(Source: EPD 2018)

Table 5: Description of Non-Recyclable Materials in HK

beverage or milk cartons with plastic or aluminum interior coatings
aerosol cans, chemical containers
mops, correction fluid containers or medicine containers
light-bulbs

(Source: EPD 2018)

2.2.4 MSW Recovered Situation in HK

About 98% of the city's "recyclable" (about 2 million tons in 2015) were transported to mainland China and other countries. Table 6 shows the detailed composition of recovered municipal solid waste. The major types of recyclable wastes recovered included paper, plastics, ferrous metal and non-ferrous metal, which accounted for about 97% of the waste recovered. The remaining 3% include electrical & electronic waste, wood, textile, rubber tires and glass.[7]

[7] Recovery and Recycling of Municipal Solid Waste in Hong Kong , Waste Reduction and EcoPark Group Environmental Protection Department , March 2012 , Web Source: https://www.wastereduction.gov.hk/sites/default/files/wr_msw.pdf

Table 6: Composition of recovered municipal solid waste in HK

Unit: Thousand Tons

Composition	2004	2005	2009	2010	2011	2012	2013	2014	2015
Paper	883	908	1 027	1 195	1 278	1 162	1 035	948	896
Plastics	265	644	1 211	1 577	843	317	243	99	94
Wood	22	14	17	17	18	9	6	6	1
Ferrous metal	956	829	733	566	667	500	523	845	864
Non-ferrous metal	99	108	101	155	115	78	79	76	84
Glass	2	2	3	5	5	18	10	8	9
Textile	18	15	16	20	11	4	7	4	5
Rubber tire	21	21	9	10	15	12	22	5	7
Electrical and electronic equipment	37	53	64	61	67	56	56	56	59
Food waste(1)	–	–	–	§	1	7	29	7	14
Total	2 305	2 594	3 181	3 603	3 019	2 163	2 009	2 053	2 033

Notes:

(1) :Environmental Protection Department launched the "Food Waste Recycling Partnership Scheme'' with commercial and industrial sectors since 2009.

– : Not applicable

§ : Magnitude less than half of the unit employed

(Source: Environmental Protection Department, Web Source: www.epd.gov.hk)

Figure 4 illustrates the annual amount of MSW delivered to landfills versus recovered MSW from 2004 to 2015. In 2015, about 3.71 million tons (10,159 tons per day) of MSW were sent to landfill and 2.03 million tons (5,569 tons per day) of MSW were recovered. The recovery rate was approximately 35% in 2015, which represented a decrease of 1% as compared to 2014, and a decrease of 15% compared to the peak value in 2010. Figures 4 and 5 show that the total amount of recovered MSW reached a peak value of 3.6 million tons in 2010, however, it has been dropping sharply and is now at such low levels (2.03 million tons), a decrease of more than 40%.

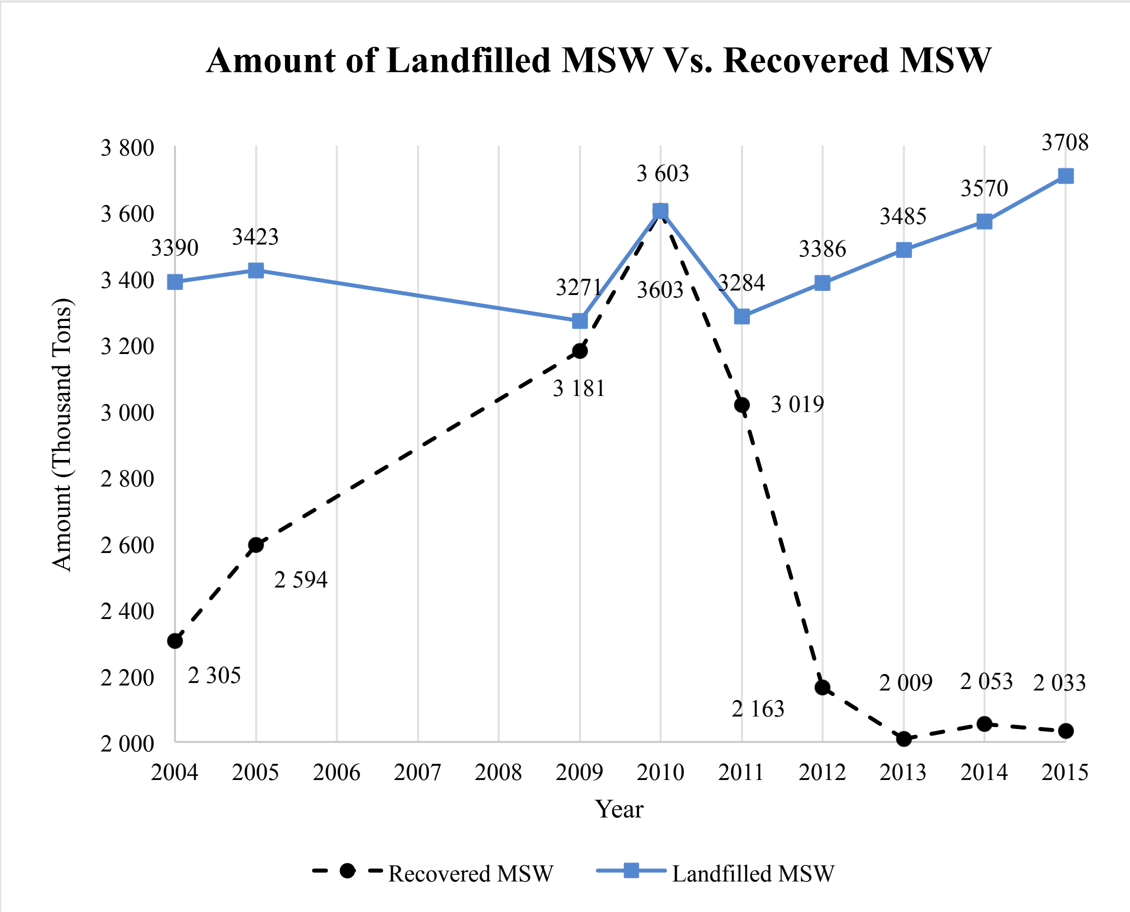

Figure 4: Annual amount of Landfilled MSW vs. Recovered MSW in HK

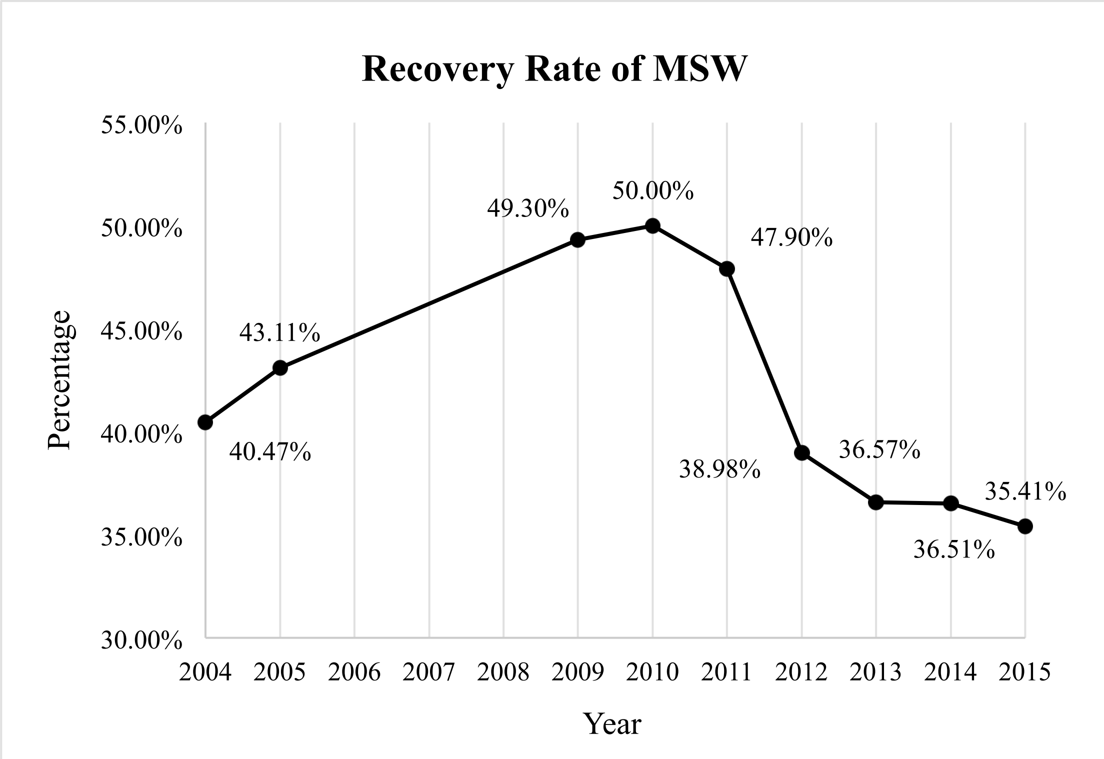

Figure 5: Annual MSW recovery rate in HK

2.2.5 Moisture Content in MSW

Moisture content is a very important factor in determining the quality of MSW. Hong Kong's MSW contains high moisture, and most of which is due to food waste. As Figure 6 shows, 1.44 million tons of food waste went to landfill in 2015, accounting for 38.6% of the landfilled MSW in 2015. However, only 14,000 tons of food waste were recovered (0.97% recovery). The recovery rate of paper was 52%, plastic 11%, wood 0.68%, metals 92%, glass 6%, textile 4%, and all others 27%.

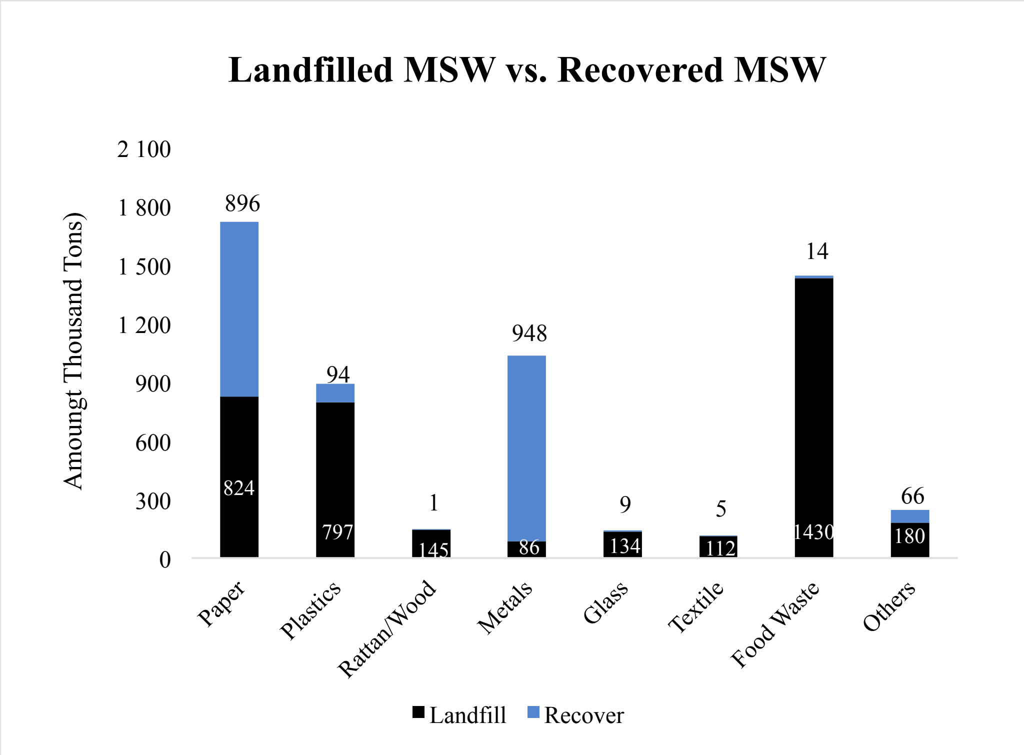

Figure 6: Amount and Composition of Landfilled MSW vs. Recovered MSW in HK in 2015

There are a lot of problems in combusting high moisture MSW, first MSW is hard to ignite, second it will need more energy to dry the MSW before combustion, last, it also requires a long residence time for burn out (Huang, Y.Chi, Nickolas. T, A. Estrada. 2014).

2.2.6 Method of Processing MSW in HK

As discussed earlier, with such a large population and limited land resources, Hong Kong has been facing the problem of solid waste management for a longtime. In 1960, the first landfill of Hong Kong was built on Gin Drinkers Bay, Kwai Tsing District, Tsuen wan, with 29 hectares and a capacity of 3.5 million tons (12.1 tons/m^2). This first landfill was filled and closed down in 2000, transformed now to a park called Kwai Chung Park. After that another 12 landfills were opened to serve Hong Kong and by now have been closed (Table 7).

Table 7: Description of Closed Landfills in Hong Kong

Landfill	Location	Hectare	Opened	Capacity	Rehab Period	Current use
Gin Drinkers Bay	Kwai Tsing District, Tsuen Wan	29	1960	3.5 million tons	1999–2000	Now Kwai Chung Park
Ngau Tam Mei	Tam Mei, Yuen Long District	2	1973	0.15 million tons	1999–2000	Green Belt
Plover Cove	Tai Mei Tuk, Tai Po District	50	1973	15 million tons	1996–1997	Golf driving range
Ma Tso Lung	Kwu Tong, North District	2	1976	0.2 million tons	1999–2000	Recreation center for Tung Wah Group of Hospitals
Ngau Chi Wan	Wong Tai Sin District, East Kowloon	8	1976	0.7 million tons	1997–1998	Ngau Chi Wan Park
Sai Tso Wan	Kwun Tong District, East Kowloon	9	1978	1.6 million tons	1997–1998	Sai Tso Wan Recreation Ground opened in 2004
Siu Lang Shui	Castle Peak	12	1978	1.2 million tons	1999–2000	Green Belt
Junk Bay Stage I	Tseung Kwan O, Sai Kung District	68	1978	15.2 million tons	1997–1999	Proposed site for football academy and driving range
Ma Yau Tong West	Kwun Tong, East Kowloon	6	1979	6 million tons	1997–1998	Planned recreation facilities
Ma Yau Tong Central	Kwun Tong, East Kowloon	11	1981	1.0 million tons	1997–1998	Future Lam Tin Park
Pillar Point Valley	Tuen Mun District	38	1983	13 million tons	2004–2006	N/A
Jordan Valley	Kwun Tong, East Kowloon	11	1986	1.5 million tons	1997–1998	Jordan Valley Park, Opened 2010.
Junk Bay Stage II-III	Tseung Kwan O, Sai Kung District	42	1988	12.6 million tons	1997–1999	Temporary home for Hong Kong Air Cadet Corps model plane training facilities

(Source: Wikipedia 2018)

At this time, there are three principal landfills in use, West New Territories (WENT) Landfill, South East New Territories (SENT) Landfill and North East New Territories (NENT) Landfill (Figure 7). These landfills have adopted advanced technology to meet more demanding environmental requirements and provide much needed capacity for waste disposal in Hong Kong. However, as shown in Table 8, by 2019, all the three existing landfills in use in Hong Kong will be full.

Table 8: Description of Strategic landfills in use in Hong Kong

Landfill	Location	Hectare	Opened	Capacity	Status
West New Territories Landfill (WENT)	Nim Wan, Tuen Mun	110	1993	61 million m^3	Active (Full by 2018/2019)
South East New Territories Landfill (SENT)	Tseung Kwan O, Junk Bay	100	1994	43 million m^3	Active (Full by 2014/2015)
North East New Territories Landfill (NENT)	Ta Kwu Ling, North District	61	1995	35 million m^3	Active (Full by 2016/2017)

(Source: Wikipedia 2018)

Figure 7: Location of Existing Strategic Landfills in Hong Kong

(Source: EPD 2016)

In addition to adopting sanitary landfilling methods, in the early 2000s, the Hong Kong government began to look at other options for disposing sewage sludge. In 2015, Hong Kong T Park, a sludge treatment facility was completed. It is a unique self-sustained advanced facility that combines a variety of advanced technologies with recreational, educational and ecological features in a single complex. According to government estimates, Hong Kong generates about 3 million cubic meters of sewage per day, resulting in 1,200 tons of sludge per day. With four incineration trains in the facility, T Park can handle a maximum capacity of 2,000 tons of sludge per day, i.e., 730,000 tons of sludge per year. The total cost of T Park was at HK$5.5 billion (US$ 702 million).

2.3 Government Initiatives in Waste Reduction and Recycling

The Environmental Protection Department (EDP) of Hong Kong is involved and works closely with several sectors, such as property management, education, non-governmental organizations and industry, to reduce and recycle wastes in Hong Kong. Many measures have been implemented, including Waste Separation Bins, Land Allocation Policy, Amendment of Building Regulations, Program on Source Separation of Domestic Waste, Program on Source Separation of Commercial and Industrial Waste, Promotion Program on Source Separation of Waste, Community Recycling Network, Cooperation with District Councils, Environment and Conservation Fund, Hong Kong Awards for Environmental Excellence, Producer Responsibility Scheme, Recovery Program for Waste Electrical and Electronic Equipment (WEEE), Mobile WEEE Collection Centre Service (EPD 2012).

The Program on Source Separation of Domestic Waste is an example of these measures. It was implemented in Hong Kong in 2005 to encourage more people to sort their waste for recycling. The program encourages and assists property management companies to provide waste separation facilities on each floor of a building, making it easier for residents to sort waste at the source. It has also expanded the recyclable categories of waste paper, plastic, metal, electrical and electronic equipment and used clothing. Additional income can be earned by collecting and selling recyclable materials which can be used to subsidize administrative expenses.

3.

4. HONG KONG’S PLASTIC WASTE

3.1 Definition of Plastic

Plastic is material consisting of any of a wide range of synthetic or semi-synthetic organic compounds that are malleable and so can be molded into solid objects.[8] Plastic consists wholly or partly of a combination of carbon, oxygen, hydrogen, nitrogen, other organic or inorganic elements. The name "plastic" refers to the property of plasticity, which is the ability to deform without breaking.[9] There are two types of plastic thermoplastics and thermosetting polymers. The main difference between them is their behavior upon heating. Thermoplastics can be repeatedly melted and remolded. PS, PP, PVC, PET, LDPE, and HDPE are the six major thermoplastic resins and constitute the majority of plastics, about 80%. Thermosetting plastics, also known as thermosets, are usually liquid or malleable before curing, and assume a permanent shape after curing.

In order to assist in the recycling of disposable items, the Plastic Bottle Institute of the Society of the Plastics Industry designed a series of recycling number to mark plastic bottles. Table 9 shows the detail of each type of recycling plastic.

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[8] Wikipedia, March 2001, Web Source: https://en.wikipedia.org/wiki/Plastic
[9] What is Plastic? Definition in Chemistry, Web Source: https://www.thoughtco.com/plastic-chemical-composition-608930

Table 9: Resin Identification Code

Recycling Number	Plastic Resin	Abbreviation	Chemical Formula
1	Polyethylene Terephthalate	PET	$(C_{10}H_8O_4)_n$
2	High-Density Polyethylene	HDPE	$–(CH_2\text{-}CH_2)_n–$
3	Polyvinyl Chloride	PVC	$(C_2H_3Cl)_n$
4	Low-Density Polyethylene	LDPE	$–(CH_2\text{-}CH_2)_n–$
5	Polypropylene	PP	$(C_3H_6)_n$
6	Polystyrene	PS	$(C_8H_8)_n$
7	Other	O	N.A.

Polyethylene Terephthalate (PET or PETE) is the recycling number 1 plastic, it is collected mostly from the curbside recycling programs. PET had chemical properties of gas and moisture resistant, and physical properties of tough and strong. It can be used to make polyester fibers, carbonated beverage containers, furniture, food containers, paneling etc.

High-Density Polyethylene (HDPE or PE-HD) is number 2 plastic with properties of chemically and moisture resistant. HDPE has a lot of applications, such as non-carbonated beverage bottles, snack food packaging, packaging for detergents and bleach, playground equipment, grocery sacks films and so on. Waste HDPE materials usually collected through curbside recycling program, but some will not accept containers without necks.

Polyvinyl Chloride (PVC or V) is number 3 recycling plastic. Due to the properties of transparent, stable, chemically resistant, resistant to weathering, can be rigid or flexible, it can be made of pipes, fittings, window profile, children's toys, synthetic leather products etc. Europe recycled PVC extensively. There were 481,000 tons of PVC been recycled in 2014 through Vinyl 2010 and Vinyl Plus initiatives.[10]

Low-Density Polyethylene (LDPE or PE-LD) also known as Linear Low-Density Polyethylene is number 4 plastic. With the chemical and physical properties of tough, flexible, transparent, stable electrical, it was applied to made shopping and grocery bags, which can be returned to many stores for recycling. It can also use to make flexible bottles, lids, various molded laboratory equipment, wires, cables etc. However, the curbside program is not often accepting LDPE.

Polypropylene (PP) is number 5 recycling plastic. It can be made of industrial fibers, food containers, dishware and so on because of its properties of heat and moisture resistant, chemically resistant, can be rigid or flexible. This type of plastic can be recycled through the curbside program.

Polystyrene (PS) is number 6 plastic with properties of clear, hard and brittle, it is an excellent thermal insulator, and also can be rigid or expanded to foam cups, trays, take-out containers, egg cartons etc. Medical packaging, food packaging, and labware also can be made by PS. Recycle can be easily done by some curbside programs.

Other plastics will be recycling number 7. They include plastics such as nylon, acrylic, polycarbonate, polylactic acid, and multilayer combinations of different plastics. It always used in bottles, plastic lumber applications, headlight lenses, and safety shields or glasses. This kind of plastics have usually not been recycled, however, some of the curbside program will also collect some of them. (Demetra, 2013)

3.2 Plastic Waste in China

[10] Resin Identification Code, Table of Resin Codes, 0ct 25,2018, Web Source: https://en.wikipedia.org/wiki/Resin_identification_code

According to the non-profit organization Plastic Oceans, the world produces nearly 300 million tons of plastic per year. More than 8 million tons of plastics ends up into oceans each year and humanity uses more than one million plastic bags per minute.

Over the years, the growing Chinese economy provided a reliable market for recycled plastics and other materials. Figure 8 shows the top 5 import partners for China. Taking the U.S. as an example, due to changes in U.S. recycling practices, the US "recyclable materials" exported to mainland China and other Asian countries increasingly contained dirty and poorly classified materials, some even contaminated with hazardous substances such as lead or mercury. In 2013, China launched an offensive to clean up these imports through the "Operation Green Fence".

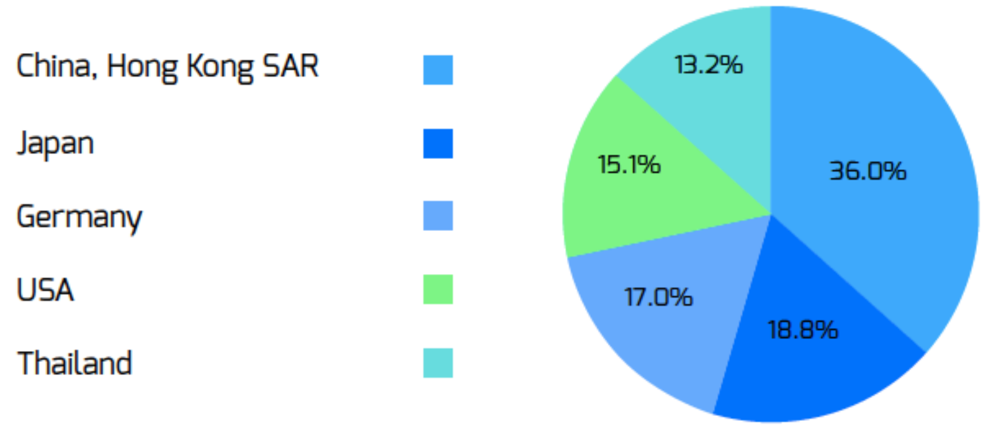

Figure 8: Top 5 importers of plastic waste to China, based on financial transactions.
(Source: Global recycling markets, Costas Velis, Sep 2014. Web source: https://www.iswa.org/fileadmin/galleries/Task_Forces/TFGWM_Report_GRM_Plastic_China_LR.pdf)

China was the world's largest importer of plastic waste, receiving ten million tons of recycled materials every year. Most of these materials were processed in the small "Plastic Waste Household Recycling Workshops". This had a significant bad impact on the local environment. Some of these materials were recycled into new clothing, toys or other items to satisfy consumer habits around the world. However, some of the imported plastics cannot be reprocessed and were discarded, polluting the environment and communities around the "recycling" shops.[11]

3.3 Hong Kong's Role in Plastic Waste Market.

3.3.1 Importer

Hong Kong serves as an entry point to China, re-exporting to mainland China most of the imported quantities. As Figure 9 shows, Hong Kong is the second largest (19.7%) importer around the world. The UK used Hong Kong as a key destination, because it allowed imports of mixtures, while mainland China only allowed mixtures of waste plastics that included PE, PVC, PS and PET.

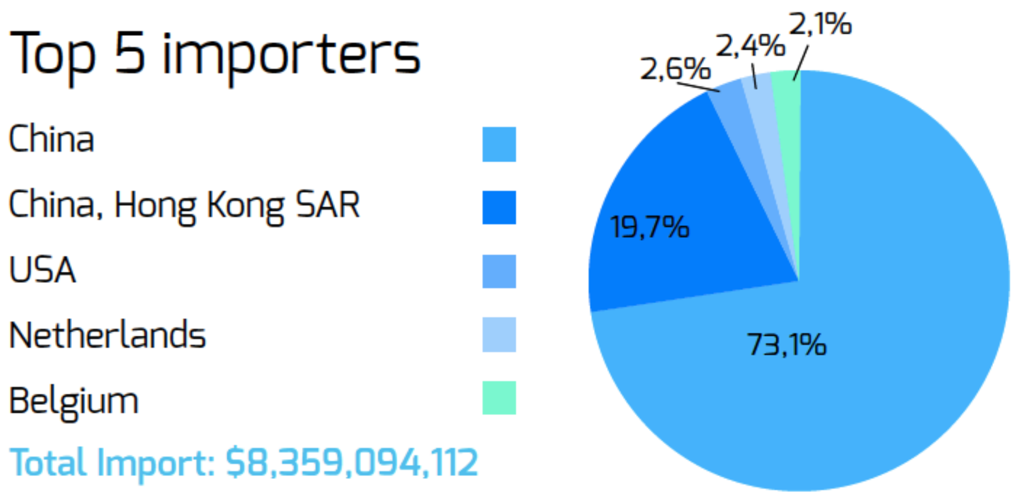

Figure 9: Top 5 importers of plastic waste worldwide.

(Source: Global recycling markets, Costas Velis, Sep 2014. Web source: https://www.iswa.org/fileadmin/galleries/Task_Forces/TFGWM_Report_GRM_Plastic_China_LR.pdf)

Figure 10 shows that approximately 78% of UK plastic exports to China were shipped through Hong Kong in 2008. However, the relative proportion has decreased significantly to about 53% in 2011. There is evidence that plastics from imported Waste Electrical and

[11] Athena Lee Bradley, Plastic World, November 7, 2017, web source: https://nerc.org/news-and-updates/blog/nerc-blog/2017/11/07/plastic-world?gclid=EAIaIQobChMIiNHsltqu3gIVl4SzCh35HAFIEAAYASAAEgLXlPD_BwE

Electronic Equipment (WEEE) were separated from metal scrap in Hong Kong and then transported to China. More stringent regulations effectively prevents non-qualified plastic waste from entering mainland China.[12]

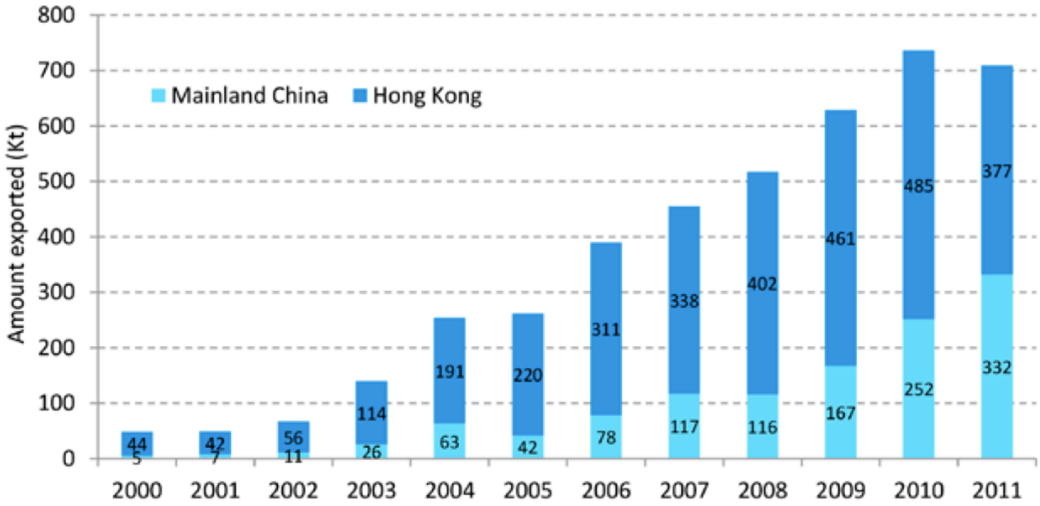

Figure 10: World exports of recovered plastics to China including HK

(Source: Costas Velis, September 2014, Global recycling markets: plastic waste)

3.3.2 Exporter

Hong Kong does not have internal market for plastic waste, so it exports most of the domestically collected plastic waste. Figure 11 shows that HK is the top exporter of plastic waste in the world (26.9% of total). About 98% of the city's actual recycling is done outside Hong Kong. Another reason is that several countries use HK as "Transfer Station" for plastic waste, with the final destination being China.

[12] Costas Velis, September 2014, Global Recycling Markets: Plastic Waste, Pg28

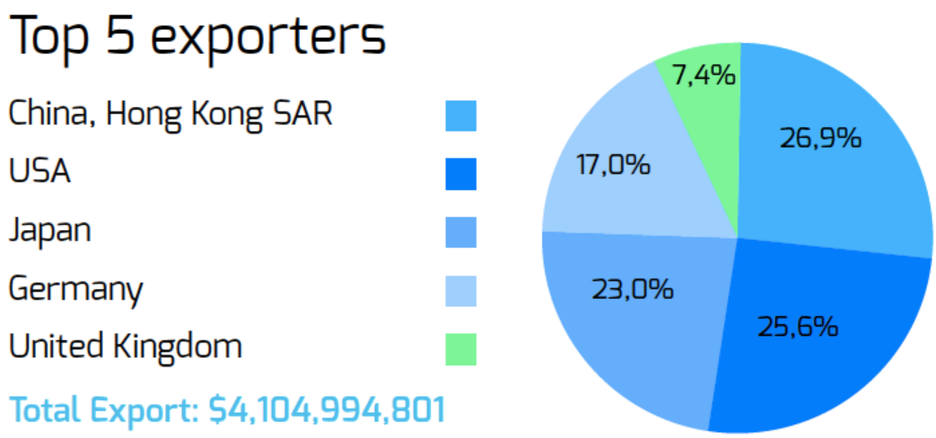

Figure 11: Top 5 exporters of plastic waste worldwide.

(Source: Global recycling markets, Costas Velis, Sep 2014. Web source: https://www.iswa.org/fileadmin/galleries/Task_Forces/TFGWM_Report_GRM_Plastic_China_LR.pdf)

Figure 12 shows that recycling and exportation of plastic peaked at 1.58 and 1.57 million tons in 2010, separately. In 2011, about 0.84 million tons of plastic waste were collected by separation program in HK, of which 99.5% was exported to mainland China. There are two processing routes for the exports. Most of them are packaged and exported directly by local commercial recyclers. The rest is reprocessed at the plastic resource recycling center, EcoPark Tuen Mun, where they are cleaned, crushed, dried and the shredded flakes are pelletized.[13]

[13] Costas Velis, September 2014, Global Recycling Markets: Plastic Waste, Pg28

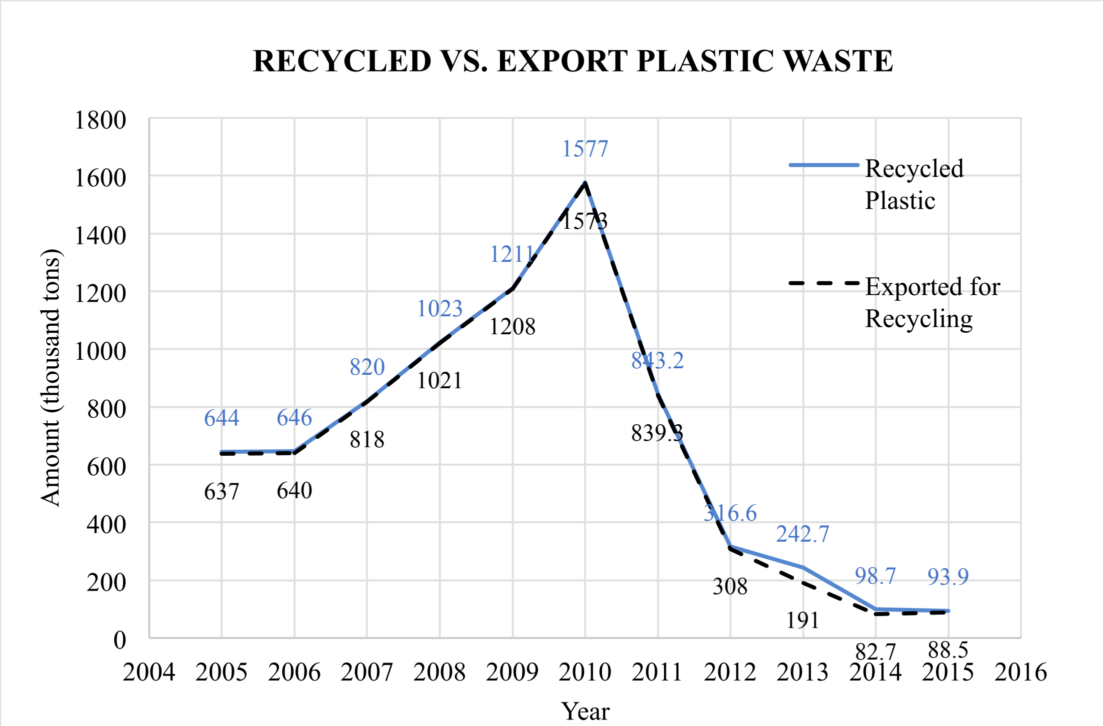

Figure 12: Amount of Annual Recycled vs. Exported Plastic Waste in HK

3.4 Plastic Recycling in HK

There is a lot of controversy about what actually happened in Hong Kong for the separation and recycling of plastics. Many people believe that the plastic waste they collected will eventually go to landfill.

Plastic recycling depends on several factors, including its cleanliness, volume, and demand for that type of plastics. Contamination of food, household products, and oil can make the entire batch of plastic non-recyclable. There are many types of plastics that can be sold at a higher price if sorted and processed by type. For example, PET bottles are more valuable if they are not mixed with other types of plastics. All plastics are potentially recyclable, but there needs to be sufficient quantity to make it cost effective to process.

Unlike some countries with mechanized systems, the recycling process in Hong Kong is very basic. Once collected, most of the recyclables are sorted by hand, just like Figure 13. The Community Recycling Network (CRN) in Hong Kong only collects clean plastic bottles of beverages or personal care products. It will not collect contaminated plastic materials, plastic bags, and container, chemical and medicine container (e.g. bottles of engine oil), correction fluid container, mop, snacks or drinks packaging with an aluminum coating, rubber (e.g. tire, gloves) etc. If the consumer does not properly separate the recyclable waste at the source, it may eventually end up in the landfill. Because the labor required for sorting and cleaning the mixed recycling make it less cost-effective to process (Plastic Free Seas, 2013).

Figure 13: Hand Sorting of Recyclables in HK (Source: Plastic Free Seas, 2013)

Hong Kong's plastic recycling rate has been at a low level for a long time because it is directly related to oil prices. It is much easier to make plastic from virgin oil, so when oil is relatively expensive, recycling is only commercially attractive.

3.5 Plastic Recovered Situation in Hong Kong

Figure 14 was made according to the MSW recovered data in 2015. The percentage of paper and ferrous metal are the major component in recovered MSW, which is 44.07% and 42.5%, respectively. There are only 5% of recovered plastic among the total recovered MSW, but it is the third largest component in 2005. Other parts are too small to show in Figure 14, wood accounts for 0.05%, non-ferrous metal 4.13%, glass 0.44%, textile 0.25%, rubber tire 0.34%, electrical and electronic equipment 2.9%, food waste 0.69%.

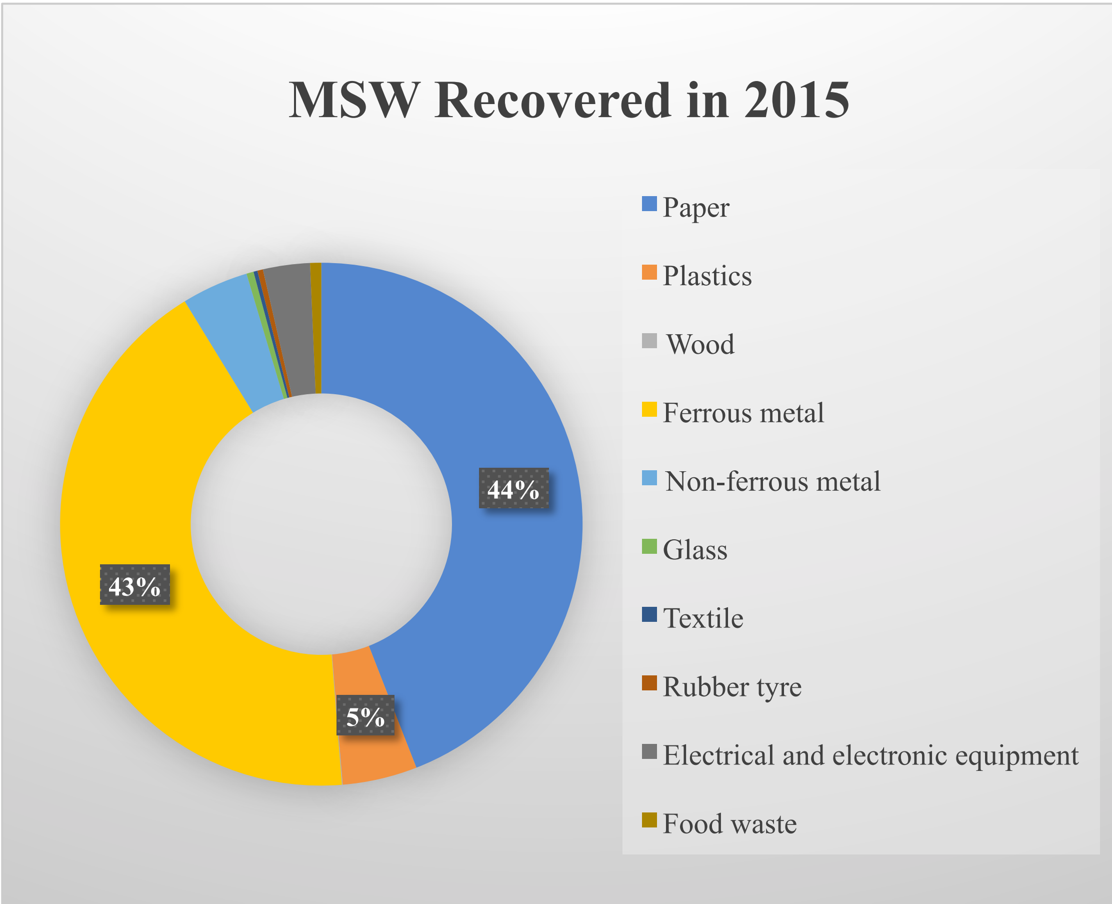

Figure 14: Distribution of Recovered MSW in Hong Kong, 2015

Figure 15 shows the amount of recovered plastic from 2006 to 2016. The annual amount of recovered plastic increased from 2006 (646 thousand tons) to 2010 (1577 thousand tons). However, after 2010, the recovery rate dropped significantly until 2016 (126 thousand tons). Compared with the peak value of recovered plastic in 2010, the amount of recovered plastic in 2006 was only 7.99%.

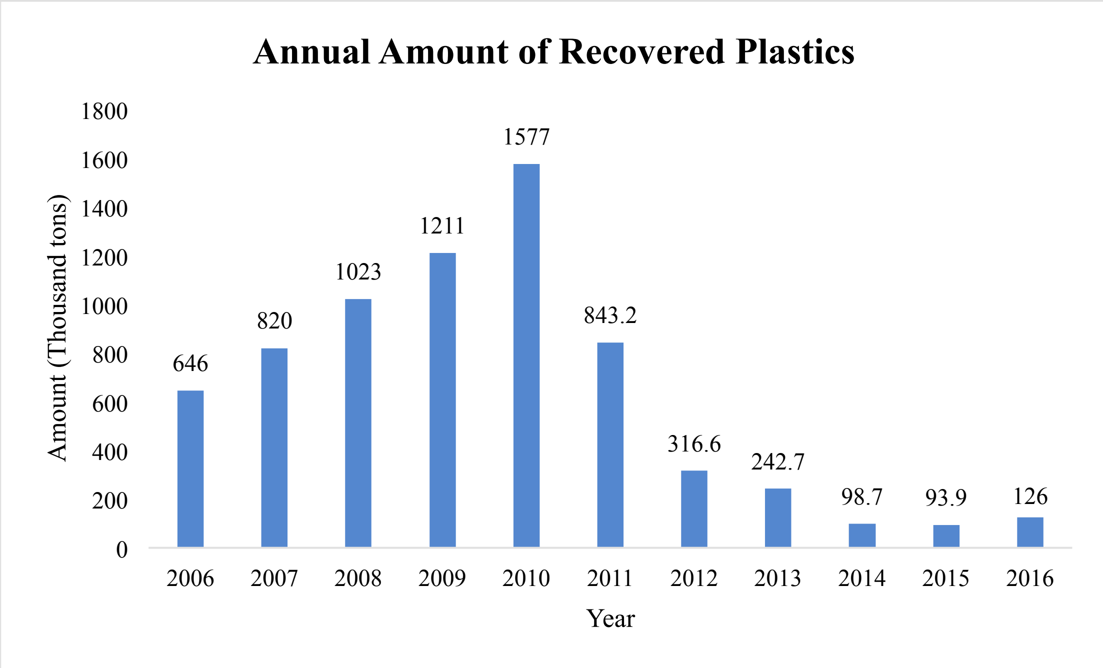

Figure 15: Annual Amount of recovered plastic from 2006 to 2016 in HK

3.6 Major Challenges in Handling Plastic Waste

There are two major challenges in handling plastic waste in Hong Kong. First of all, the cost of collection, sorting, storage, and transportation is high because plastic waste has low density, high variety and large size. The biggest problem with plastic recycling is that it is difficult to automate the classification of plastic waste. Although containers are typically made of a single type and color of plastic, making them relatively easy to classify, consumer accessories such as cell phones may have many small parts made up of dozens of different types and colors of plastic. Therefore, recycling plastics is unprofitable due to the low value of the materials.

On the other hand, the price of raw plastics is very low. Therefore, the recovery rate is not high. Plastic is made from petroleum, however, as oil price plummet, the price of new plastic is relatively low. Making new plastic is now cheaper than recycling. What's more, freshly produced plastics are more attractive to manufactures than the recycled plastics because the chemical composition is easier to distinguish, and improperly mixed plastics can have issues, like rapid degradation or more limited uses.[14]

5. FLUIDIZED BED COMBUSTION (FBC) TECHNOLOGIES

4.1 Bubbling Fluidized Bed (BFB)

4.1.1 Introduction

BFB was the first version of FBC technology, and are often preferred in small scale applications. BFB boiler is well suited for fuels with high moisture content, high ash content and low volatile.

The first BFB test facility was commissioned in 1965 (Watson, 1997). In addition, BFB boiler (<100 MWe) has been used in the aluminum and paper industry since 1970. The first application of BFB technology in the utility segment (> 100 MWe) was in 1986. Nevertheless, most of the BFB boilers are still installed in small to medium (25-100 MWe) capacity range. In the early 1990s, BFB boilers spread rapidly in China, more than 2,000 BFB boilers were in operation at that time, however, the maximum capacity was still less than 10 MW. Therefore, BFB technology is mainly applied in industrial and not in the utility segment.

4.1.2 Babcock & Wilcox Enterprises, Inc. BFB

The combustion chamber is the core part of the BFB boiler, which has water-cooled walls and bottom. Both of the lower parts of the wall and bottom has the refractory lining, which protects the combustion chamber from high temperature, corrosion, and erosion (Foster Wheeler, 2011). Since the ash, bed materials or non-combustible solids may gather together to prevent the combustor from working properly, so the particle collection, and circulation system is required (Joris Koornneef, 2006).

[14] Sarah Kramer, Apr 5, 2016, the one thing that makes recycling plastic work is falling apart. Web Source: https://www.businessinsider.com/low-oil-prices-hurt-plastics-recycling-2016-4

Figure 16 shows the BFB boiler from Babcock & Wilcox Enterprises, Inc. According to the company website, the bottom-supported capacity is up to 225,000 lb/h (28.4 kg/s), and the top-supported capacity is from 225,000 to 1,000,000 lb/h (28.4 to 126 kg/s). The steam pressure is about 2600 psi (17.9 MPa), and the steam temperature is about 1000 °F (538 °C). In addition, BFB boiler is able to burn a wide range of conventional fuels and waste fuels with high moisture. There are lots of advantages for BFB boiler like high fuel flexibility, high efficiency, low environmental emissions and low capital and operation cost (B&W).

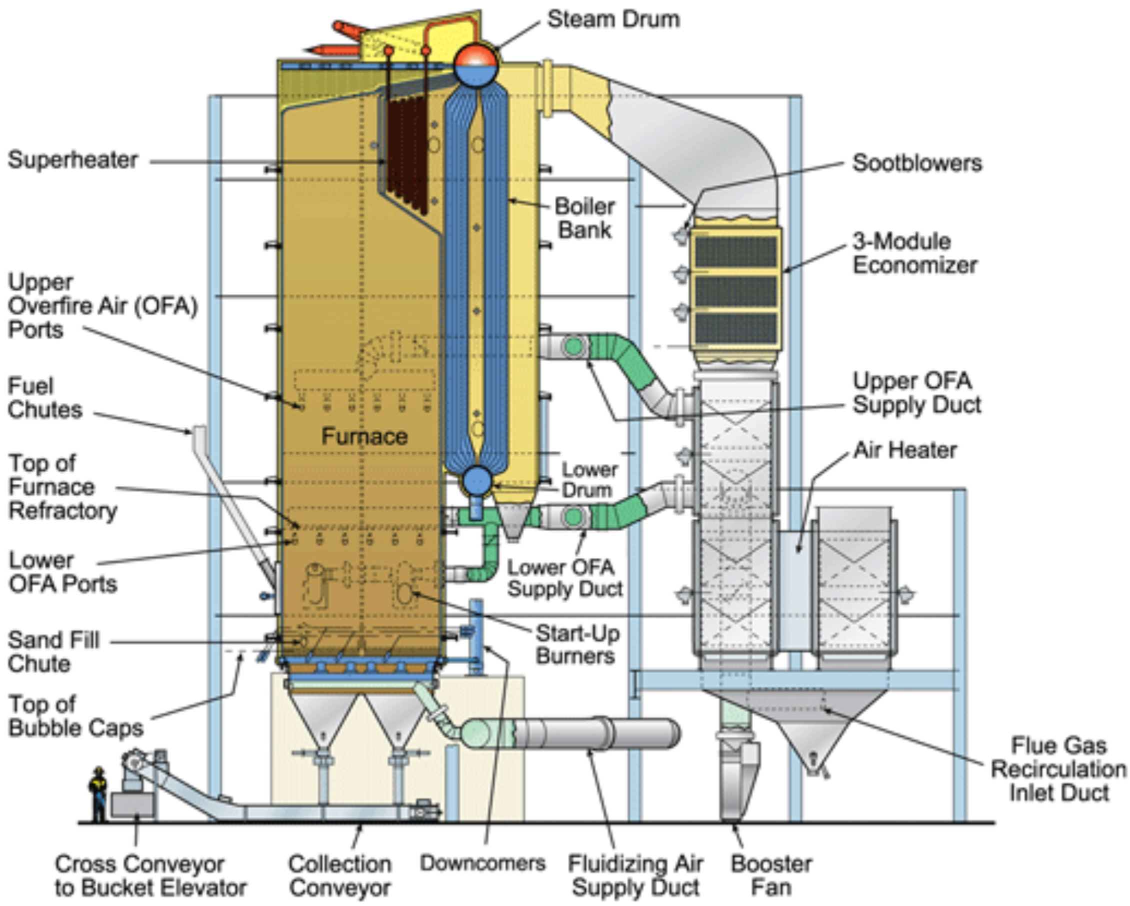

Figure 16: B&W Bottom-Supported BFB Boiler
(Source: Bubbling Fluidized-Bed Boilers, B&W Babcock & Wilcox, web source: https://www.babcock.com/zh-cn/products/bubbling-fluidized-bed-boilers)

4.2 Circulating Fluidized Bed (CFB)

4.2.1 Introduction

CFB is derived from the BFB technology. Compared with BFB, CFB has higher efficiency and better sulfur removal technology. The first commercial small size CFB boiler (5 MWe)was built in 1979 by Foster Wheeler (Engstrom F,1999). The first CFB boiler (90 MWe) installed in the utility segment was in 1985 at Duisburg, Germany. CFB boilers were accepted in the United States for non-utility scale applications in the early 1980s (Joris Koornneef, 2006).

The first CFB WTE plant In China was built by the Jin Jiang group of companies in 1998 in Hangzhou City, with a capacity of 1500 tons per day. This plant used the differential density CFB technology developed by Zhejiang University. (Huang, 2013). By now, the CFB combustion process has been developed and is widely used in China.

4.2.2 The CFB technology of Zhejiang University

As shown in Figure 17, a new CFB WTE furnace with a capacity of 2300 tons/day was designed by Zhejiang University and put into operation in Cixi City in 2012. This WTE furnace does not need any auxiliary fuel, and it is capable to deal with very low quality and a heating value of less than 4.2 MJ/kg of MSW (Huang, 2013). There are eight parts for this CFB WTE furnace, from left to right, number 1 is MSW feeder, 2 is air distributor, 3 is bottom ash discharger, 4 is CFB combustion chamber, 5 is cyclone separator, 6 superheaters, 7 is economizer, and 8 is air preheater.

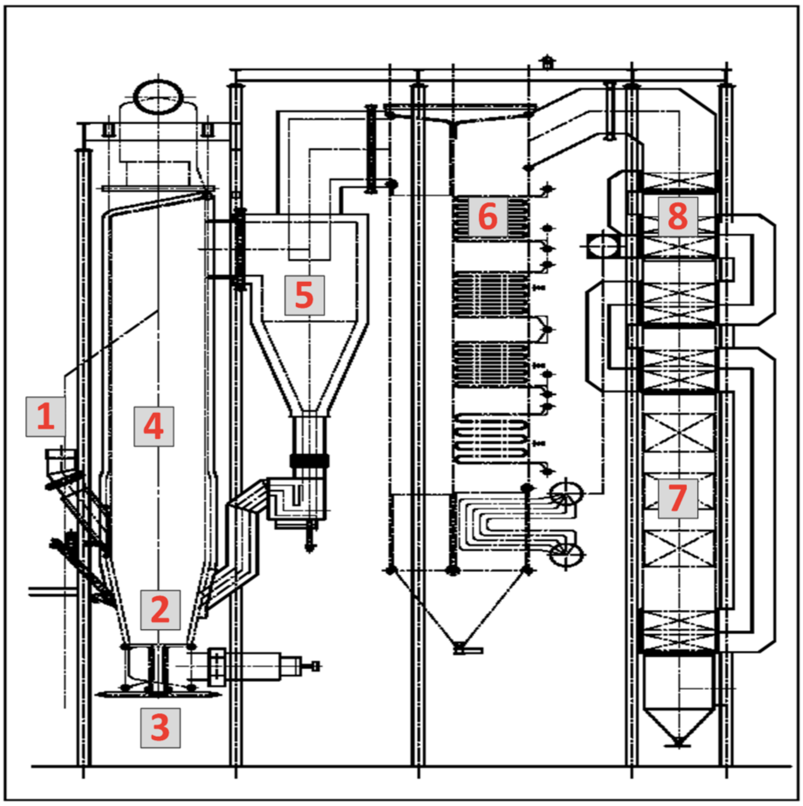

Figure 17: Layout of 800 t/d CFB incinerator at Cixi city, Zhejiang province, China

(Source: Huang, 2013)

The two shredders as shown in Figure 18, was designed to improve the homogeneity of the feedstock to less than 15cm shredded particles. Both of them will serve four lines for this plant every day, three 500 tons lines and a new 800 tons line.

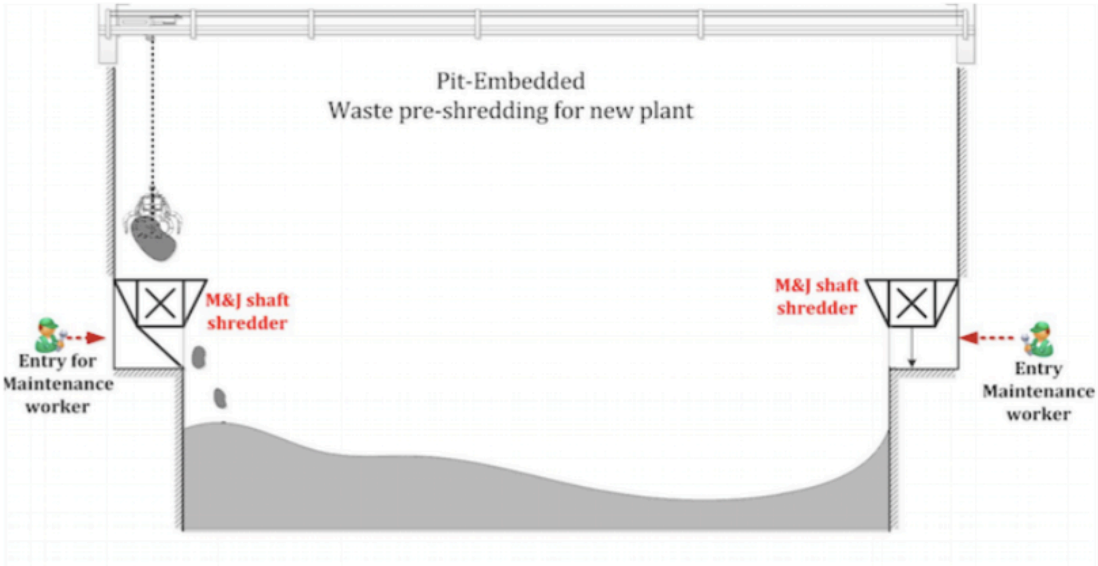

Figure 18: Location of shredders in WTE bunker

(Source: Q. Huang, Y.Chi, A. Estrada. 2014)

MSW feedstock is provided by an overhead crane (1, Figure 17). The recirculating flow of solid particles is maintained in the ratio of about 10 to the feed rate of MSW to the CFB reactor, in order to achieve uniform temperature gradient inside the combustion chamber (Huang, 2013). The high turbulence in this reactor also results in a more uniform temperature in the gas flow passing through the combustion chamber. Air distributor (2) is used as a bubbling bed reactor in which larger, heavier, unburned particles and ash were retained. The high thermal inertia and temperature of this bed can dry MSW rapidly. It also has a longer residence time which can help the waste to combust completely.

Below reactor (2), a bottom ash discharger (3) was installed to separate the larger particles from bottom ash and return the rest into the circulation if the reactor. With this bottom ash discharger, the concentration of particles in the flue gas was greatly reduced. Combustion chamber (4) was designed with water walls that are fully covered with refractory material to form a semi-adiabatic combustion environment. It usually operates between 850ºC and 950ºC (Huang, 2013).

Due to the higher fluidization velocity in the CFB reactor, high concentrations of particles were also found in the upper part of the combustion chamber (4). So, those solids (mainly unburned waste and bed material) must be separated from the flue gas before the hot gas enters the convective pass (Joris Koornneef, 2006). The particles were collected and separated from the gas in a cyclone separator (5) through centrifugal force. After the cyclone separator (5), a superheater (6) was installed followed by air preheater (8) and economizer (7). (8) is placed before (7) to increase the primary air temperature to 300 °C and improve combustion in the CFB unit (Huang, 2013).

4.2.3 Advantages of CFB

CFB has the same high combustion efficiency as moving grate and also has high adaptability to different kinds of MSW. So, CFB technology can combust almost all kinds of MSW after shredding and has a lower capital cost in the meantime. The temperature in the entire combustion chamber can be well controlled in the range of 800 to 950 °C. With this uniform temperature gradient and long residence time, emission of pollutant gases such as Oxynitride (NOx), HCl and SO_2 can be effectively controlled. In addition, the high turbulence in the CFB reactor can significantly improve the mixing of incoming cold MSW with a high-temperature bed. CFB reactor also has outstanding load adjusting capability and excellent capability of co-combustion (Huang, 2013).

4.3 Comparation of BFB and CFB

Both Circulating Fluidized Bed (CFB) and Bubbling Fluidized Bed (BFB) are variants of Fluidized Bed Combustion (FBC). Although they are based on the same principle, the design parameters of installations vary widely. Table 10 shows the detailed comparison of BFB and CFB boiler.

Table 10: Comparation of BFB and CFB Design Parameters

Design parameter	BFB	CFB
Combustion temperature (°C)	760 – 870	800 – 950
Fuel particle size (mm)	0 – 50	0 – 25
Fluidization velocities (m/s)	1– 3	3 – 10
Solids circulation	No[a]	Yes
Particle concentration	High in bottom, low in freeboard	Gradually decreasing along furnace height
Limestone[b] particle size (mm)	0.3 – 0.5	0.1 – 0.2
Average steam parameters[c]		
Steam flow (kg/s) (range)	36 (13 – 139)	60 (12 – 360)
Steam temperature (°C) (range)	466 (150 – 543)	506 (180 – 580)
Steam pressure (bar) (range)	72 (10 – 160)	103 (10 – 275)

a: Circulation of (large) unburned particles is possible in the case of bad burnout. However, solid circulation in BFB is compared to CFB a less integrated part of the combustion process.

b: Applicable in the case when limestone is used for in bed sulphur removal.

c: Data on steam parameters is collected for ca. 400 FBC installations.

(Source: Joris Koornneef, 2006, Development of fluidized bed combustion.)

The basic difference between the BFB boiler and CFB boiler is the fluidization speed. CFB has a higher fluidization speed than BFB. Compared with BFB combustor, CFB has a more uniform temperature distribution in the combustor. This is mainly because the CFB is more equally distributed with combustor height compared to BFB. Moreover, the CFB can deal with higher combustion temperature than BFB due to greater fuel quality, smaller particle size and low moisture content.

The combustion efficiency is the ability of a furnace to burn carbon. Due to better mixing of the bed mixture and smaller fuel particles, CFB has higher efficiency than BFB boiler.

CFB is more effective in sulfur removal than BFB. In CFB beds, limestone particles are more likely to collide with sulfur particles than BFB, resulting in better sulfur removal. Right now, in a CFB boiler, more than 95% of sulfur can be removed by the technology of in-bed sorbent injection.

5. PRE-FEASIBILITY ANALYSIS OF CFB WTE PLANT IN HK

5.1 Advantages of using WTE plant

Energy from waste offers recovery of energy by conversion of non-recyclable materials through various processes including thermal and non-thermal technologies. The energy that is produced in the form of electricity, heat or fuel using combustion, pyrolysis, gasification or anaerobic digestion is clean and renewable energy, with reduced carbon emissions and minimal environmental impact than any other form of energy.

Compared to Landfilling waste, Waste-to-Energy facilities offer several advantages as follow:

- Resource savings and recovery greatly expanded.
- Waste to Energy facility generates power in the form of electricity or steam.
- Waste to Energy is a Net Greenhouse Gas Reducer.
- Landfill usage and landfill expansions greatly reduced.
- Trucking of waste long distances can be greatly reduced.
- Tipping fees remain in the community where the waste is generated.
- Enhancement of community economy by creating more full-time jobs.

5.2 Regulations

Considering the pollutants that might be produced during the process of waste combustion, WTE plants are subject to the control of emission caps on four specified pollutants, namely, Sulphur Dioxide (SO_2), Nitrogen oxides (NO_x), Dioxins and Total Particulate Matters (TPM). Also, since the Chlorine (Cl) would bring corrosion to equipment, for example, the wall of stacks, we have to consider the removal of Cl.

From the Table 11, the emission control of these substances is $SO_2 < 125\ \mu g/m^3$, $NO_x < 260\ \mu g/m^3$, TPM $< 35\ \mu g/m^3$. Dioxins are not listed in the regulation, so the standard from EPA was used and dioxins should be controlled under $0.1\ ng/m^3$.

Table 11: Hong Kong Air Quality Objectives (AQOs)

Pollutant	**Limits on Concentration, ug/m^3 (Number of exceedances allowed per year in brackets)**				
	10-min	**1-hr**	**8-hr**	**24-hr**	**Annual**
Sulphur Dioxide (SO_2)	500			125	
Respirable Suspended Particulates (RSP)				100	50
Fine Suspended Particulates (FSP)				75	35
Carbon Monoxide (CO)		30,000	10,000		
Nitrogen oxide (NO_x)		260			40
Ozone (O_3)			160		
Lead (Pb)					0.5

Notes: (1) Measured at 293K and 101.325kPa. (2) Arithmetic mean. (3) Respirable suspended particulates (RSP) means suspended particulates in air with a nominal aerodynamic diameter of 10 micrometers or smaller. (Source: Air Quality Objective, EPD, 2017)

5.3 Heating Value

The heating value (or energy value or calorific value) of a substance, usually a fuel or food (see food energy), is the amount of heat released during the combustion of a specified amount of it.[15] Energy from Waste (EfW) plants are capital intensive and have high operating cost. Therefore, in order to make the concept economically attractive, revenue from recycled products is used to offset some of the increased costs. A survey of revenues for such a system shows that fuel can account for about 80% of the revenues, while ferrous metals 10%, glass 5%, and aluminum 5%. Therefore, the heating value of the fuel is a key factor for incomes. (STANLEY T.)

5.3.1 High Heating Value (HHV)

Table 12 is the HHV calculation reference value for each type of MSW in Hong Kong. The materials with higher HHVs are plastics (33959.6 kJ/kg), leather and rubber (26283.8 kJ/kg), and wood (19304.8 kJ/kg). They provide the majority heating value in MSW.

Table 12: High Heating Values

	RANGE OF VALUES		SELECTED VALUES	
Constituent	Btu/lb dry	kJ/kg	Btu/lb dry	kJ/kg dry
Paper products	7000-8000	16,282-18,608	7600	17,677.6
Plastics	11,000-18,000	25,586-41,868	14,600	33,959.6
Leather, rubber	10,000-16,000	23,260-37,216	11,300	26,283.8
Textiles	8000	18,608	8000	18,608
Wood	8000-9000	18,608-20,934	8300	19,305.8
Food waste	8000-9000	18,608-20,934	8400	19,538.4
Yard waste	6500-7500	15,119-17,445	7300[4]	16,979.8

(Source: STANLEY T.)

Take composition of MSW data of 2015 as an example, HHV of Hong Kong's MSW was calculated in Table 13. The results show that the HHV of MSW in 2015 is 19.25 MJ/kg.

[15] Heat of Combustion, Oct 30, 2018, Web Source: https://en.wikipedia.org/wiki/Heat_of_combustion#Higher_heating_value

Table13: High heating value (HHV) of dry HK MSW

Composition	Amount (Thousand Tons)	Composition (%)	HHV (MJ/kg)	HHV in MSW (MJ/kg)
Paper	824	22.22	17.68	3.93
Plastics	797	21.49	33.96	7.30
Rattan/Wood	145	3.91	19.31	0.76
Metals	86	2.32	0	0.00
Glass	134	3.61	0	0.00
Textile	112	3.02	18.61	0.56
Putrescibles	1 430	38.57	16.86	6.50
Others	180	4.85	4.2	0.20
Total	3 708	100		**19.25**

5.3.2 Low Heating Value (LHV)

The HHV for dry MSW of Hong Kong in 2015 was 19.25 MJ/kg, assume there is 45% moisture in Hong Kong's MSW since the evaporation for water is 2.26 MJ/Kg, then the LHV for MSW of HK in 2015 is 8.57 MJ/kg as shown in Equation 1.

$$LHV = \left(19.25\frac{MJ}{kg} \times 0.55 - \frac{2.26MJ}{Kg} * 0.45\right) - 1 = 8.57\ MJ/kg \qquad \text{Eq.1}$$

The "Decision Makers' Guide to Municipal Solid Waste Incineration" provided by World Bank (World Bank, 1999) indicate that incineration is applicable only when the LHV of feedstock is on the average over 7 MJ/kg and should never fall below 6 MJ/kg in any season. (Huang, 2013)

As discussed earlier, the LHV of Hong Kong's MSW is 8.57 MJ/kg, which means this relatively low LHV reached the minimum standard of 6 MJ/kg, and slightly above the average of 7 MJ/kg. The moisture content in MSW of Hong Kong is 45%. With such a low heating value and high moisture content, the CFB WTE Plant seems to be the optimum technology for Hong Kong's current situation.

5.4 R1 Formula

According to the HHV calculated earlier, Heat Losses, Turbine losses, plant consumption, and energy exported to the grid can be calculated through equation 2 to 6 as shown.

$$HHV = 19.25\,\frac{MJ}{kg}\times 2.78\times 10^{-10}\,\frac{MWh}{J}\times 10^{6}\,\frac{J}{MJ}\times 10^{3}\,\frac{kg}{ton} = 5.35\,MWh/ton \quad \text{Eq.2}$$

$$Heat\ losses = 5.35\times 0.1 = 0.54 \quad \text{Eq.3}$$

$$Turbine\ losses = (5.35 - 0.54)\times 0.72 = 3.46 \quad \text{Eq.4}$$

$$Plant\ consumption = (5.35 - 0.54 - 3.46)\times 0.15 = 0.2 \quad \text{Eq.5}$$

$$Energy\ exported\ to\ the\ grid = 5.35 - (0.54 + 3.46 + 0.2) = 1.15 \quad \text{Eq.6}$$

The result calculation of energy and mass balances are shown in Table 14 and Table 15, respectively.

Table 14: Energy balance of WTE plant

Energy Input (MWh/ton)	Energy lost or consumed (MWh/ton)	Remaining energy (MWh/ton)

Energy in waste	5.35	**Heat losses in furnace, ash, and stack gases (10%)**	0.54	**Energy exported to the grid**	1.15
		Turbine losses	3.46 (thermal efficiency of the WTE steam turbine is about 28%)		
		Plant consumption	0.2 (15% of electrical energy)		
Total	5.35	**Total**	4.2	**Total**	1.15

Table 15: Mass balance of WTE plant

Mass input (tons)		**Mass consumed during combustion (tons)**		**Remaining mass (tons)**	
Waste	1	Mass consumed during combustion	0.75	Bottom ash	0.225
				Fly ash	0.225
Total	1	Total	0.75	Total	0.225

Assume 60% of heat is being used in the factories near the plant, then R1 can be calculated using equation 7.

$$R_1 = \frac{2.6\times\text{MWh elec.} + 1.1\times\text{MWh heat}}{0.97\times\text{MWh stored in MSW}} = \frac{2.6\times1.15+1.1\times2.62\times0.6}{0.97\times5.35} = 0.91 \qquad \text{Eq.7}$$

Since R_1 is larger than 0.65, therefore, the plant can be considered as an energy recovery system. The best way of operating the plant in the real practice should be figured out since the R1 formula is purely a mathematic calculation and European standard. And this number has a close relationship with the composition of the MSW. Since the government is promoting recycling, which indicates possible composition change in the MSW, so this plant should always be operated under real situations.

5.5 Site Selection

Compared with landfills which are usually located at Greenfields far away from inhabited areas, CFB WTE plants are normally sited where they can both functionally improve nearby communities and esthetically be pleasing and attractive to visitors.

There are several factors that should be considered for the selection of the CFB WTE plant site:

- Proximity to waste generation center
- Proximity to electricity connection lines
- Proximity to district heating or cooling
- Proximity to water
- Proximity to industrial steam consumers
- Proximity to landfill (for ash disposal)
- Access roads
- Transportation
- Utilities

After considering various factors such as topography, geology, and transportation, Tai Chik Sha, Tseung Kwan, a location near South East New Territories (SENT) Landfill as the final site (Figure 19).

Figure 19: Route from Tai Chik Sha to SENT Landfill

This site also has the following advantages. First of all, considering its proximity to the SENT represented in Figures 20 and 21, one of the biggest landfills in Hong Kong, it is convenient for the bottom ash disposal after treatment. Second, considering its proximity to the sea, the cost for the utilization of water would be relatively lower. Third, Tseung Kwan O Industrial Estate, a projected electricity and heat consumer is also located nearby, the generated electricity could bring a promising revenue. Fourthly, the cost of transportation could also be relatively low due to the proximity to many places. Finally, this site is far away from the residential areas, which would meet less resistance for plant construction.

Figure 20: Location of SENT in HK

Figure 21: SENT Landfill in HK

(Source: Environmental Protection Department, The Government of the Hong Kong Special Administrative Region, February 2018)

To increase the feasibility and reliability of the site selection, the distance from plant to electric grid line and voltage/amperage requirements for connection of the plant electrical production to the grid were considered.

The voltage requirements for connection of the plant electrical production to the grid is 220V. Begin from the power plant, the voltage of electricity will change from 10kV then to 110kV and finally to 200V. As shown in Figure 22, CLP Tseung Kwan O Town Center Substation was chosen as the power plant of the CFB WTE plant, which is the nearest power plant with only a 5.8 km distance (Figure), and a 6280kJ/kg 15MW power generator will be used.

Figure 22: Location of Power stations in Hong Kong

Figure 23: Distance from SENT Landfill to CLP Power Station.

5.6 Transportation

Though the site is close to the sea, cargo shipment is not the choice of transportation. First of all, there is no suitable port for the cargo to load and discharge the MSW. Besides, the potential leak of MSW to the sea is hazardous to the marine environment. Most importantly, even if there is a suitable port, there is still a need to use other transportation to transfer the MSW from the port to plant, which would not cut down the overall cost.

The next transportation method is by train. But, with the similar problem of a cargo shipment, it will not be considered as the most convenient way of transportation.

Finally, considering the previous site selection is located at south-eastern New Territories, one of the most prosperous districts with a well-developed road network in Hong Kong, trucks would be the best choice in this case. Since collection sites are close to the WTE plants, no transfer stations are needed.

6. CONCLUSION AND RECONMMENDATION

6.1 Conclusions

Hong Kong is a city with rapid economic growth and has the freest economy in the world. It is currently the No. 2 importer of plastic waste worldwide (19.7%), and No. 1 exporter of plastic waste worldwide (26.9%). However, with China's ban on importing waste, the world's pattern of waste disposal is about to change.

Landfilling is currently the main method of waste disposal in Hong Kong. In 2015, 5.5 million tons of solid waste were delivered to landfills, including 3.7 million tons (about 67%) of MSW. Food waste (1.4 million tons), paper (0.82 million tons), and plastic (0.80 million tons) were the top three constitutions of the MSW sent to landfills. The recovery (recycling) rate from MSW in Hong Kong is relatively low, that is only 35.41% in 2015. Among the materials recovered, metal recovery (92%), paper (52%), and plastic (11%) are the top three.

Hong Kong's operating landfills are almost full, and there is no land to build more landfill sites. The MSW in Hong Kong contains high moisture of 45% and its Lower Heating Value is 8.57 MJ/kg. Both the Bubbling Fluid Bed (BFB) and Circulating Fluid Bed (CFB) technologies are well suited for high moisture content and low heating value. In comparison to BFB, CFB has a more uniform temperature distribution in the combustor and can be operated at higher combustion temperature. In addition, CFB has higher efficiency, and it is more effective in sulfur removal than BFB. Moreover, BFB is only preferred in small-scale applications. Therefore, a CFB WTE plant with a capacity of 2000 tons per day seems to be the optimum choice for Hong Kong. Tai Chik Sha, Tseung Kwan, a location near the Sent landfill in South East New Territories, is considered to be a suitable site for a WTE plant. Transportation of MSW to the CFB WTE plant will be by truck.

6.2 Major Constraints and Recommendations on Waste Recovery/ Recycling

There are many factors that hinder the implementation of sustainable waste management in Hong Kong.

(1) Public participation: although the public awareness of environmental protection has increased significantly in recent years, their willingness to actively participate in waste reduction still needs to be improved (EPD, 2012).

(2) Waste charging: according to the current situation in Hong Kong, it may not be enough to purely promote waste avoidance on environmental reasons. Waste charging is a key policy tool for avoiding and minimizing waste. By charging a certain fee for generating waste, people's waste habits and behaviors could be changed (EPD, 2012).

(3) Producer Responsibility Schemes (PRS): PRS is a key policy tool in waste management strategy in HK; this policy requires stakeholders, including manufacturers, importers, wholesalers, retailers, and consumers to share the responsibility for the collection, recycling, treatment and disposal. This measure would result in reducing the environmental impact of various products in the post-consumer phase.[16]

(4) Market Demand: There are many problems with recycled materials, such as low value, high transportation costs, and lack of market demand for recycled materials, especially glass, wood, tires and organic materials (EPD, 2012). Therefore, the government should encourage the use of recycled materials and give appropriate subsidies.

(5) Cost: high land prices and labor cost affect the economic viability of setting up local recycling facilities.

6.2 Use of the WTE plant as Visitors/Education Center

The use of a WTE plant as Visitors/Education Center has lots of benefits. It could become an excellent means for educating the general public as to the benefits of WTE and

[16] Producer Responsibility, Oct 29, 2018, Environmental Protection Department, The Government of the Hong Kong Special Administrative Region, Web Source; https://www.epd.gov.hk/epd/english/environmentinhk/waste/pro_responsibility/index.html

sustainable waste management. In fact, in many communities, public acceptance is one of the main obstacles to the construction of WTE plants. It is natural for residents who know little about the WTE technique to feel anxious about it, especially with the facilities locate near their communities.

With the help of the Visitors or Education Center, the residents could learn more about the detailed working process of the whole plant, including some specific control technologies of waste and emissions. For example, visitors might be surprised when standing in front of the huge tank of waste but smell no undesirable odor. And they would feel even safer when they get in touch with the real-time monitoring of all the emissions.

Also, both of the specialists and the public can benefit from such face-to-face communication. For the public, concerns and questions could be solved when seeing how the plant works with their own eyes. For the specialists, it is more direct and effective to further understand what the public really fears, therefore the education center and CFB WTE plant can be better improved.

Some special entertainment events and propaganda methods are encouraged to apply to increase public acceptance as follow:

- Special days to promote environmental protection, such as environmental protection day.
- Publish some posters and videos about the introduction of WTE plant to help the public better understand the knowledge of the WTE plants.
- Environmental sports meetings

In general, it's crucial to help the public realize that WTE is not only a better treatment method compared with landfilling, but also offers other benefits, such as conservation of land and reduction of greenhouse gases.

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