Janette Mäkipää

Food Waste Conversion into Biopolymers and Other High Value-Added Products in Hong Kong

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This Bachelor's Thesis was carried out at Nano and Advanced Materials Institute Limited (NAMI), Hong Kong, under the supervision of the Technical Manager Dr. Alice HO.

The aim of this study is to report the feasibility of developing biopolymers and other high-value added products from food wastes in Hong Kong. The aim has been achieved by first determining the current situation and composition of local food waste, investigating existing and emerging valorisation solutions, evaluating the feasibility of applying these technologies in Hong Kong and finally proposing recommendations. Several researches, projects and technologies used by international companies have been reviewed to provide an overall image of the possibilities, challenges and future of food waste valorisation in Hong Kong.

It is concluded that in Hong Kong it is currently not feasible to convert food waste into biopolymers or other value-added products due to several reasons. These reasons include the type of food waste generated in Hong Kong, the current recycling habit and lack of research done regarding utilization of other than single type of food waste. However, constant effort is being made to overcome these problems, and it is, therefore, justified to assume that a feasible solution will be found at any time. Until that, it is suggested that Hong Kong continues practising source separation and encouraging people to innovative thinking in food waste valorisation.

Keywords	Food waste, valorisation, biopolymer, polymers, recycling

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Tämä insinöörityö tehtiin Nano and Advanced Materials Institute Limited (NAMI) nimisessä tutkimusinstitituutissa Hongkongissa teknisen johtajan, tohtori Alice HOn, valvonnassa.

Työn tavoitteena on raportoida hävikkiruuan hyödyntämismahdollisuuksia biopolymeerien ja muiden arvokkaiden valmisteiden tuottamisessa Hongkongissa. Tämä toteutettiin ensiksi määrittelemällä paikallisen hävikkiruuan koostumus ja nykytilanne, tutkimalla olemassa olevia sekä orastavia hyödyntämisratkaisuja sekä arvioimalla näiden teknologioiden soveltamismahdollisuuksia Hongkongissa ja lopuksi suosittelemalla ehdotuksia. Useita kansainvälisiä tutkimuksia, projekteja ja teknologioita tutkimalla on saatu muodostettua yleiskuva hävikkiruuan hyödyntämisen mahdollisuuksista, haasteista ja tulevaisuudesta Hongkongissa.

Yhteenvedettynä tällä hetkellä ei ole kannattavaa valorisoida (hyödyntää) hävikkiruokaa biopolymeerien ja muiden arvokkaiden valmisteiden tuottamisessa Hongkongissa useista syistä. Näitä syitä ovat muun muassa Hongkongissa tuotetun hävikkiruuan koostumus, nykyinen kierrätystottumus ja heterogeenisen hävikkiruuan hyödyntämismahdollisuuksia koskevan tutkimuksen puute. Joka tapauksessa näiden ongelmien ratkaisemisen eteen tehdään jatkuvasti töitä, joten onkin oikeutettua sanoa että toteuttamiskelpoinen ratkaisu tullaan löytämään minä hetkenä hyvänsä. Siihen aikaan asti ehdotetaan, että Hongkong jatkaa hävikkiruuan lajittelemista lähteessä sekä kannustaa ihmisiä innovatiiviseen ajatteluun hävikkiruuan hyödyntämismahdollisuuksien tiimoilta.

Avainsanat	Hävikkiruoka, valorisaatio, biopolymeeri, polymeeri, kierrätys

Contents

List of abbreviations

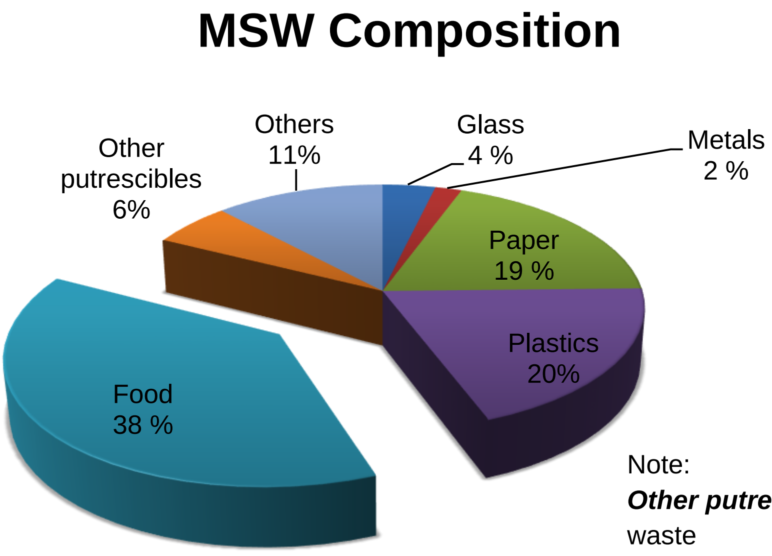
C&I	Commercial and Industrial
EIA	Environmental Impact Assessment
EPD	Environmental Protection Department
FVW	Fruit and vegetable waste
GTW	Grease Trap Waste
KBPCP	Kowloon Bay Pilot Composting Plant
MSW	Municipal Solid Waste
OWTF	Organic Waste Treatment Facility
TFA	Trifluoroacetic acid
TPS	Thermoplastic starch
UCO	Used Cooking Oil
WEEE	Waste electrical and electronic equipment

1 Introduction

Tremendous amounts of municipal solid waste are being generated and dumped of at landfills every day. The largest single category is represented by biodegradable food waste, which being landfilled results in several environmental and economic issues [1, 2]. In this chapter the current situation of municipal solid waste and food waste in Hong Kong are introduced to enable the evaluation of potential utilization possibilities and their feasibility later on.

1.1 Municipal solid waste situation

In year 2013 Hong Kong disposed municipal solid waste (MSW) of at landfills more than 3.484 million tons in total, meaning as much as 9,547 tons each day. Municipal solid waste composition can be seen in Figure 1.



Note:
Other putrescibles - Other organic waste
Others - Hazardous and miscellaneous waste, wood/rattan and bulky items

Figure 1. Composition of municipal solid waste in 2013 [1]

Figure 1 shows the composition of municipal solid waste landfilled daily in Hong Kong. **Food waste**, constituting the largest MSW category (38%), is being sent to the landfills as much as 3,648 tons per day (tpd). The second largest landfilled category is **plastics**, constituting 20% of MSW which means 1,866 tpd. Plastic waste consists of items, such as plastic bags, polyfoams, plastic bottles and packaging materials. **Paper** waste includes, for example, cardboard, newsprint, office and tissue papers, and constitutes 19% of total MSW composition, meaning 1,195 tpd. **Glass** waste such as glass bottles and **metals** waste such as aluminium cans and ferrous/non-ferrous materials compose 4% and 2% of total MSW with 353 tpd and 177 tpd, respectively. **Other** wastes are considered to hold in textile, wood and rattan, household hazardous waste and miscellaneous waste. This category fills up to 11%, i.e. 1,130 tpd. **Other putrescible** waste is composed of other organic wastes than food, such as yard waste, and constitutes 6% of the total MSW with 541 tpd.

The share of food waste out of municipal solid waste has been growing as seen in Figure 2.

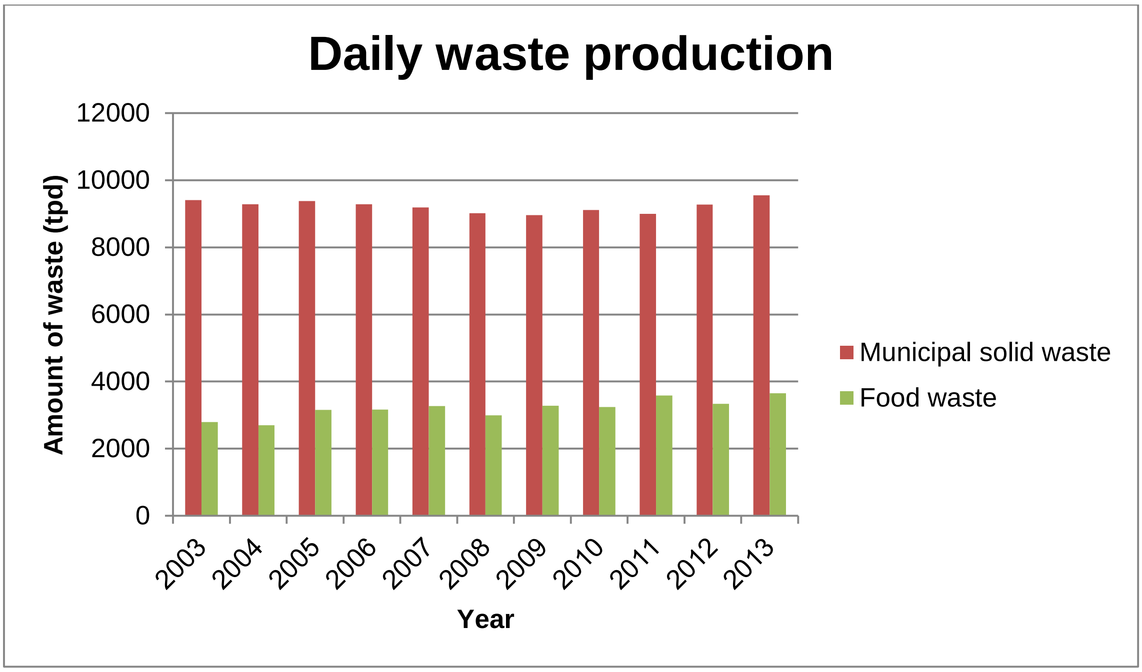


Figure 2. Daily MSW and food waste production in Hong Kong in years 2003 – 2013 [1].

Figure 2 shows the amount of daily landfilled food waste in comparison to total municipal solid waste in years 2003 – 2013 [1]. The increase in the percentage has led to thinking of alternative options for landfilling this possibly high value worth feedstock.

1.2 Food waste situation

In total 3,648 tons of food waste was disposed of at landfills in Hong Kong in 2003 [1]. Landfilling food waste is not a sustainable solution. Organic food waste decomposes easily leading to formation of environmentally harmful greenhouse gases, such as methane. In addition wastewater at landfills gets generated, which imposes several burdens on the environment. Landfilling also depletes rapidly the limited landfill space, which, at this rate, is believed to be completely exhausted by 2020 [2].

Commercial and industrial (C&I) sources, such as hotels, wet markets, restaurants, and food production and processing industries, generated 1,003 tons of food waste daily in 2013. C&I sectors' food waste production has increased dramatically from less than 400 tpd in 2002 to over 1,000 tpd in 2013 as seen in Figure 3 [1; 2].

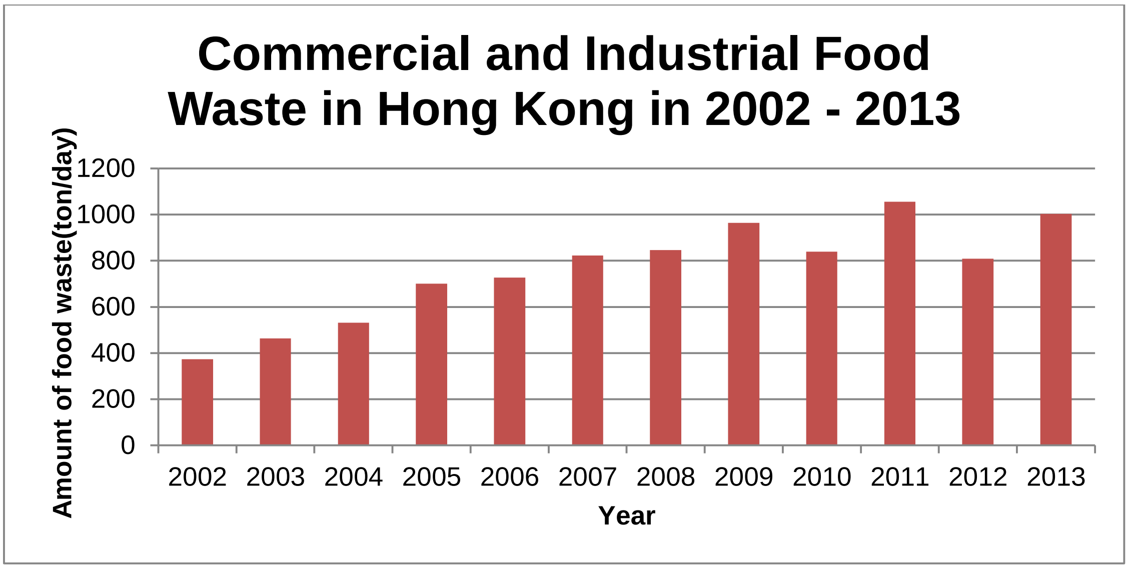


Figure 3. C&I sector's food waste generation in the past 12 years [1].

Figure 3 presents the amount of food waste produced by the C&I sector in the past 12 years. The domestic sector generates food waste nearly threefold the amount but this study focuses mostly on the food waste produced by the C&I sector due to practical reasons when considering valorisation of the food waste, such as collection of the biomass.

1.3 Food waste composition

Food waste can be divided into two general categories; pre-consumer food waste and post-consumer food waste. Pre-consumer waste consists of the food losses and wastes generated before the food meets the customer, including e.g. the unavoidable inedible parts of fruits and vegetables such as stalks, peels and other scraps. Post-consumer waste covers the served food left uneaten, having usually a very heterogeneous composition [3].

There are none investigation done regarding directly the food waste composition in Hong Kong. Thus, several aspects have to be considered when forming an overall view on generated food waste. An individual level based survey on food consumption in Hong Kong, estimations of global food losses and the traditional Chinese cuisine give some directional information about the food waste composition. Regarding the amount of research done on composition and utilization of especially fruit and vegetable waste (FVW), this study will mainly focus on that category.

1.3.1 Individual level

Hong Kong Population-Based Food Consumption Survey 2005-2007 [4] was commissioned to the Chinese University of Hong Kong by Food and Environmental Hygiene Department aiming to obtain information on Hong Kong adult population's food consumption. With 5,008 attendants aged 20-84 this research can be considered as comprehensive. Investigating food consumption some directional information about food waste generation can be obtained.

Average daily solid food intake (DSFI) was found to be 1.12 kg per person, of which cereals and grains cover more than 40% (488.75 g/day). Two thirds (60.8%) from this group consist of **rice** subgroup including rice, congee and brown rice. Pasta and noodles' subgroup covers 24.5% of cereals and grains.

Vegetable intake was nearly 16% (176.96 g/day) of total DSFI, most consumed vegetables being from leafy, stalk and shoot vegetables and brassica subgroup (68.4%) such as Chinese flowering cabbage and European lettuce.

Fruit intake was 15% (168.91 g/day) of the total DSFI, oranges (32.9%) and apples (12.7%) being the most consumed ones.

Meat, poultry and game group items, fish and aquatic animal and finally egg and egg products covered only 112.5 g/day, 70.78 g/d and 15.8 g/d, respectively.

1.3.2 Food waste preceding consuming

In addition to this survey, the food waste generated in earlier steps prior consuming must also be taken into account when forming a general view of food waste composition.

It is estimated that, globally, roughly one-third even of only the edible parts of food gets lost or wasted, meaning about 1.3 billion ton per year, throughout the food supply chain. The steps preceding fruits and vegetables arrival to consumers include agricultural production, post-harvest handling and storage, processing and distribution.

In industrialized Asia about one-fourth of generated fruits and vegetables get wasted before consumption and 15% of mass is discarded by consumers, excluding the inedible portions. This means that for each ton of fruits and vegetables produced for human consumption, about 250 kg never meet the consumer and more than 360 kg in total is lost, wasted and currently in Hong Kong directly dumped to landfills. Figure 4 presents the fruit and vegetable waste (FVW) generations at different stages.

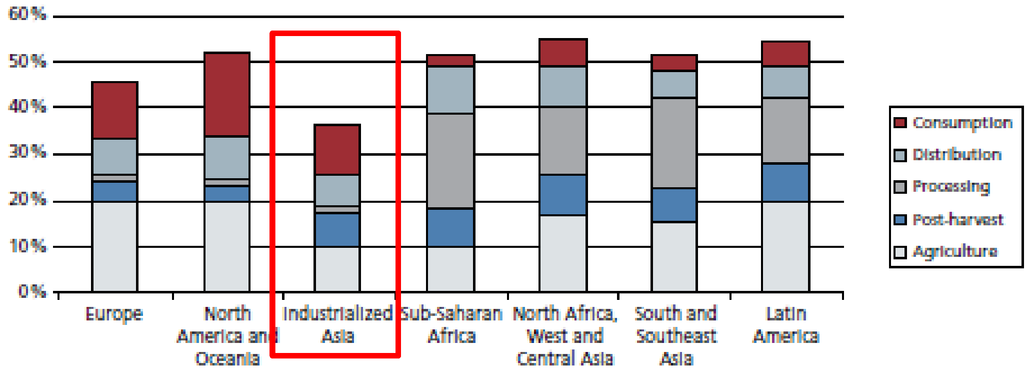


Figure 4. Fruit and vegetable wastes and losses throughout the food supply chain [5].

Agricultural production losses come up to 10% of the total biomass and consist of for example mechanical damage during harvest operation and crops being sorted out post-harvest.

Post-harvest handling and storage cause losses up to 8% due to spillage and degradation during the handling, storage and transportation processes between farm and distribution.

Processing losses, 2% of the mass derived, are caused by spillage and degradation during industrial or domestic processing. Losses may also occur due to crops being unsuitable for processing or during for instance washing, peeling, slicing and boiling.

Distribution, at which 8% of the vegetables and fruits received gets wasted or lost, include tossing in the market system, for example, in supermarkets, wholesale markets, retailers and wet markets [5].

1.3.3 C&I sector in Hong Kong

Commercial and industrial producers, such as restaurants, hotels, wet markets and other food processing industries produce more than 1,000 tons of food waste daily; yet, the composition of it is currently unknown. According to own experience gained working in a grocery store in Finland, a remarkable amount of fruits and vegetables that are in principle edible get discarded due to strict quality control. The practice can be assumed to be worldwide, resulting in tremendous fruit and vegetable losses in Hong Kong as well. Results of a Chinese research “The effect of food shape abnormality on purchase intentions in China” support the assumption. A significant decrease in purchase intentions were found when the food deviated from the norm i.e. Chinese consumers have the highest purchase intentions for normally shaped food compared to any food shape abnormality [6].

Restaurants produce different kinds of food waste in large amounts daily. Most commonly used vegetables in Chinese cuisine are bell peppers, carrots, mushrooms, zucchini, onions, scallions, celery and broccoli. Of these, the inedible portions usually consist of carrot peels, broccoli stalks and celery leaves.

Also wong bok, bok choy, gai lan, choy sum, water chestnuts, bamboo shoots and turnips are commonly used. The inedible portions of these vegetables consist of at least water chestnut peels, which are arguably removed before reaching the restaurant [7].

1.3.4 Conclusions of food waste composition

Taking into account the survey carried out at individual level, estimation of global food loss and waste extent and causes and the traditional composition of Chinese cuisine, some conclusions of the food waste composition can be drawn.

Hong Kong people seem to consume great amounts of fruits and vegetables resulting in various kinds of fruit and vegetable waste (FVW) residues throughout the food supply chain. In theory it is possible to collect and separate the losses and generated FVW from other wastes in every step. In Hong Kong the main focus can be put on the FVW losses at distribution and consumption steps since most of the fruits and vegetables in addition to products derived from them are imported from other countries. This means that the access to direct waste streams of food processing industries (e.g. apple pomace from apple juice production or potato peels from potato factories) is not granted.

In addition to high fruit and vegetable consumption, rice is also being prepared and served in large quantities resulting possibly in post-consumer food waste. When evaluating the compositions of these components on molecular level (in chapter 3.1), an idea of possible high-value added production processes can be obtained.

2 Problems and potential solutions for Hong Kong

Problems in food waste valorisation are faced in many steps of the waste management process. Food waste conversion into high-value added products starts with the source separation followed by collection, transportation and finally the processes at the receiving institution. In this chapter the problems with mainly source separation and recycling in addition to potential solutions for them will be evaluated.

2.1 Food waste recycling

2011 was the first year with any reported data of recovered recyclable food waste in Hong Kong. The quantity of recovered recyclable food waste in 2011 was 0.6 thousand tons in year, meaning only less than 0.05% from the yearly produced food waste. In 2012 and 2013 these food waste recovery rates were 0.55% and 2.15%, respectively [1]. These recycling rates are currently very low in comparison to other countries but food waste recycling is being promoted increasingly, which enables the recycling trend to grow.

There are some food waste collectors and recyclers in Hong Kong collecting e.g. used cooking oil, grease trap wastes, bean dregs, spent grain, bread and frozen seafood from restaurants [8]. One of the biggest recyclers, Biomax Hong Kong Limited, converts food waste amongst other kinds of organic wastes into fertilizer within 24 hours on site. Their digester that utilizes a technology called Rapid Thermophilic Digestion Technology can be installed in, for example, restaurants, hotels, shopping centres and food processing factories [9].

2.1.1 Food waste recycling in other countries

South Korea effectuated food recycling by imposing levies on garbage in 1998. After 2005 it has even been prohibited to send food waste to landfills. Currently, the food waste recycling rate in South Korea exceeds 90% and the levies have decreased the overall amount of food waste by more than 20%. The government has provided financial support to expand public recycling facilities transforming food wastes into compost, biomass and feed to poultry to promote recycling. The South Korean Government have invested 782.3 billion Korean won (about HK$5.6 billion) to build 17 biogas facilities and four sewage sludge drying fuel facilities by 2013. These facilities could turn up to 188,000 tons of organic wastes into fuels annually [10].

Similar results have been noticed in **Taipei**, where levies on garbage bags have been imposed since 2000, and it is mandatory for both households and industrial food waste to be recycled. As a result of this, the food waste recycling rate in Taipei has increased from 2.4% in 1999 to 44% in 2010 [11].

In **Ireland** the Waste Management (Food Waste) Regulations entered into force in 2010. In the Regulations, all major food waste producers are compelled to place the food waste into a separate bin and ensure that it is not mixed with other waste. The collected food waste is subsequently recycled by composting or by other approved recycling process. The purpose of the legislation is not only to increase recycling but also to comply with strict EU legislation. The Landfill Directive requires all EU countries to reduce the amount of waste sent to landfill sites [12]. Ireland has raised the landfill levy from EUR30/ton

(HK$260) to EUR75/ton (HK$655) and this is believed to be the cause for a significant reduction in municipal solid waste generation [13].

In **Finland** the recycling of organic waste is growing. Several producers separate food waste at source. In grocery stores, generated bread waste is separated from other food waste. Bread waste can be fed to animals whereas the other organic waste is converted into biogas and compost (method explained in chapter 2.3). On site composting is also being practiced by restaurants [14].

2.2 Food waste planning

A Food Waste & Yard Waste Plan for Hong Kong 2014–2022 (the Plan [3]) is a companion document to Hong Kong: Blueprint for Sustainable Use of Resources 2013-2022 (the Blueprint) mapping out several aspects for the food waste and yard waste management in Hong Kong provided by the Environment Bureau in 2014. The Plan includes a comprehensive strategy, targets, policies and action plans for the mentioned waste management in the upcoming years. Administration’s target of reducing food waste disposal to landfills by at least 40% in 2022, from 3600 tpd to 2160 tpd, is outlined in the Plan. Food waste is proposed to be tackled by “reduction at source, reuse and donation, recyclable collection, and turning food waste into energy”. Education and publicity are believed to be very important in food waste reduction.

It is stated in the Plan that for achieving the target of food waste reduction, Hong Kong needs to build a network of 5 -6 Organic Waste Treatment Facilities (OWTFs) with a total capacity of about 1,400 tons per day.

2.3 Source separation and sorting

Already in 1998 the 3 coloured bins collecting waste paper, aluminium cans and plastic bottles were introduced in housing estates and residential blocks in Hong Kong. A trial in 2004 of separating and collecting recyclable domestic waste (such as waste paper, metals, plastics, rechargeable batteries and old clothing, computers, electrical appliances) at source resulted in doubling the amount of recovered waste in some estates and earning even $100,000/year by selling recyclables and eventually expansion of the programme by the Government [15].

Commercial and industrial generators produce daily approximately 1,000 tons of food waste whereas domestic food waste production is more than 2,500 tons. Currently the source separation and recycling of food waste in Hong Kong is being practiced only by C&I sector in pilot scale [16]. Source separation of recyclable waste has been adopted well in the domestic sector giving some promising prediction of the possibilities of even domestic food waste recycling.

Even if everything goes according to the plans and a network of five to six OWTFs are opened until 2024, the total recycling capacity (1,400 tpd) would still cover less than half of the produced food waste (3,600 tpd) [1; 3]. This opens a great opportunity for the utilization of food waste in also other ways than energy production.

As mentioned earlier, several types of municipal solid waste are being separated at source. EcoPark in Tuen Muen strives to promote the turning of wastes into resources by returning recyclable materials to the production line and the consumption loop. Amongst the thirteen lots showed in Figure 5, two of the centres are non-profit organizations for waste plastics and waste electrical and electronic equipment (WEEE) recycling [17].

Figure 5. Different EcoPark recycling lots [17].

A greatly appreciated visit at Yan Oi Tong (Waste Plastics) and St Jame's Settlement (WEEE) on 2nd July 2015 revealed some recycling technology used. Current practice relies much on manual work but some automated processes are also being used. Labour force is used in e.g. plastic type separation and dismantling the electronic waste, as seen in Figure 6. Some automatics are used, for example, in disassembling the electric cables (Figure 7).

Figure 6. EcoPark plastic recycling employees sorting the received plastic wastes according into seven plastic categories (left picture) and a WEEE employee disassembling a computer keyboard (right picture) [18].

Figure 7. An electric cable-disassembling machine [18].

The whole electric cable disassembling machine can be seen in Figure 7, portions a – c. Electric cables are inserted into the machine (Fig. 7a) and the cables are drifted forward by the conveyor belt (Fig. 7b). Surrounding coating is cleaved during the processes (Fig. 7c) and the valuable materials, such as copper, can be separated and collected (Fig. 7d). This copper can be utilized in the production of new products [18]. Separation at source has several benefits, such as maintaining a higher quality of recyclable material and allowing the waste to be sent directly to correct processing places instead of a separating facility in between. However, people will always throw some waste to wrong bins, either by accident or ignorance.

The incorrect food waste separation can be overcome with a food waste sorter at the receiving institution. Sorting technology can be based on several aspects, such as water-based technologies that separate organic fractions from recyclables. Separation can also include manual removal of larger items in the first step, items separation by size, weight and magnetism or ultraviolet optical scanners with targeted air jet sets [19].

A recommended way to sort organic waste from inorganic waste is to use a combination of X-ray transmission (XRT) and near-infrared spectroscopy (NIR). Initial size screening and metals recovery is followed by NIR to remove different polymers. Finally compounds, such as glass and stones, are removed by XRT detector based on their atomic density. This allows also recovery of other recyclable products simultaneously [20].

2.4 Organic Waste Treatment Facility

Organic Waste Treatment Facilities (OWTFs) are, as their name suggests, facilities designed to treat source separated organic wastes that are soon to be built in Hong Kong.

The facilities will adopt biological technologies, such as composting and anaerobic digestion, which are presented in Figure 8.

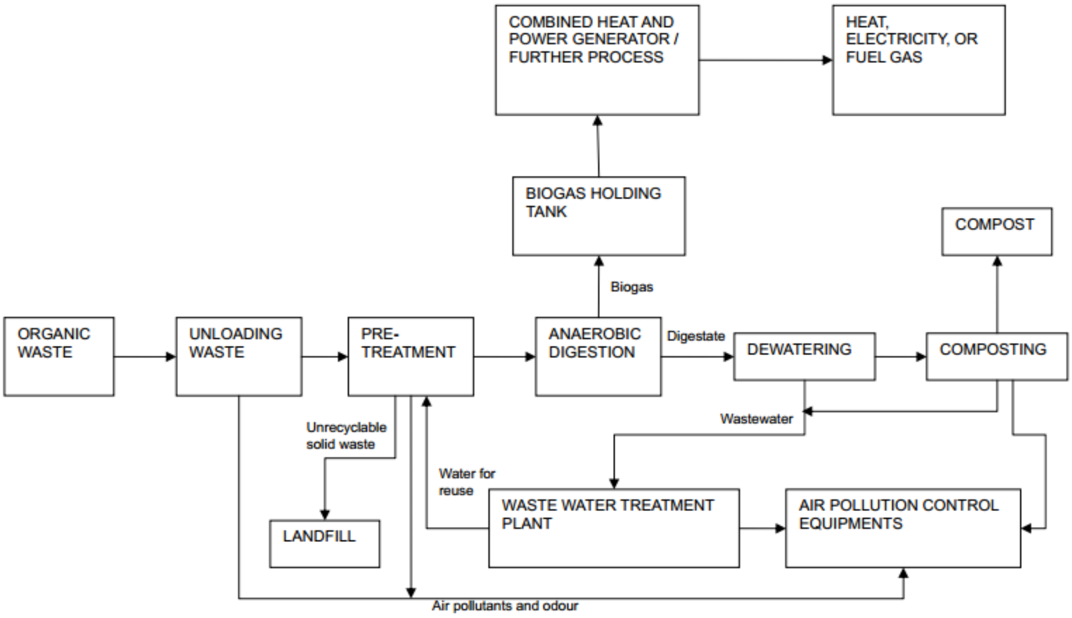


Figure 8. Process flow of the production of energy and compost from organic waste at OWTF [22].

The received organic waste will get pre-treated to remove the unrecyclable solid waste and to prepare the biomass for fermentation. Anaerobic digestion takes place with the help of microorganisms resulting in digestate and biogas. Digestate is dewatered and composted yielding compost for soils, while biogas is further processed to yield heat, electricity or fuel gas [21].

The Environmental Protection Department (EPD) plans to develop OWTFs in phase and aims for a network of five to six OWTFs until 2024 with the total recycling capacity of 1,300 – 1,500 tons per day. Building of these facilities is a Government-funded Design-Build-Operate (DBO) project.

In 2011 the first facility, OWTF1, was expected to be open in late 2014 [22]. Currently it is expected to start operation in 2017 with the daily treatment capacity of 200 tons of source separated organic waste daily. Its estimated surplus electricity production is 14 million kWh, being equivalent to electricity used by some 3,000 households. The first phase will be constructed at Siu Ho Wan, receiving its organic wastes from Lantau Island, Tsing Yi, Tsuen Wan, Kwai Chun and West Kowloon. The feasibility study and Environmental Impact Assessment (EIA) have already been committed for Phase 1 [21].

The second facility, OWTF2 is planned to start operations at Sha Ling, receiving the wastes from Sheung Shui, Fanling, Yuen Long and Shatin. EIA has been committed and it has to be taken forward expeditiously using the established DBO arrangement.

The third facility, OWTF3 is expected to be opened around 2021 at Shek Kong. EIA for OWTF3 needs to be taken forward as quickly as possible. OWTF1, 2 and 3 will therefore cover most of New Territories and West Kowloon.

EPD underlines that it welcomes private sector to participate in the development of further OWTFs. EPD states to be “very open to options and proposals either on sites identified by the Government or other sites proposed by the private sector” [3].

2.5 Existing technologies to solve the current problems

Several things have already been done to promote the food waste recycling and utilization of the produced waste biomass in Hong Kong. Some of the approaches and technologies are introduced below.

2.5.1 Guidelines for C&I sector

The government has published general guidelines for source separation and recycling of food wastes individually for food and catering industries, wet markets, hotels and shopping malls. These directions are stated to provide food waste generators information and assistance on the avoidance, source separation and recycling of food wastes. Sectors are asked to train, assist and encourage their staff to practice source separation. It is suggested that for example several small-sized recycle bins shall be placed in different locations (near the chopping board at restaurants and wet markets’ chopping blocks), that the filling of the bins should be monitored regularly and that the bins should be labelled properly to make the source separation easy. Source separated food waste is promoted to be recycled to produce compost or animal feed and in future to be sent to the OWTFs. Some C&I sectors are also suggested to consider the installation of small on-site waste treatments machines to reduce the amount of waste for disposal [23].

2.5.2 UCO and GTW collection

The separation and selling of used cooking oil (UCO) and grease trap waste (GTW) to collectors are already being practiced by several restaurants. UCO is being separated from other forms of kitchen waste while GTW is being collected by specialized collectors from the grease traps, which are mandatory for all commercial kitchens [3]. No statistics on UCO generation in Hong Kong are available but the estimation is that it is being somewhere between 16,000 and 20,000 tons per year. Collected UCO and GTW can be exported or sold to local biodiesel manufacturers. Collectors offer restaurants and food businesses HK$2,000-5,000 per ton of UCO whereas local biodiesel manufacturers pay HK$4,000 per ton [16]. Oil from UCO and GTW gets extracted for biodiesel production and wastewater gets treated to required environmental standards [3]. This process stands as a good example showing that commercial and industry producers are capable of separating food waste at source.

2.5.3 Food waste recycling partnership scheme

Food Waste Recycling Partnership Scheme [24] is a 3 years lasting scheme launched by EPD together with C&I sectors in 2009. The purpose of the scheme is to “promote good food waste management practice and to gain experience on food waste source separation and recycling”. Each year around 12 public or private corporate participants are invited to practice source-separation of food waste. This food waste, collected by EPD, is transported to the Kowloon Bay Pilot Composting Plant (KBPCP) for recycling.

2.5.4 Kowloon Bay pilot composting plant

Kowloon Bay Pilot Composting Plant (KBPCP) is a pilot composting plant located at the Kowloon Bay Waste Recycling Centre developed by EPD in 2008. The purpose of Pilot Plant is to accumulate experience and information on both collection of source separated food waste and the biological technology application to recycle food waste in Hong Kong.

The treatment process consists of four steps: pre-treatment, composting, curing and post-treatment of the final products (mainly compost), which can be seen in Figure 9.

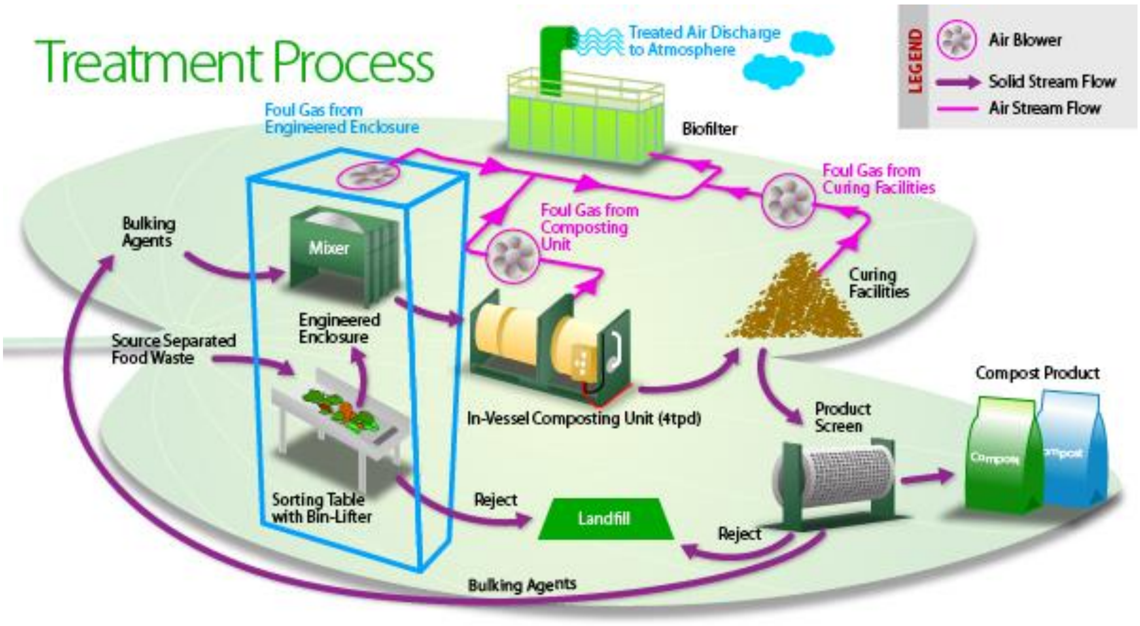


Figure 9. Treatment process of the food waste at Kowloon Bay Pilot Composting Plant [25].

Firstly, the delivered source separated food waste is pre-treated by manual sorting to remove bigger inorganic objects and draining of excessive water. To achieve optimum moisture content and porosity bulking agents (such as bark chips and saw dust) are added. Mixing is followed by feeding the waste to the composting drum units, where biological bacteria action takes place to decompose the food waste. After 10 days' decomposition, the premature compost undergoes a 30 days curing period on the curing pads to ensure complete decomposition. Finally the mature composts undergo through a post-treatment process, meaning that the bulking agents and possible contaminants are removed before packing the product for delivery to the users. Compost products' possible uses are landscaping and production of fruits and vegetables.

The total yearly treatment capacity is 500 tons of food waste feedstock and approximately 50 tons of compost products can be produced by this in-vessel composting technology [25].

2.5.5 High protein feed from food waste

South China Reborn Resources (Zhongshan) Co., Ltd. is a company located in Zhongshan, Guangdong Province, with a fully computerized and automated product line focused on the reutilization of residual resources from solid and liquid wastes. Automated technology removes the need for manual operation, i.e. labor force, consequently enabling the staff to concentrate on other challenges, such as research and development of the processes and future challenges.

Food waste received goes through the production line, where wastewater and oils and fats get separated from the remaining food waste. Wastewater undergoes wastewater treatment, extracted oil and fat are treated separately to produce biodiesel and remaining food waste is converted into high protein content feed. This high protein base material is utilized to manufacture various kinds of livestock and aquatic feed [26].

2.6 Concluded solutions

Even though the current situation of recycling and utilizing organic waste in Hong Kong is not bright, the future of it seems optimistic. The Government is investing money on promoting the food waste reduction and recycling which arguably will increase the recycling rates. Although various programs and educational campaigns to promote food waste reduction have been initiated and supported by the Government over the past years, it is good to note that not all of the food waste is avoidable; even if the waste problem managed to be tackled as stated in the plan, some waste will always be generated due to for example inedible parts of fruits and vegetables.

UCO & GTW collection in addition to general guidelines on source separation and Food Waste Recycling Partnership Scheme are great examples showing that commercial and industrial waste producers are capable of replacing the old habit of discarding food waste into municipal solid waste with separating it at source. Moreover, based on the worldwide popularity of source separation in addition to own experiment gained in food industry sector, it is justified to state that separating food waste at source does not require extra time or effort once it has become a habit.

Regarding the wanted end product, an automated sorting process at the receiving institution should be considered to overcome the human error in source separation.

3 Food waste into biopolymers and other products

Food waste results from the production, preparation and consumption of food, posing increasing severe pollution problems, in addition to representing a loss of valuable biomass and nutrients. In the last decade the interest in alternative use of waste streams beyond disposal or fertilization has increased drastically. New methods and policies for waste handling and treatment have been introduced in the last few years regarding the recovery, bioconversion and utilization of valuable constituents from food processing waste. Desirable modification methods for the applications are economically attractive and simple [27].

Nearly 90% of vegetables' and fruits' dry matter is composed of carbohydrates, of which 75% is sugars and hemicellulose, 9% is cellulose and 5% is lignin [28; 29]; whilst, the major plant biopolymers with largest application possibilities are cellulose and starch. Thus, the main focus of the feasibility study would be on cellulose and starch [30].

3.1 Molecular contents of the food waste

As mentioned earlier, oranges are being consumed widely in Hong Kong. Nearly half (44%) of oranges weight mass is constituting of the citrus peels, composing of 40% of cellulosic materials. Oleic acid and palmitic acids are found on the peel surface as free fatty acids [31]. Pineapples, which can be prepared as desserts or concluded in the main dish, in turn constitute 60% of pure waste materials; 21% foliage, 33% peel and 46% other wastes. Main components of the peel are cellulose (70%) and lignin (16%) [32]. A mixed stock of vegetable and fruit waste, consisting of equal quantities of apple, banana, carrot, potato and lettuce, was found to contain hemicellulose, cellulose and lignin fractions 19.2%, 3.9% and 1.0%, respectively [33].

Rice contains nearly 80% carbohydrates of which more than 95% is in the form of starch [34]. In conclusion cellulose and starch are available abundantly in food waste produced in Hong Kong.

3.1.1 Cellulose

Cellulose is the most abundant renewable polymer in nature possessing an ideal structure for the formation of strong fibres. Cellulose is a crystalline un-branched polymer with a straight chair conformation consisting of 1,4-linked β-D-glucose units [35]. The structure is held together by hydrogen bonds between hydroxyl groups of adjacent chains (Figure 10).

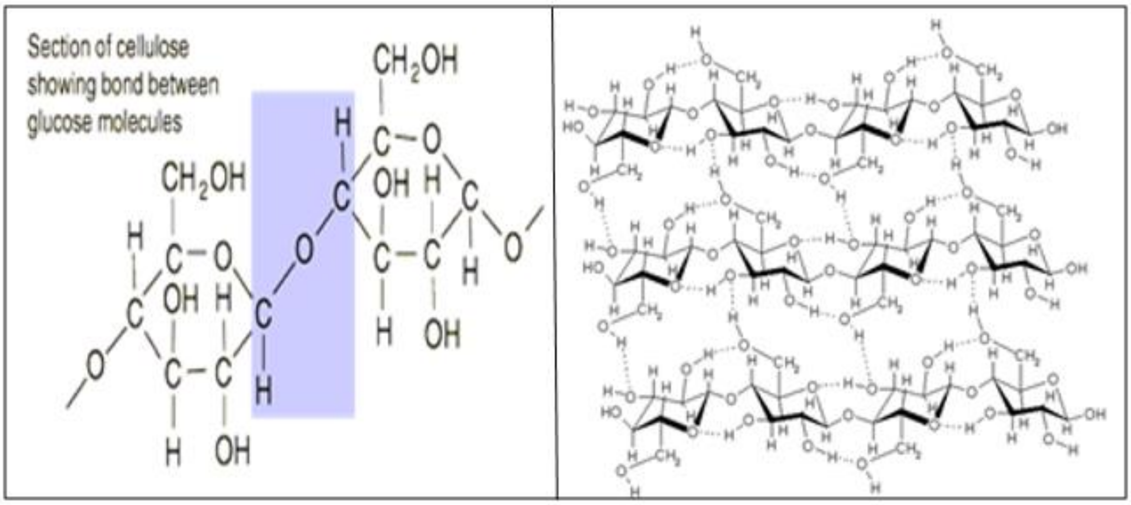


Figure 10. Cellulose structure. Two glucose units (left) and cellulose intermolecular structure (right) [36; 37].

The highly structured intermolecular hydrogen-bonding network results in the recalcitrance of the biomass, i.e., problems from the biopolymer producers' point of view [38; 39]. As the theoretical melt temperature is above the degradation temperature, cellulose is not thermoplastic and therefore cannot be heat sealed [40a]. Cellulose can be decrystallized by strong mineral acids, certain polar solvents, swelling agents or mechanical treatment. However, these processes require expensive reagents and/or high energy costs and thus are not feasible. This is why focus has been put on overcoming the recalcitrance with a new method meanwhile utilizing cellulose mainly in its derivative forms, such as esters and ethers [38; 39]. Ester and ethers yield nitrocellulose, cellophane, carboxymethyl-cellulose, tencel fiber and cellulose acetate. Derivatizion can be accomplished by treatment with short chain fatty acids (such as acetate, propionate and butyrate) [30].

3.1.2 Starch

Starch (Figure 11) is the second major agricultural commodity being the cheapest and easiest to handle biopolymer. Starch consists of α-D-glucose units that form amylose and amylopectin polymers. The ratio of these polymers varies depending on the source type, for instance potato starch is made up of 20% amylose and 80% amylopectin [41].

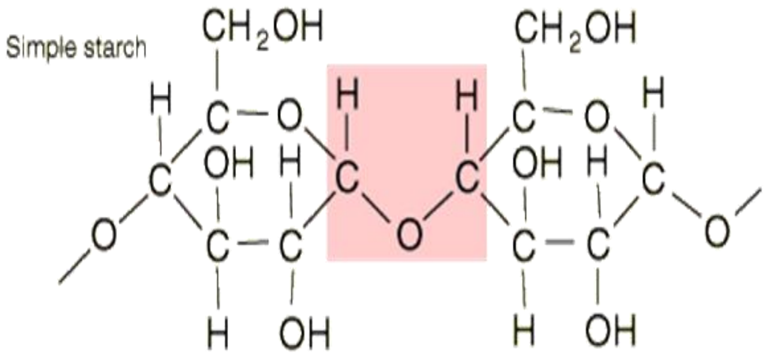


Figure 11. Starch structure [36].

Starch is utilized in bioplastics production by a range of small and large companies worldwide, such as Novamont, BIOP Biopolymer Technologies, Biotec, Rodenburg Biopolymers, Green Light Products, National Starch and Chem and Earthshell [30]. The starch crops used include corn, wheat, potato, tapioca and rice. Currently, the predominant raw material for the production of starch polymers is corn, but for instance the European companies BIOP Biopolymer (Germany) and Rodenburg Biopolymers (the Netherlands) both utilize potato starch, Rodenburg Biopolymer receiving its biomass directly from a local potato processing company's waste stream (e.g. peels, which are considered as waste at the factory) [40b]. In starch-based bioplastics starch is fully utilized with a yield of close to 100% whereas in starch-derived bio-plastics the yield is only 45%. Starch-derived bio-plastics are synthetized from monomers and require more complex processes, such as fermentation of glucose syrup, providing therefore less efficient use of resources [42]. Starch polymer production technologies are introduced in Figure 12.

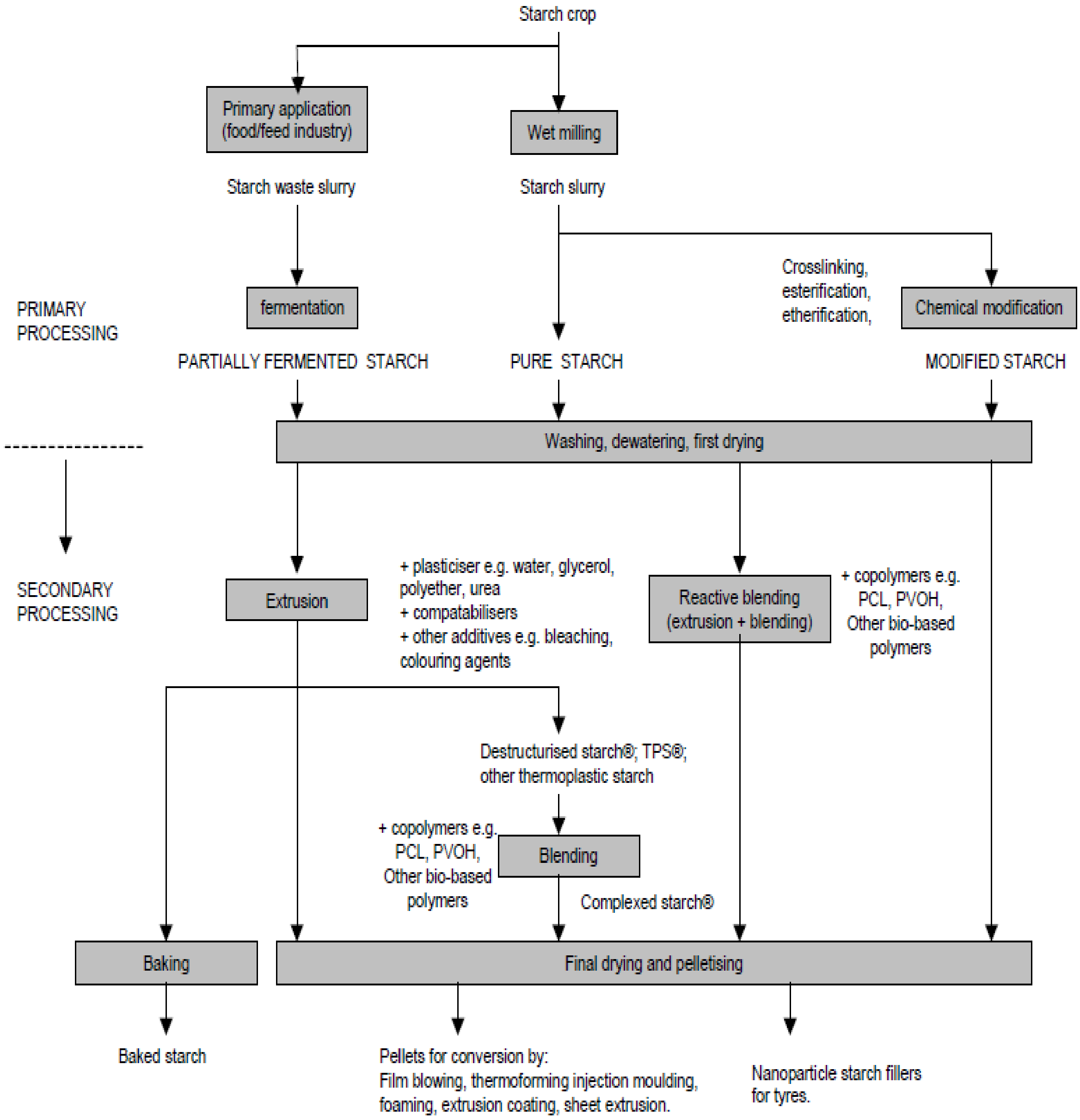


Figure 12. Starch polymer production technologies [40b].

After the first drying step, a secondary processing stage may be identified. When starch is complexed with other co-polymers, the result can vary from a plastic as flexible as polyethylene to one as rigid as polystyrene [40b]. Thermal processing of starch results in thermoplastic starch (TPS), possessing thermo-plastic like processability with temperature and shear, while having similar properties (linear and branched structures, molar mass, glass transition temperature, plasticizer modification, crystallinity and melting temperatures) than any other polymer [43]. TPS is mainly used in industry to produce diapers, cardboard paper, fabrics, plastics, plaster, detergents, assist in water treatment, oil drilling and filler for tires. Drawbacks of TPS include it being mechanically weak, brittle, sensitive to moisture and retrogradation, interacting poorly with plasticizers and hydrophobic polymers, having slow production rates in plastic film equipment and being suitable for only short life applications. Drawbacks have been tried to overcome with several property-improving attempts, such as chemical derivatization (e.g. introduction of ester and ether-groups), using a water-barrier coating for films or blending TPS with biodegradable hydrophobic polymers [30].

3.1.3 Proteins

Fruit and vegetable wastes are in general known to have low protein content. However, it is estimated that the amount of protein co-products from future large-scale biofuel production is increasing, resulting in the development of protein-based bio-plastics industry. Thus the protein based biopolymer production is introduced briefly.

Plastics and resins, which can be derived from natural plant proteins, are usually based on zein (corn protein), soy protein and gluten from wheat. Biopolymer and bio-plastics production from these sources are presented in Table 1 [30].

Table 1. Protein co-products potentially available for the production of bio-plastics or biopolymers [30]

Protein	**Total crop harvest (t/year)**	**Protein content (%)**	**Use of protein as material**	**Price and volume**
Zein (maize)	692×10e6	4	Films, bio-plastic, fibres	800–1600 HKD/kg, <1000 t/year
Soy protein (Soy bean)	209.5x10e6	38–45	Films, extruded foams, injection molded products	Price slightly higher than conventional plastics
Gluten (wheat)	626x10e6	9–15	Films, coatings, bio-plastics, resins	Not available

Protein-based bio-plastics have also been studied as potential medical and food packaging applications due to their antibacterial properties. However, several objects, such as the water and oxygen vapour permeability properties, as well as the examination of addition of different materials to the bio-plastic blends, need to be further studied before scaling up. Large-scale use of gluten and soy protein that theoretically are extractable from Hong Kong food waste in bio-plastics production is currently not feasible [30; 44].

3.2 Energy

Waste utilization is the most economical process for the production of renewable energy, such as biogas, hydrogen and bio-hydrogen [45].

Biogas is the main product of anaerobic digestion process composing mainly of methane and carbon dioxide. Biogas is used as a renewable fuel for power and heat production and the secondary product from the process can be directly used as soil fertilizers or after a drying treatment even as fuel for energy production. Fruit and vegetable wastes (FVW) are highly suitable for anaerobic digestion due to their quick degradation based on contaminating microbes. FVW digestion has mostly been examined only in laboratory scale reactors (max. size approximately 20 L) [46].

Bio-hydrogen can be produced from food waste and food processing waste by means of anaerobic degradation. In general the biohydrogen is a result from carbohydrate degradation through acidogenesis and acetogenesis. The process is highly sensitive to certain environmental factors, such as food waste concentrations, inoculum sources, volatile fatty acids, hydrogen partial pressure, temperature and pH. Producing bio-hydrogen from mixed food waste that contains carbohydrates, fats, cellulose and hemicelluloses have different metabolic pathways, which have not yet been studied in detail. Bio-hydrogen production overall is prohibitively costly and utilizing food waste could bring the processing costs down. However, further research and process developments are required [45].

Biofuel for transportation uses can be produced by purifying biogas to remove carbon dioxide and other impurities, such as hydrogen sulphide, water, particles and siloxanes. Refined biogas is completely equivalent to fossil-based gas in respect to properties and can thus replace the traditionally used gas [47].

PlasCarb is an EU-funded project aiming to transform biogas into high value graphitic carbon and renewable hydrogen. High-value products, such as graphene and new type of bioplastic, can be produced from graphitic carbon and hydrogen, respectively. A low energy microwave plasma process is able to split the methane from biogas without CO_2 emissions. The project was launched in 2013 and is due to end in late 2016. So far food waste has already been reported to successfully transform into graphite and graphene [48].

Lithium-ion battery (LIB) materials have recently been obtained from food wastes on laboratory scale. Rice husks and corn stalks were valorised to yield silica or porous LiFePo4/C nano-sheets for LIB-anode and cathode materials, respectively. The performances of LIB materials produced from agricultural wastes were found to be competitive to the ones produced in traditional ways. Drawbacks of the processes are high temperatures (750–850 °C), low conversion rates (7.7% for silica) and lack of research [49; 50].

3.3 Glass

In 2013 Colorado School of Mines materials engineers developed a method to convert food waste into glass. The fine white powder resulting from garbage grinding and pounding contains pure minerals, such as silica and oxides. The silica powder melts into molten red substance at 1,650 °C (3,000 °F) that morphs to glass when poured into molds [51]. There are also patents regarding the production of glass from organic waste streams [52].

Glass production from food waste removes the need for heavy digging and use of toxic chemicals in mining to obtain silica and oxides, which are required for glass formation. Downside of the process is extremely high heating temperature, which currently cannot be avoided in glass fabrication [51].

3.4 Plastics

The production of plastics has grown dangerously from 100 million tonnes per annum (mtpa) 20 years ago to 200 mtpa 10 years ago and finally reached 288 mtpa in 2012 worldwide [53]. Being non-biodegradable yet breaking down over time into toxic micro-fragments that leach easily into the surrounding ecosystems has forced the research efforts towards innovative and economical fabrication of environmentally degrading plastics [54]. A direct conversion route of food waste into bio-plastics was introduced very recently whereas indirect routes have already been used on industrial scale by several companies worldwide.

3.4.1 Direct transformation

Bayer, I. S., et al. [38] introduced a novel method allowing the direct transformation of edible vegetable waste into bio-plastics. In this study wastes of spinach and parsley stems, rice hulls and cocoa pod husks were digested in trifluoroacetic acid (TFA), casted and evaporated resulting in the formation of amorphous cellulose-based plastics. Cellulose recalcitrance is overcome with the TFA-treatment based on the de-crystallization in cellulose and spontaneous regeneration of substituted OH-groups. The research stated that depending on the cellulose source (food waste type) used the biopolymers produced obtain diverse properties. These properties include mechanical properties ranging from soft and stretchable to brittle and rigid. Conversion rates were not announced but the nondissolvable portion can be valorised by redispersing in TFA resulting in residual film suitable as feedstock for enzymatic plant waste processing for instance.

Cellulose can be treated with other F-containing compounds to achieve de-crystallization and highly hydrophobic and lipophobic polymers. Such compounds are 3,3,3-trifluoropropionic (TFP) and pentafluorobenzoic (PFB) acids, as seen in Figure 13 [55]. TFA is currently the only compound of these that is known to successfully convert food waste directly into bio-plastic. Pilot-scale trials would require further research on e.g. effects of expired TFA digestion if a mixed waste feedstock is used and a proper design of a closed loop process system to reclaim TFA vapours by condensation or distillation [38].

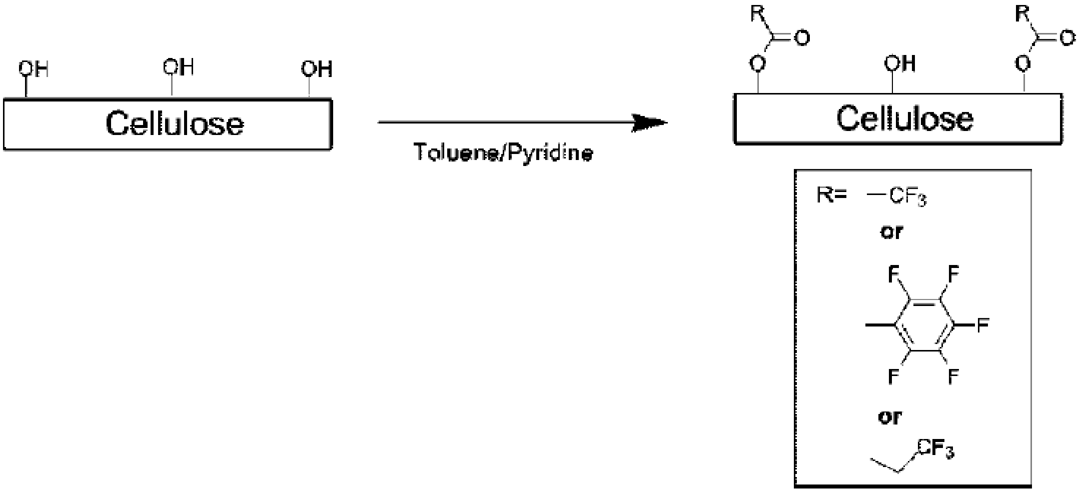


Figure 13. Hydrophobization and lipophobization of cellulose fibers with TFA, TFP or PFB [55].

3.4.2 Indirect transformation

Food wastes are utilized in the production on bio-plastics by several companies and the topic is constantly being further researched to develop even more cost-efficient and environmental friendly production processes. Bio-plastics, other than the ones converted directly from biomass, can be produced conceptually in three ways, which are shown in Figure 14.

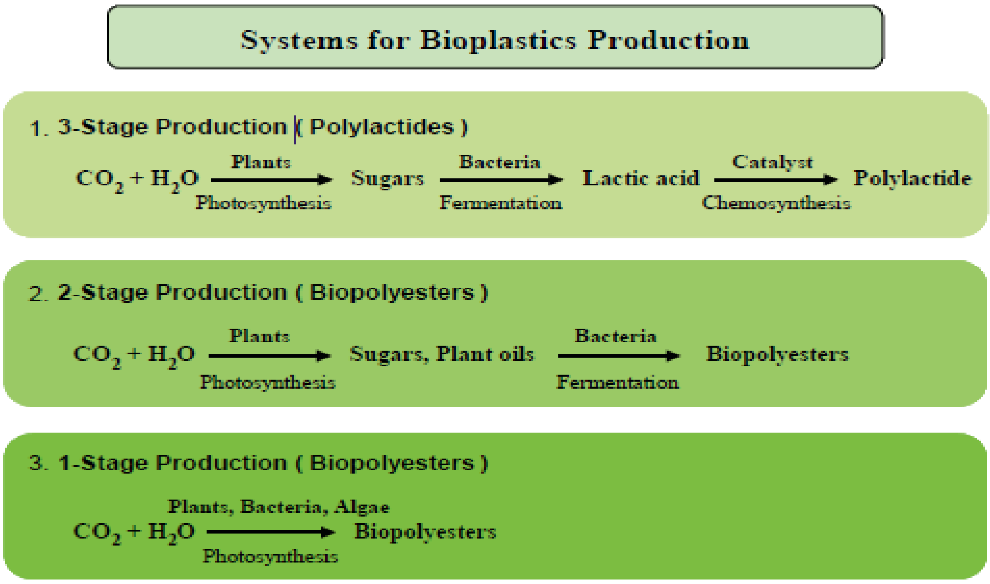


Figure 14. Systems for the production of materials by bioengineering [56].

In a three-stage process feedstock is harvested, refined to yield sugars, fermented to yield subunit monomers and chemically processed to form the polymers that will finally be molded into plastic parts. Polylactide production will be described in details shortly.

Two-stage production uses plant sugars as substrates to support growth of bacteria. Polymeric materials are directly synthetized by bacteria to store their own excess energy. Many materials produced from, for instance, soybean and other plant oils are produced like this.

In single-stage production the material of interest is directly grown within the plant. This technology holds great promises for additional environmental benefits, and it is, currently, being pursued by Metabolix Inc for PHA production. Single-stage production requires genetic engineering and separation of product polymers from plant tissues, and it is the most futuristic option of the three technologies [56].

Some of the most commonly produced bio-plastics and their production routes are introduced below.

PLA, polylactic acid, is a biopolymer potential to replace cellophane and polyethylene terephthalate (PET) in transparent packaging [56]. PLA production requires fermentation of sugars (dextrose, glucose or fructose) that can be harvested from starch. World's biggest bio-PLA producer NatureWorks LLC produces 140,000 tons of PLA per year which goes under the product name "Ingeo®" [57]. Simplified flow diagram for the manufacturing process is schematized in Figure 15.

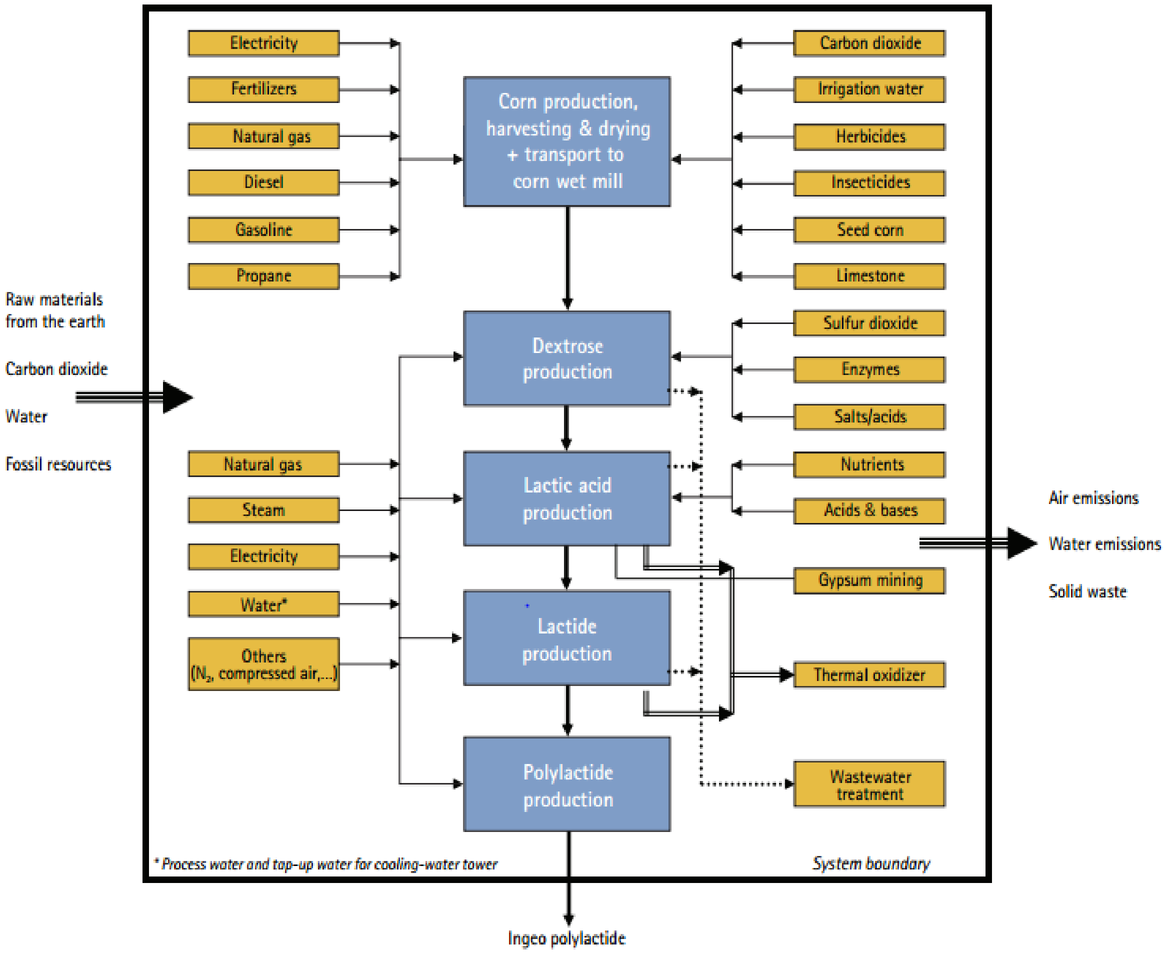


Figure 15. Flow diagram of the manufacture of Ingeo polylactide biopolymers by NatureWorks [57].

NatureWorks derives its sugar, dextrose, from field corn. Sugar is fermented to lactic acid by microorganisms. Lactic acid is then dehydrated into cyclic lactide through dimerization followed by its polymerization to polylactic acid [57; 58; 59]. Formed long PLA chain is usually transformed to pellets to increase the value before selling it further to partners who apply it in for example serviceware, food packaging, durable goods and home textiles [57]. Zheijan Hisun Biomaterials (China), BioAmber (Canada) and BASF SE (Sweden) are also important PLA/PLA-blend producers. PLA is also one of the most commonly used desktop 3D printing materials [60]. As 3D printers are becoming more accessible and popular, a more cost-efficient and simple method for bio-PLA production can assumed to be developed in the future [61].

PBS, Polybutylene succinate, is produced bio-based with **succinic acid** and 1,4-butanediol (BDO), which can be derived from succinic acid [62]. Succinic acid is produced petrol-based hydrogenating petrochemical maleic acid or anhydride catalytically. Bio-based route consists of fermentation of starch-derived glucose using natural producers or engineered organisms. The School of Energy and Environment of City University of Hong Kong introduced a promising method to convert mixed food waste into succinic acid with the help of some fungus and bacteria. With this method it was possible to reach the yield of up to 240 kg of succinic acid per 1000 kg of food waste, utilizing the by-products as soil fertilizers [63]. BioAmber is a Canadian company producing 30,000 tons of succinic acid from corn farming per year. This factory was being built at a cost of $125 million, preceding a large-scale demonstration facility in France from 2010 to 2014 using a 350,000 liter fermenter. Produced succinic acid is sold to customers utilizing it to make variant products, such as paints, artificial leathers, food additives, nylons, biodegradable plastics and pharmaceutical compounds [64].

Bio-PE, Bio-polyethylene, can be obtained from starch. General production route consists of fermentation of naturally derived sugars to synthetize ethanol, dehydration of ethanol to yield ethylene and classical polymerization reaction of ethylene into polyethylene [65]. Braskem’s bio-PE production begins with crushing starch-rich sugarcane crop to obtain sucrose. The sugar juice is fermented and distilled to produce ethanol at the distillery, followed by the dehydration process in which the ethanol is transformed in ethylene. Formed ethylene is polymerized in polyethylene production units, which are then transformed into final products [66]. Conversion rates for Bio-PE production with this method are low; glucose – ethanol 48% and ethanol – ethylene 48% [58].

Bio-PET production is a complex multi-step process, as seen in Figure 16, beginning with starch. In summary, after hydrolysis the glucose is fermented in two different tanks to gain ethanol and isobutanol. These are further processed into MEG (mono-ethylene glycol) and PTA (purified terepthalatic acid), respectively, and then esterificated and polycondensated to obtain bio-PET [58]. Generally PET consists of 70% PTA and 30% of MEG. PET is traditionally used to produce plastic bottles and currently a bio-PET bottle costs 30–40% more to produce. Another drawback in bio-PET production is the additional step of converting bio-ethanol to ethylene. Bio-based route may also involve more steps than oil-based in the PTA production, leading to increased energy costs and possible emissions [67; 68].

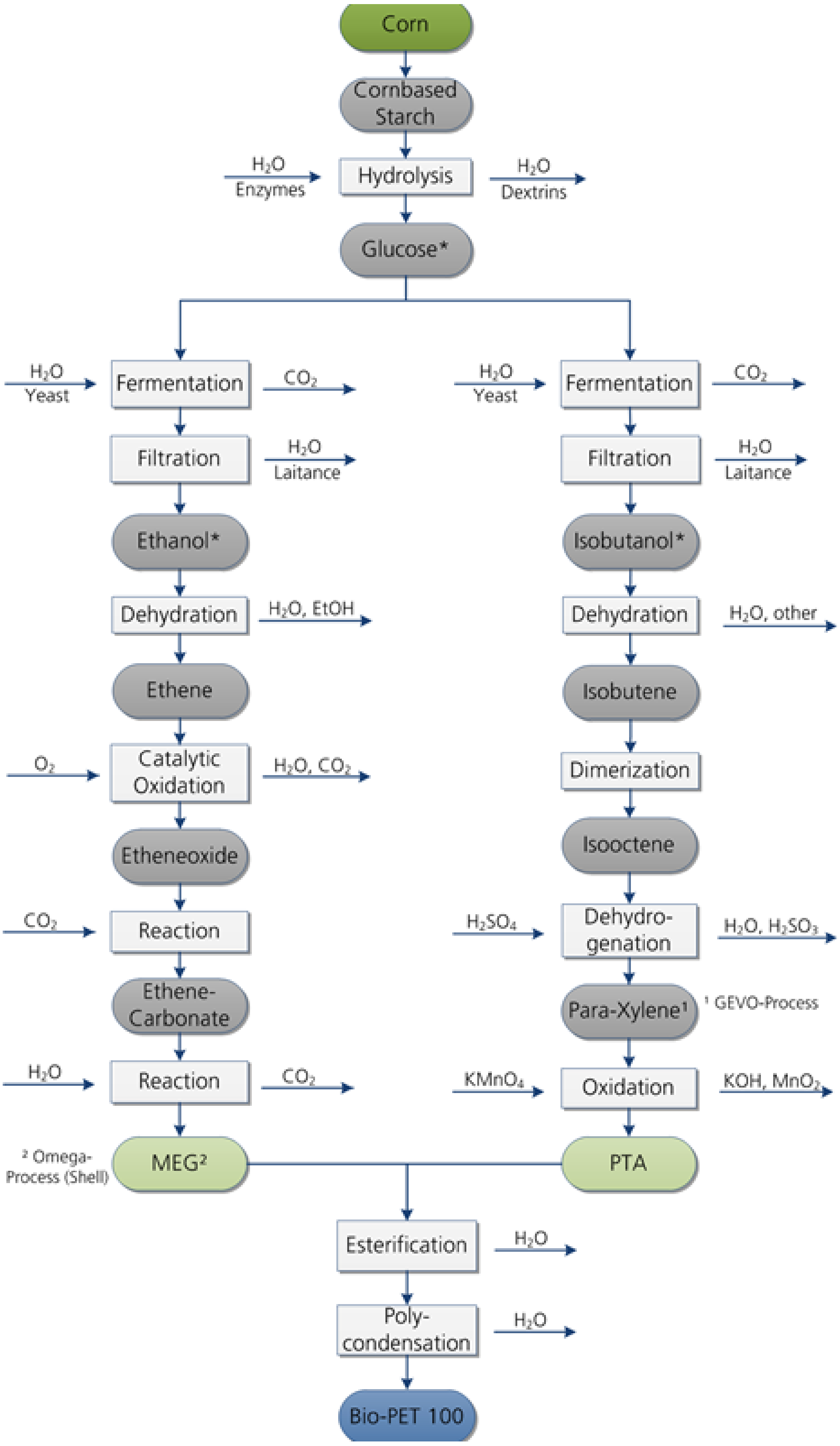


Figure 16. Bio-PET production route [58].

Adipic acid is the most important aliphatic dicarboxylic acid in the chemical industry. Its esters are used as plasticizers and lubricants. Nearly 90 % of the domestic U.S. adipic acid is used in the polymerization reaction to form nylon-6,6, thus making the production rates closely correlated with nylon consumption trends [69; 70]. Nylon-6,6, premium nylon fiber, can be applied in, for example, carpet fibers, apparel, airbags, tires and hoses [71].

Vardon D.R., et al. introduced an environmental friendly route of adipic acid from lignin. Ligning-derived compounds will first be biologically processed to enable conversion into *cis,cis*-muconic acid. This muconic acid will then be separated from the biological culture followed by catalytically converting it to adipic acid [72].

BioConSepT (Bio-Conversion and Separation Technology) is a four years lasting (2012-2015) project funded by the Knowledge Based Bio Economy Project of the EU, aiming to deliver processes that convert 2nd generation lingocellulosic biomasses and non-edible fractions of fats and oils into valuable chemicals. Lignocellulosics are pretreated and saccharized to sugar polymers and monomers whereas fats and oils are pretreated and hydrolized to fatty acids and glycerol. These routes must be 30% cheaper and 30% more sustainable than the corresponding ones derived from 1st generation feedstock, such as glucose. Some key findings regarding the end uses, feedstock and potential versus capacities in utilization of 2nd generation feedstock have already been established. The intermediates with biggest chances to have real success have estimated to be bio-adipic acid, bio-acrylic acid, bio-furmaric acid, bio-succinic acid mainly by BDO (1,4-butanediol) PBS and FCDA (2,5-Furandicarboxylic acid) mainly by PET. The flexibility of feedstock is seen as an advantage. However it is good to keep in mind that even if the mass production was able to start very soon it would still take at least 10 years for the bio placed platforms to replace even a small part of petroleum based market [73].

3.4.3 Innovative transformation

If already existing technologies for biopolymer production are wished to be utilized, a method for refining simple sugars from mixed food waste streams must be invented. Such method must take into consideration varying sugar contents (for instance, concentration and monomers) of different units in the mixed heterogeneous biomass.

Some other methods for deriving bioplastics from food waste have also been found. In 2013 a sixteen-year-old student, Elif Bilgin, won Google Science Fair for developing a chemical process that converts banana peels into bioplastics. Peels are dipped in sodium metabisulfide solution, following by being boiled and pureed. Paste is molded into a Petri dish and heated resulting in a bioplastic product [74]. Also Hong Kong Chinese Women's Club College reported a successful production of green plastics using food wastes, such as bread, rice and jelly with simple, safe and environmentally friendly methods [75]. Inventions like these show that the solution for conversion of mixed fruit and vegetable wastes into biopolymers in Hong Kong can be found surprisingly near.

3.5 Other valuable compounds

Remarkable amount of other compound are also derivable from food wastes. Recovery stages usually consist of pre-treatment, macro- and micro-molecules separation, extraction, isolation and purification and finally product formation [76]. Figure 17 summarizes some of the findings in a recent review of valorisation of food (especially fruit and vegetable) manufacturing wastes. The most promising sources of valuable compounds from fruits and vegetables are seemed to be olives, exotic fruits, and tomatoes. Of these, exotic fruits (for instance, passion fruit, pineapple, mango, coconut, papaya and guava) are arguably the most abundant in Hong Kong. Processing and consumption provides wastes, such as peels, seeds and flesh that are rich in, for example, fibres, bioactive compounds, phenols, carotenoids and vitamins. Several researches have focused on recovery technologies and new uses for these types of wastes. Other vegetables and fruits, such as cauliflower, soybean, cabbage and watermelon peels, can be treated to yield various value-added products. For instance production of dietary fibre, pectin and carotene has been studied broadly [29]. Dietary fibres have various food applications, pectin is commonly used in food industry as a gelling agent, thickener and stabilizer and phenolic compounds can be used as antioxidants, antimicrobials and even anticancer compounds [77]. Miscellaneous wastes consist of mixed waste streams and they have been reported to have potential to yield biosorbents for heavy metals removal from waste waters, antimicrobial activity possessing food packaging material, dietary and cellulosic fibres and several other valuable compounds [29].

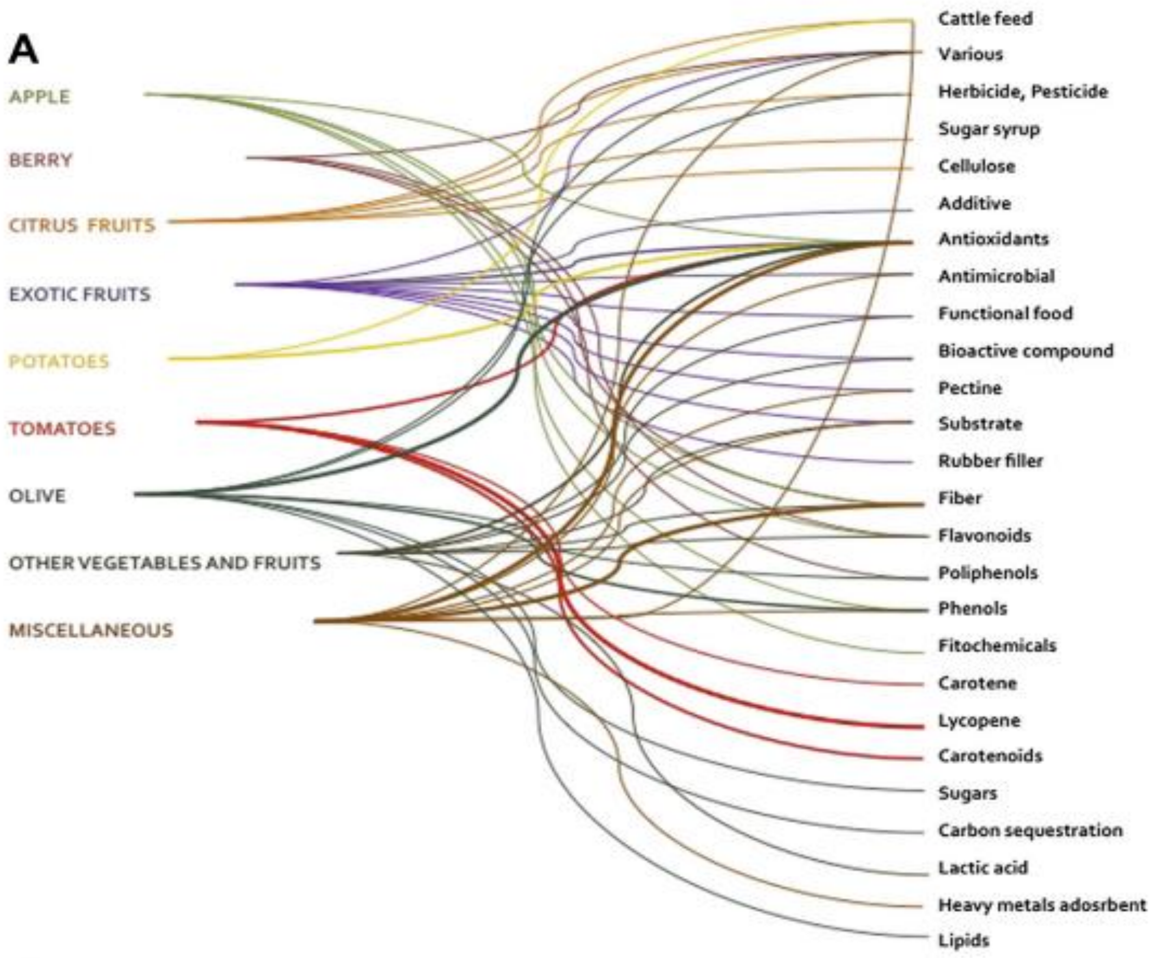


Figure 17. Valuable compounds derivable from fruit and vegetable wastes [29].

The recovery of valuable compounds from food wastes is an important challenge for the scientists. It is a difficult task to succeed in scale up without affecting the valuable functional properties of the target compound while meeting the consumers' high quality standards for safety and sensory characteristics in the product developed. Even though theoretically procedures might seem simple, there are several aspects that need to be taken into account before considering scaling up a process. These aspects are evaluated more on the next chapter [76].

3.6 Novel researches

Some interesting approaches that are slightly outside the project scope (due to the difficulty of appliance in Hong Kong) are shortly introduced.

Treating mixed food waste with ethanol and ultra-sonication followed by centrifugation and filtration yielded photoluminescent green carbon nanodots (**G-dots**) and plant growth promoting by-products. G-dots are used in, for instance, biomedical imaging and solution state optoelectronics, since they possess high photo- and aqueous stability as well as low cytotoxicity. However, 100 kg of mixed food waste and 500 L of ethanol yielded only 120 g G-dots [78].

Several fruit and vegetables [27] as well as spent coffee grounds have found to have potential in **wastewater treatment**. Traditionally used adsorbents for heavy metal removal, such as activated carbons, are relatively expensive for wastewater treatment. Spent coffee grounds have found to adsorb Cadmium from aqueous solutions effectively [79]. Untreated coffee grounds were also proven to adsorb Cu(II) and Cr(VI) with good removal results and high recyclability [80]. Waste peels' (from for example banana, lemon, cassava, pomegranate and garlic) potential have been examined with promising results. However, fruits and vegetables release soluble organic compounds into water during the treatment process; thus, further research is required until industrial scale processes can be considered [81]. Coffee wastes in turn have found to be a valuable resource for the production of several interesting production. Unfortunately coffee consumption in Hong Kong is too low to benefit these findings [82].

Edible films for food industry have been developed utilizing apple peels [83], skin of different fish [84, 85], other seafood products, potato starch and many other food residues [86]. Edible films and coatings are used in food industry to e.g. extend the products shelf life by protecting it from mechanical damage, physical, chemical and microbiological activities [87]. Studies of singular waste types have shown promising results yet waste mixtures potential in edible films production remains unclear. It is unfeasible to separate and collect only e.g. apple peels from a restaurant whereas collection directly from an apple processing factory would produce enough apple wastes for this application to be worth considering.

4 Conclusions and recommendations

Currently food waste conversion into biopolymers or other high-value compounds in Hong Kong is not feasible. In order to valorise the produced food waste an operational procedure for source separating and sorting, collecting and transporting and ultimately processing the food waste must be generated. A lot of research on food waste valorisation is being done; yet, solutions for utilizing large quantities of mixed food wastes are still lacking.

Big biopolymer producers worldwide receive their feedstock directly from e.g. farming or processing industries, resulting in consistent output and input. Commercial and industrial food waste producers in Hong Kong are mainly restaurants and other individuals, instead of big industries that treat only one kind of components. This leads to heterogeneity of the food waste thus necessity to come up with methods that can utilize mixed food wastes or at least achievably separated food wastes.

The overall process must not cause more costs or emissions than the traditionally used methods for the production of polymers and other valuable chemicals.

Moreover, the innovativeness of especially youths is worth mentioning; teenagers being able to come up with relatively simple methods that convert food waste into plastic propose that people should be encouraged to think up creative suggestions.

4.1 Separating and sorting

Current situation of separating food waste from other municipal solid waste at source in Hong Kong is insufficient. However, a great effort is being put into promoting the source separation and it can be assumed that the habit of recycling will increase.

It has already been proved by several other countries that source separation is theoretically and practically possible whereupon it is time for Hong Kong to follow the example.

Separation at source might require some extra effort from the waste producers in the beginning but once the staffs get familiar the habit, it will not cause any time or personnel costs assuming that the requirements are achievable. For instance locating a fruit and vegetable waste (FVW) bin next to a chopping board at a restaurant; thus, collecting all the FVW produced, will make the source separation effortless. On the other hand if the individual generator is required to segregate every, for example, vegetable waste type produced, into separate waste containers, feasibility is not in question any more.

Generated fruit and vegetable waste have high water content, which results in both odour nuisance at source due to spoilage and high transportation costs. This can be overcome by installing for instance a dewatering machine on site. Traditionally outcome of these kinds of machines have been used as fertilizers, but alternative applications can be researched [88]. A sorting system is also possible to install at the receiving institution.

4.2 Technical drawbacks

Big portion of the currently used biopolymer production methods require fermentation. Heterogeneity of even only fruit and vegetable waste biomass results in technical issues. Lignocellulosic biomass consists of pentose and hexose sugars, pentose sugars being harder to break down by the microorganisms. Developing a system to improve the fermentation of pentose sugars in mixed feedstock and systems to separate, ferment and utilize pentose sugars can help overcoming the problem. Political focus is mostly on bioenergy and biofuels production, which puts bio-based materials uses at competitive disadvantage [89].

4.3 Summary of recommendations

While concentrating on practising source separation, more focus should be put onto research and pilot scale experimenting on mixed food waste / mixed fruit and vegetable waste conversion into high-value products. For instance an attractive method of directly converting vegetable wastes into bio-plastics by a simple TFA-treatment and its feasibility in Hong Kong could be investigated more. In addition an alternative use for the by-product obtained from anaerobic digestion of organic waste could be inspected.

According to the effort made in increasing the recycling rates and coming up with innovative valorisation options, a feasible method for food waste utilization in biopolymer and other valuable products production in Hong Kong is achievable in the near future.

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