Research on transforming food waste into valuable products

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Abstract. Transforming food waste into valuable products could solve the double crises of both depletion of fossil fuels and environmental pollution. Literature and filed research were combined for identifying the transforming technologies. Material balance analysis was used for the calculation of outputs from these technologies. Composting, feeding, anaerobic digestion, bioethanol conversion, biodiesel conversion as well as the integration system-biorefinery were the common technologies applied around world. With the material balance analysis, the outputs of each technology were compost, insect-based feed, biogas, bioethanol and biodiesel respectively. The amount of productions is not at a high level, both less than 20%, however when substituting fossil energy or materials, these food waste-based products could achieve good benefits. On the other hand, with the diversified technology systems, how to choose the optimal of technology with a good balance on resource, energy and environment respects, is another problem to be solved.

1. Introduction
The depletion of fossil fuels and environmental pollution are the double crises facing the world today. With the increase of world population, the global demand for energy is increasing year by year. Global energy demand is reported to have increased by 56% in 2040 from 2010 [1].

Worldwide demand for clean, renewable energy and the policy orientation of moving waste away from landfills are the main driving forces for research on waste energy recovery [2]. Biomass is the world's fourth-largest energy source after coal, oil and gas and the only renewable carbon source. As an important biomass waste, food waste has attracted wide attention.

The composition of food waste is influenced by social factors, economic development level, eating habits, climate and regional characteristics, but it has certain regularity on the whole. In terms of chemical composition, food waste mainly contains oil, protein, carbohydrates and a small amount of chloride and nitrogen and phosphorus nutrients. There is inevitably a small part of non-food waste in food waste, such as plastic, stone, chopsticks, metal and so on.

The food waste has been paid more and more attention because of its environmental pollution and renewable resources. Its environmental pollution attribute is mainly reflected in the high water content, high organic matter content, and bring pollutions by gases and leachate [3]. At the same time, compared with other components of municipal solid waste, the higher content of organic matter and nutrients makes food waste have great potential on resource utilization [4]–[6].

With the implementation of waste classification in China, municipal solid waste shall gradually be collected, stored, transported and disposed of by classification. The emphasis of waste classification is
to separate wet waste, that is, food waste, and to realize the classification, collection and treatment of dry and wet waste. The completion of the treatment technology is the key factor to realize the comprehensive implementation of the domestic waste classification policy. Therefore, the choice of resource treatment technology for food waste has become particularly important.

2. Methods and materials

2.1. Literature and field research
Extensive literature and in-depth field researches were combined. For literature research, technologies of composting, biogas, biodiesel production, bioethanol production, protein-rich feed as well as the biorefinery systems were considered. Some of the typical treatment pilot of food waste in China were chosen field research, such as composting plant, anaerobic digestion plant.

2.2. Material balance analysis
Material balance is the primary consideration of the food waste treatment system, since it involves the distribution of materials and effecting the outputs of valuable products. In our study, material balance analysis was used on the field research for valuable products calculation.

3. Technologies for turning food waste to valuable products
There are a variety of options for food waste recycling technologies, including fertilizer, feed, energy and biological refining around world.

3.1. Composting
High temperature aerobic composting is one of the conventional methods for recycling food waste. Composting is the process of stabilizing organic solid waste through biological action under controllable external conditions. The organic matter content is high, the nutrition element is more comprehensive, the carbon-nitrogen ratio is suitable, is the good nutrition substrate for the microorganism in the aerobic composting process, is very suitable for the composting raw material. At the same time, the content of impurities (such as metals, plastics, etc.) and toxic substances in food waste is less, which is conducive to the utilization of compost products. Products after high temperature aerobic composting can usually be used as organic fertilizers for agriculture, forestry and landscape. The advantage of this method is that the process is relatively simple and the nitrogen can be retained in the product.

3.2. Feeding
The organic matter content of food waste is high and the nutrient elements are abundant. It is a rare potential feed resource. However, countries around the world have different attitudes towards food waste used as animal feed. Some countries strictly prohibit the use of food waste, such as the European Union [7] to prevent the spread of disease. Another group of countries supported the use of food waste feed on the premise that food was safe and processed harmless [8], such as Korea, Japan, China, etc. to achieve resource savings and reduce waste. In 2007, Japan revised the food waste recycling law, which clearly stipulates that for the treatment of food waste, animal feed is selected [9]. The feed rate of food waste in Korea is as high as 45.2 % [10].

Insect transformation is another way to feed food waste. With the increasing in population, the global demand for protein feed is also increasing [11]. It is estimated that the demand for meat and milk in 2050 will be 58% and 70% higher than the level in 2010, and a large part of this increase will come from developing countries [12]. In recent years, large-scale facilities have been established around world to convert food waste into protein feed using insect, including Italy [13], Indonesia [14] and China [15]. Researchers are focusing on the potential uses of the larvae of black solider fly [16], [17] and selection of different types of substrates [18].
3.3. Anaerobic digestion
During anaerobic fermentation, organic matter is decomposed by microorganisms, and some organic carbon is converted into methane and carbon dioxide. The feasibility of anaerobic digestion of food waste has been widely practiced, and the mixed co-digestion technology of food waste and other organic wastes has also attracted more attention. It is found that co-digestion with one or more substrates of animal feces, human feces, greening waste, domestic sludge, dewatered sludge, distiller's grains and so on is an effective method to improve the yield of biogas and methane[19].

3.4. Bioethanol conversion technology
Food waste is rich in carbohydrates, which account for more than 50% of dry weight[20]. Bioethanol can be produced by saccharification, hydrolysis and ethanol fermentation[21]. Bioethanol production based on different substrates is divided into 3–4 generation technologies. In the 1970s, the global oil crisis prompted Brazil to produce the first generation of bioethanol, the substrate of which includes sucrose and starch, such as sugar cane, sorghum, corn and so on. The second-generation bioethanol conversion technology uses lignin as substrate to increase the role of bagasse in this process, such as wood, straw and so on[22],[23]. At present, scholars at home and abroad focus on the technology of producing bioethanol from waste, such as agricultural waste, domestic waste, food waste, etc.

3.5. Biodiesel conversion technology
Biodiesel is a non-toxic, biodegradable and environmentally friendly alternative to fossil diesel, so it is considered as a renewable green fuel[24],[25]. Animal and vegetable oils and microbial oils can be used as raw materials for biodiesel production. Biodiesel and its by-products can be obtained by reaction with short-chain alcohols (methanol, ethanol, propanol, etc.) under the action of catalyst to form long-chain fatty acid esters[26]. The cost of raw materials accounts for almost 70%–95% of the total cost of biodiesel produced from high-quality edible oils such as vegetable oils and animal fats[27]. Using low-cost raw materials (such as fried oil, recycled waste oil, non-edible oil, etc.) can reduce the cost of biodiesel production. Using waste oil in food waste as raw material to produce biodiesel can not only reduce the burden of edible food market, but also solve the problem of food waste.

3.6. Biorefining system
Biorefining is a new paradigm introduced by traditional petrochemical refining, which refers to the extraction of fuel, gas and high value-added chemical products from biomass under the integrated process of biomass (including biomass waste) conversion, including chemical, bioengineering, etc.) process to maximize the level of resource utilization of raw materials[28]. With the integration of more and more biotransformation processes, the product range of biorefinery is also expanding, and the input range is also extended to municipal domestic waste, food waste, domestic sludge, animal manure and biofuel processing residue. According to IEA Bioenergy Task 42[29], the products provided by the biorefinery, including energy, chemical and material products, such as fertilizers, feed, electricity, bioethanol and biodiesel, are considered as high value-added products.

4. Resource-based product outputs
With the results of field research, the outputs of each treatment based on 1 ton of food waste was shown on Table 1. The results show that the amount of productions is not at a high level, both less than 20%, however, food waste-based valuable products can bring good benefits when substituting fossil energy or materials.

| Technology  | Products       | Substitution        | Outputs from food waste |
|-------------|----------------|---------------------|-------------------------|
| Composting  | Compost        | Chemical fertilizer | 10%                     |
| Feeding     | Insect-based Feed | Chemical feed     | 9%                      |
### 5. Conclusion

Fertilization, feed, energy and biorefining are the main technologies treated for food waste. Varieties of technologies, energy consumptions and the utilization of products, enhanced the complexity of technology selection. With the diversified biorefining technology systems, how to choose the optimal treatment to achieve the comprehensive optimization of resource, energy and environment is a bottleneck problem that needs to be resolved urgently.

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