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Review

Food waste-to-energy conversion technologies: Current status and future directions

Thi Phuong Thuy Pham, Rajni Kaushik, Ganesh K. Parshetti, Russell Mahmood, Rajasekhar Balasubramanian *

Department of Civil and Environmental Engineering, National University of Singapore, 1 Engineering Drive 2, Singapore 117576, Republic of Singapore

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ABSTRACT

Food waste represents a significantly fraction of municipal solid waste. Proper management and recycling of huge volumes of food waste are required to reduce its environmental burdens and to minimize risks to human health. Food waste is indeed an untapped resource with great potential for energy production. Utilization of food waste for energy conversion currently represents a challenge due to various reasons. These include its inherent heterogeneously variable compositions, high moisture contents and low calorific value, which constitute an impediment for the development of robust, large scale, and efficient industrial processes. Although a considerable amount of research has been carried out on the conversion of food waste to renewable energy, there is a lack of comprehensive and systematic reviews of the published literature. The present review synthesizes the current knowledge available in the use of technologies for food-waste-to-energy conversion involving biological (e.g. anaerobic digestion and fermentation), thermal and thermochemical technologies (e.g. incineration, pyrolysis, gasification and hydrothermal oxidation). The competitive advantages of these technologies as well as the challenges associated with them are discussed. In addition, the future directions for more effective utilization of food waste for renewable energy generation are suggested from an interdisciplinary perspective.

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1. Introduction

As of 2011, the world has generated an estimated 2 billion tons of municipal solid waste (MSW) (Amoo and Fagbenle, 2013). The amount of MSW generated is expected to grow much higher due to rapid urbanization, industrialization and population growth, which is projected to reach 9.5 billion by 2050 (FAO, 2009). According to Intergovernmental Panel on Climate Change (IPCC, 2006), food waste makes a dominant contribution to MSW (25–70%), which is composed of plastic, metal, glass, textiles, wood, rubber, leather, paper, food waste and others with the exception of

* Corresponding author. Tel.: +65 6546 5135; fax: +65 6774 4202.
E-mail address: ceerbala@nus.edu.sg (R. Balasubramanian).

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industrial waste (Fig. 1). About 1.3 billion tons, one third of the food produced in the world for human consumption annually, are lost or wasted throughout the supply chain, from production to consumption (FAO, 2011). Food waste in a food supply chain can be sub-categorized into pre-consumer (e.g. wastes generated from agriculture, processing and distribution) and post-consumer wastes (e.g. wastes from meal preparation and consumption) (Pfaltzgraff et al., 2013). The National Resources Defense Council (NRDC, 2012) has recently estimated that approximately 40% of food produced in the United States of America is lost in the form of waste during its processing and distribution by retailers, restaurants and consumers. The United Kingdom and Japan also follow a similar trend, discarding between 30% and 40% of their food produced every year (Kosseva, 2009). In South Africa, food waste generation was estimated to be 9 million tons per annum (Oelofse and Nahman, 2013). Singapore, a highly populated, industrialized city, produced 542,720 tons of food waste in 2006 and reached about 703,200 tons in 2012 according to Singapore's National Environmental Agency (NEA, 2012). In the European Union, food garbage is expected to increase from 89 million tons in 2006 to 126 million tons in 2020 (European Commission, 2010). Every year the European food-processing industry produces vast volumes of aqueous wastes. These wastes are composed of fruit and vegetable residues and discarded items, molasses and bagasse from sugar refining, bones, flesh and blood from meat and fish processing, stillage and other residues from wineries, distilleries, and breweries, dairy wastes such as cheese whey, and wastewaters from washing, blanching, and cooling operations (Kosseva, 2011). Many of these wastes contain low levels of suspended solids and low concentrations of dissolved materials, which cause not only visual discomfort by producing different moldering gases and offensive odors, but also cause adverse environmental impacts due to leaching in landfill sites. These wastes lead to a waste of resources used in food production and distribution, including land, water, energy, fertilizers, pesticides, labor and capital. Currently, most of food wastes are recycled, mainly as animal feed and compost (Lin et al., 2013). The remaining quantities are incinerated and disposed off in landfills, causing serious emissions of methane (CH_4), which is 23 times more potent than carbon dioxide (CO_2) as a greenhouse gas and significantly contributes to climate change.

Apart from the environmental challenges posed, the inherent complexity of food waste composition makes it a very attractive source of value-added products. Most of the materials generated as wastes by the food-processing industries contain components that could be utilized as substrates and nutrients in a variety of microbial/enzymatic processes. Joshi (2002) and Marwaha and Arora (2000) discussed the value-added products actually produced from food industry wastes, or potentially so, which include animal feed, single-cell protein and other fermented edible products, baker's yeast, organic acids, amino acids, enzymes (e.g., lipases, amylases, and cellulases), flavors and pigments, the biopreservative bacteriocin (from the culture of *Lactococcus lactis* on cheese whey), and microbial gums and polysaccharides.

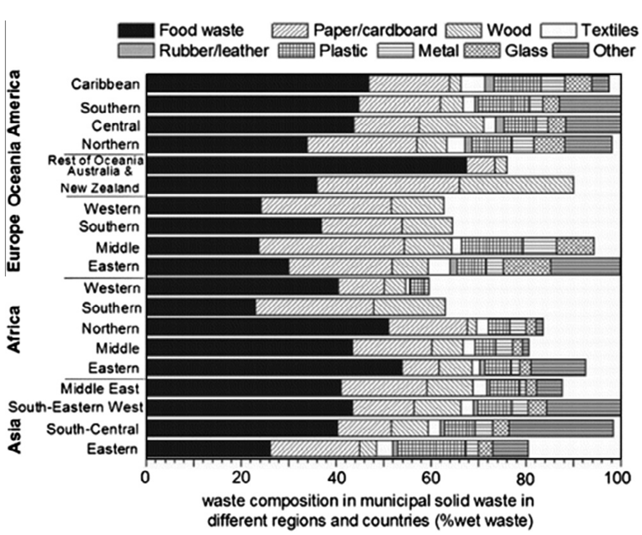

Fig. 1. The percentage of different waste types in municipal solid waste in different regions and countries (reproduced from IPCC, 2006).

In recent years, it has been recognized that food waste is an untapped resource with great potential for generating energy. Thus, energy recovery from food waste is an additional attractive option to pursue, particularly from the energy security viewpoint. This realization has motivated fundamental research on technologies that help to recover some valuable fuels from food waste to reduce the environmental burden of its disposal, avoid depletion of natural resources, minimize risk to human health and maintain an overall balance in the ecosystem. Although there has been a considerable amount of research focused on the conversion of food waste to renewable energy, there is a lack of comprehensive reviews of the published literature. McKendry (2002) reviewed various biomass-to-energy conversion technologies, but there was no specific emphasis on the use of food wastes as feedstocks.

In the current review, we provide insights into various technologies that have been explored for food-waste-to-energy conversion including biological (e.g. anaerobic digestion and fermentation), thermal and thermochemical technologies (e.g. incineration, pyrolysis, gasification and hydrothermal oxidation) (Fig. 2). This review discusses the advantages as well as the major challenges associated with these technologies. In the light of recent technological advances and the drive towards using food waste as a raw material to both reduce the environmental burden of its disposal and address the concerns about future resources, this review identifies key knowledge in food-waste-to-energy conversion technologies. In addition, we suggest future directions for more effective ways of treating food waste for renewable energy generation from the resource recovery viewpoint.

2. Current technologies for energy generation from food waste

2.1. Biological technology

2.1.1. Anaerobic digestion

Anaerobic digestion (AD) of organic wastes in landfills produces biogas comprising mainly CH_4 and CO_2, and traces amounts of other gases such as nitrogen (N_2), oxygen (O_2) and hydrogen sulfide (H_2S) that escape into the atmosphere and pollute the environment (Zhu et al., 2009). Under controlled conditions without oxygen, the same process has the potential to convert the organic wastes into useful products such as biofuels (e.g. biogas) and nutrient enriched digestates which can be used as soil conditioners or fertilizers (Chanakya et al., 2007; Guermoud et al., 2009). With the introduction of both commercial and pilot AD plant designs during early 1950s, AD of organic wastes has received worldwide attention (Karagiannidis and Perkoulidis, 2009). AD has many environmental benefits including the production of a renewable energy platform, the possibility of nutrient recycling, and the reduction of waste volumes (Kosseva, 2011).

It was reported that 1 m^3 of biogas from AD is equivalent to 21 MJ of energy, and it could generate 2.04 kW h of electricity considering the 35% of generation efficiency (Murphy et al., 2004). However, the major problem is the long duration of the microbial reaction, which is generally in the range of 20–40 days (Table 1). Also, the high concentration of free ammonia (NH_3) resulting from