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Review

Municipal solid waste (MSW) as a renewable source of energy: Current and future practices in China

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ABSTRACT

With rapid economic growth and massive urbanization, China faces the problem of municipal solid waste (MSW) disposal and the pressing need for development of alternative energy. Waste-to-energy (WTE) incineration, which recovers energy from discarded MSW and produces electricity and/or steam for heating, is recognized as a renewable source of energy and is playing an increasingly important role in MSW management in China. This article provides an overview of the WTE industry, discusses the major challenges in expanding WTE incineration in China, namely, high capital and operational costs, equipment corrosion, air pollutant emissions, and fly ash disposal. A perspective on MSW as a renewable energy source in China is also presented. Currently, only approximately 13% of MSW generated in China is disposed in WTE facilities. With the significant benefits of environmental quality, the reduction of greenhouse gas (GHG) emissions, and government policies and financial incentives as a renewable energy source, WTE incineration industry is expected to experience significant growth in the coming decade and make greater contribution to supplying renewable energy in China.

1. Introduction

In the traditional sense, renewable sources of energy are those that can be replenished by nature, such as hydropower, wind power, solar power, and biomass. Municipal solid waste (MSW) refers to the materials discarded in urban areas, including predominantly household waste with sometimes the addition of commercial wastes, collected and disposed by the municipalities. MSW contains a significant fraction of paper, food waste, wood and yard trimmings, cotton, and leather, and is a source of biomass. Materials derived from fossil fuels, such as plastics, rubber, and fabrics, are also found in MSW. The U.S. Environmental Protection Agency considers MSW a renewable energy resource because the waste would otherwise be sent to landfills (U.S. Environmental Protection Agency, 2006a). The U.S. Department of Energy includes MSW in renewable energy only to the extent that the energy content of the MSW source stream is biogenic (Energy Information Administration, 2007). The non-renewable portion of MSW has to be either separated or accepted as part of the fuel (Themelis and Millrath, 2004), and practically all the wastes in MSW after material recovery and recycling are treated as renewable.

Waste-to-energy (WTE) processes recover the energy from the waste through either direct combustion (e.g., incineration, pyrolysis, and gasification) or production of combustible fuels in the forms of methane, hydrogen, and other synthetic fuels (e.g., anaerobic digestion, mechanical biological treatment, and refuse-derived fuel). Incineration and gasification are the two primary WTE technologies that have been used successfully throughout the world. It is estimated that about 130 million tonnes of MSW are combusted annually in over 600 WTE facilities worldwide, producing electricity and steam for district heating and recovered metals for recycling (Themelis, 2003). WTE incineration has long been accepted as a solid waste management option, complementing landfilling and composting (American Society of Mechanical Engineers, 2008; Denison, 1996; Themelis, 2003; United Nations Environment Programme, 1996). The advantages and limitations of the major MSW disposal technology options, landfilling, composting, and incineration, are compared in Table 1. Incineration of MSW in WTE facilities prevents the possible aqueous and gaseous pollution associated with landfilling and provides a source of reliable, renewable energy. As a proven, environmentally sound technology, WTE has been used extensively in Europe and developed countries in Asia such as Japan and Singapore (American Society of Mechanical Engineers, 2008).

The demand for sustainable urban growth in China is unprecedented: 300 million people will move from the countryside into cities (~18–20 million people/year), necessitating the building of over 400 new cities in the next two decades (Brookins, 2007; Cheng and Hu, 2010; Hart and Milstein, 1999; United Nations, 2008; United Nations Population Fund, 2007). It is expected that 70% of China's population, or approximately 1.0 billion people, will

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Table 1
Comparison of the major MSW management technology options: landfilling, composting, and incineration.

Technology	Advantages	Disadvantages
Landfilling	An universal solution that provides ultimate waste disposal; Relatively low cost and easy to implement; Complements with other technology options for handling the residual waste; Can derive landfill gas as a byproduct for household and industrial uses; Costs incurred incrementally as landfill expands.	Cost increases significantly with liner, leachate collection and removal system, and stricter regulations; Requires large area of land; Does not achieve the objectives of reducing volume of MSW and converting MSW into reusable resources; May result in secondary pollution problems, including groundwater pollution, air pollution, and soil contamination; May serve as breeding ground for pests and diseases; Long postclosure care obligations and unknowns exist, and sets long-term restrictions on site land use; Site location may be limited by the local geology and natural stability of the underground soil; Due to public acceptance and space limitation, landfills are often far away from the places where waste is generated, necessitating long distance transport of the waste.
Composting	Converts decomposable organic materials into an organic fertilizer; Reduces the amount of waste to be landfilled and integrates well with landfilling and materials recovery/recycling.	Takes up more space than some other waste management technologies; Can be costly to implement and maintain, and has no environmental or economic advantages compared to incineration; Requires waste size reduction and some degree of waste separation/processing; There are issues with public perception, such as odor and bioaerosol emissions during the composting process, and the control of disease producing organisms, weeds, and insects; Quality of the fertilizer produced is low and volume is disproportionately large, resulting in poor market demand; Compost product may cause soil pollution by heavy metals and pathogens.
Incineration	Provides substantial reduction (by 90%) in the total volume of waste requiring disposal in landfill; Requires minimal pre-processing of waste; The bottom ash from incineration is biologically clean and stable, and can be used in road building and the construction industry; A very stable process, and virtually all wastes can be burned and the burning process can be adequately controlled; Heat from combustion can be used as energy source for generation of steam and/or electricity; Incineration facilities can be located near residential areas, thereby reducing costs of transporting MSW to locations of waste disposal; Air emissions can be well controlled; More optimal land use and more efficient integration of resources than landfilling.	High capital and operational and maintenance costs, compared to other, non-incineration options; Significant operator expertise is required; Air pollution control equipment is required to treat the flue gas, and the fly ash needs to be disposed in hazardous waste landfills; More raw material have to be used to replace those that have been incinerated, and it does not save energy in the long run as resources are not recycled; May some time discourage recycling and waste reduction; Public perception is sometimes negative, primarily with dioxins emission.

be living in urban areas by 2050 (Feiner et al., 2001; United Nations, 2008). Dealing with the increasing volume of MSW generated as a result of both the increasing urban population and the improving life style of the people presents a daunting challenge (Cheng et al., 2007; Cheng and Hu, 2009). At the same time, China, which is the world's second largest consumer of energy and the third largest importer of oil (Energy Information Administration, 2009), also faces massive demand for energy to power its economic growth. Discarded MSW is a viable energy source for electricity generation in a carbon-constrained world (Kaplan et al., 2009), thus a MSW management technology with the benefits of recovering energy from the waste is a promising alternative in solving the MSW disposal problem in China. WTE is gaining increasing popularity in China primarily for its ability to reduce the volume of MSW that requires landfilling, it also lessens the country's dependence on fossil fuel and greenhouse gas (GHG) emissions. This article provides an overview of the situations of MSW disposal and the development of WTE incineration in China. The major challenges facing the growth of WTE incineration industry are discussed and the perspective of MSW as a renewable energy source in China is also presented.

2. China's urban expansion and MSW management challenge

China is the world's most populous country and is developing rapidly: its total population increased from 963 million in 1978 to 1330 million in 2008, with the urban population increased from 17.4 to 43% (National Bureau of Statistics of China, 2009). Increasing population, rapidly developing economic and social systems, accelerated urbanization, and need for improvements in both the standards of living and the surrounding ecosystems pose multiple environmental challenges in China, including air pollution, water and soil pollution, waste disposal, water shortage, and massive energy demand (Cheng et al., 2007, 2009; Cheng and Hu, 2009, 2010; Liu and Diamond, 2005). Among them, MSW management is one of the major problems that affect China's environmental quality and the sustainable development of its cities.

Fig. 1a shows the trends in the amounts of MSW collected and treated in China. MSW generation has been increasing at an annual rate of 8–10%, with over 150 million tonnes of MSW being produced each year now (Nie, 2008; Xu and Liu, 2007; Yuan et al., 2008). The fraction of MSW treated by MSW management facilities has increased from approximately 5% in the 1980s to around 55%. MSW is managed by a combination of landfilling, composting, and incineration in China. Fig. 1b depicts the amounts of MSW treated by these three technologies between 2001 and 2006. Landfilling is the dominant form of waste disposal in China, handling over 80% of the treated MSW. However, serious surface water and groundwater contamination has occurred in many landfill sites due to the lack of leachate collection and treatment systems in over half of the existing landfills (Ministry of Construction of China, 2006; Yan and Wu, 2003). On the other hand, the availability of land space limits construction of new lined landfills in many cities.