Applied Energy xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Energy and emissions benefits of renewable energy derived from municipal solid waste: Analysis of a low carbon scenario in Malaysia

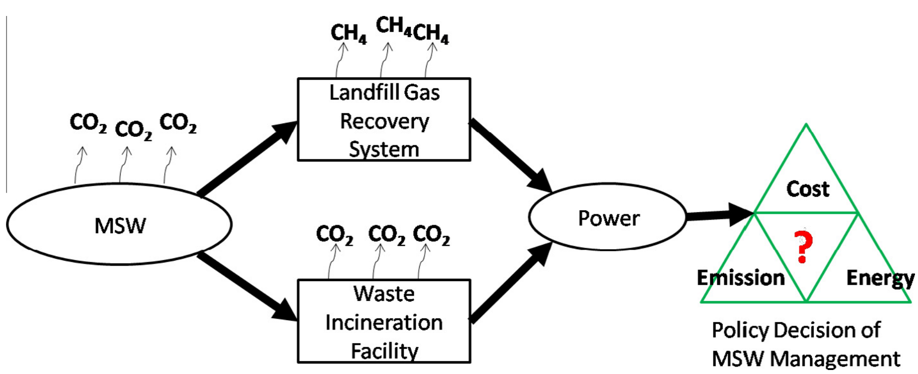
Sie Ting Tan [a,c], Haslenda Hashim [a,*], Jeng Shiun Lim [a], Wai Shin Ho [a], Chew Tin Lee [b], Jinyue Yan [c,d]

[a] Process System Engineering Centre (PROSPECT), Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
[b] Department of Bioprocess Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
[c] School of Sustainable Development of Society and Technology, Mälardalen University, SE-72123 Västerås, Sweden
[d] School of Chemical Science and Engineering, Royal Institute of Technology, SE-100 44 Stockholm, Sweden

HIGHLIGHTS

- Feasibility study on the energy and GHG emission reduction for WtE strategies for municipal solid waste (MSW) in Malaysia.
- Greenhouse gases (GHG) emissions from WtE strategies analysed using IPCC guideline.
- Scenario analysis by comparison of different WtE strategies.
- Impact of moisture content of MSW towards energy potential and GHG emission reduction.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 31 October 2013
Received in revised form 27 April 2014
Accepted 9 June 2014
Available online xxxx

Keywords:
Waste-to-energy (WtE)
Landfill
Incineration
Municipal solid waste (MSW)
Carbon emission reduction

ABSTRACT

Ineffective waste management that involves dumping of waste in landfills may degrade valuable land resources and emit methane gas (CH_4), a more potent greenhouse gas than carbon dioxide (CO_2). The incineration of waste also emits polluted chemicals such as dioxin and particle. Therefore, from a solid waste management perspective, both landfilling and incineration practices pose challenges to the development of a green and sustainable future. Waste-to-energy (WtE) has become a promising strategy catering to these issues because the utilisation of waste reduces the amount of landfilled waste (overcoming land resource issues) while increasing renewable energy production. The goal of this paper is to evaluate the energy and carbon reduction potential in Malaysia for various WtE strategies for municipal solid waste (MSW). The material properties of the MSW, its energy conversion potential and subsequent greenhouse gases (GHG) emissions are analysed based on the chemical compositions and biogenic carbon fractions of the waste. The GHG emission reduction potential is also calculated by considering fossil fuel displacement and CH_4 avoidance from landfilling. In this paper, five different scenarios are analysed with results indicating a integration of landfill gas (LFG) recovery systems and waste incinerator as the major and minor WtE strategies shows the highest economical benefit with optimal GHG mitigation and energy potential. Sensitivity analysis on the effect of moisture content of MSW towards energy potential and GHG emissions are performed. These evaluations of WtE strategies provides valuable insights for policy decision in MSW management practices with cost effective, energy benefit, environmental protection.

* Corresponding author. Tel.: +60 7 553 5478; fax: +60 7 5588166.
E-mail address: haslenda@cheme.utm.my (H. Hashim).

http://dx.doi.org/10.1016/j.apenergy.2014.06.003
0306-2619/© 2014 Published by Elsevier Ltd.

1. Introduction

Rapid generation of solid waste resulting from economic development and population growth had become one of the most significant environmental issues of our time. It requires an appropriate management of municipal solid waste (MSW) which involves control of the atmospheric emissions and aqueous effluents coming from landfills, waste collection, transportation, and processing of waste. MSW can be processed in one of three ways: thermal treatment, biological treatment, or landfilling [1]. Thermal MSW treatment reduces the volume of waste through heat energy and produces biofuels (i.e., syngas, char, or bio-oil). The typical thermal treatment of waste involves combustion (incineration), gasification, and pyrolysis. Biochemical treatment on the other hand, is an environmentally friendly method of waste disposal which is based on enzymatic decomposition of organic matter by microbial action to produce methane (CH_4) or alcohol. Waste residues obtained through both thermal conversion and biological conversion is then landfilled. These waste treatment approaches and their products are illustrated in Fig. 1.

Waste-to-energy (WtE) is recognised as a promising alternative to overcome waste generation problem and a potential renewable energy (RE) source. Energy can be recovered from biodegradable and non-biodegradable matter through thermal and biochemical conversions [2]. The most two common practice for WtE method is waste incineration and landfill gas (LFG) recovery system. Waste incineration is suitable for waste which is non-biodegradable matter with low moisture content. It solves the degradation of valuable land resources for landfill and avoids generation of methane gas (CH_4) from landfill. Some large-scale WtE has been implemented in developed countries such as Japan, Germany, Sweden, The Netherlands, Denmark, and the United Kingdom. However, WtE is still under development in Malaysia [3]. Only one incineration plant is currently in operation, with an energy recovery system that can produce 1 MW of electricity from 100 t/d of MSW, in Langkawi, Malaysia [4]. The other four Malaysian incineration plants, located at Pangkor Island (20 t/d), Tioman Island (15 t/d), Cameron Highland (40 t/d) and Semenyih (100 t/d), have been discontinued due to the high operation costs arising from high moisture content of waste [5]. Challenges remain for the other existing incinerators, where many units require improvements before they can be incorporated into an energy recovery system, nevertheless, because the high moisture content of waste (52.65–66.2%) [6], it leads to high operational and fuel costs.

Due to high price of incineration technologies, the generation of LFG from landfill site has gained increasing attention. LFG recovery system is well suited to a high percentage of biodegradable matter with high moisture content. It helps in mitigation of GHG emissions from waste by converting CH_4 to carbon dioxide (CO_2). This option has therefore been considered as an important and crucial factor to successful waste management. Most of the landfills in Malaysia involve small-scale operations in controlled or uncontrolled open dumps with minimal or non-existent environmental control [7]. In 2007, there were approximately 291 waste disposal landfill sites in Malaysia, but only 3% were sanitary landfills [8]. The number of landfills in Malaysia encourages the implementation of LFG recovery at landfill sites because it would reduce environmental problems such as GHG emissions and river pollution arising from discharged leachate [8]. The utilisation of LFG as a RE could reduce CH_4 emissions from the landfill sites. Statistically, 47% of the total CH_4 emissions in Malaysia are generated from landfills [9], and there are currently four LFG recovery plants in Malaysia, located at Bukit Tagar (Kuala Lumpur), Taman Beringin (Kuala Lumpur), Seelong (Johor) and Kampung Kelichap (Johor). The first grid-connected RE facility in Malaysia was commissioned at the Air Hitam Sanitary Landfill in 2004, with a capacity for processing 7 Mt of MSW and the ability to generate up to 2 MW of power. However, this facility's operations were halted in 2007 due to technical problems [4].

Feasibility analyses of WtE in Malaysia have been explored by local researchers over the past decade. Johari et al. (2012) have conducted a study of the economic and environmental benefits of LFG, using the Intergovernmental Panel on Climate Change (IPCC) methodology to estimate the CH_4 generated by the disposal landfill. They have concluded that approximately 310,220 t CH_4/y could be generated from MSW in Malaysia, and approximately 1.9 billion kW h of electricity could be generated from these sources [8]. Another similar study by Noor et al. (2013) has estimated the projection of CH_4 emissions from 2015 to 2020 using IPCC methodology, also proving that LFG could be a promising energy source that would fulfil approximately 1.5% of Malaysia's energy requirement [10]. Moreover, Kalantarifard and Goh (2011) have presented a real case study of the feasibility of landfill gas use at the Tanjung Langsat landfill in Johor Bahru, Malaysia. Their

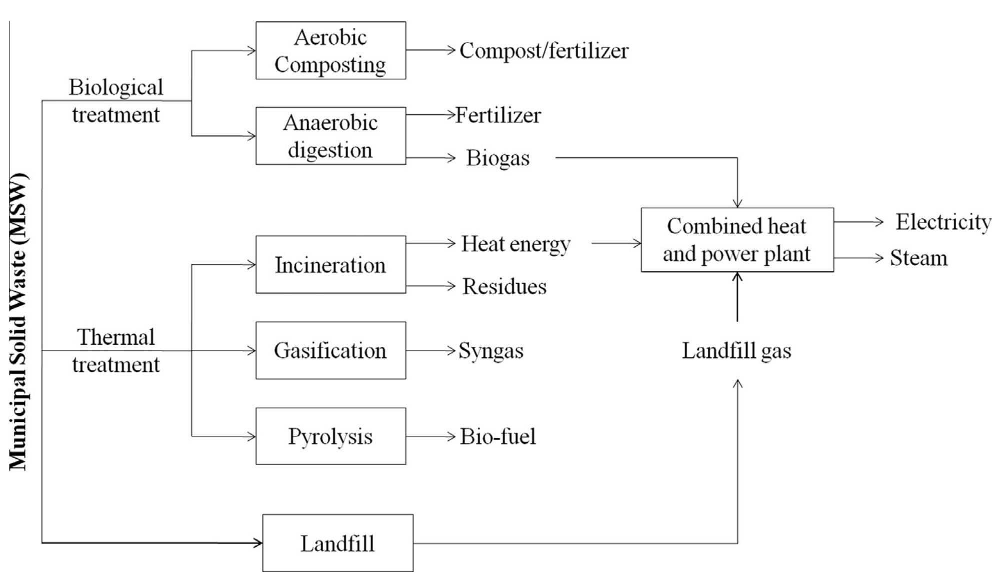


Fig. 1. Alternative waste treatment technologies and their products.