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The crucial role of Waste-to-Energy technologies in enhanced landfill mining: a technology review

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ABSTRACT

The novel concepts Enhanced Waste Management (EWM) and Enhanced Landfill Mining (ELFM) intend to place landfilling of waste in a sustainable context. The state of the technology is an important factor in determining the most suitable moment to valorize – either as materials (Waste-to-Product, WtP) or as energy (Waste-to-Energy, WtE) – certain landfill waste streams. The present paper reviews thermochemical technologies (incineration, gasification, pyrolysis, plasma technologies, combinations) for energetic valorization of calorific waste streams, with focus on municipal solid waste (MSW), possibly processed into refuse derived fuel (RDF). The potential and suitability of these thermochemical technologies for ELFM applications are discussed. From this review it is clear that process and waste have to be closely matched, and that some thermochemical processes succeed in recovering both materials and energy from waste. Plasma gasification/vitrification is a viable candidate for combined energy and material valorization, its technical feasibility for MSW/RDF applications (including excavated waste) has been proven on installations ranging from pilot to full scale. The continued advances that are being made in process control and process efficiency are expected to improve the commercial viability of these advanced thermochemical conversion technologies in the near future.

1. Introduction

Waste management has – in accordance with the waste hierarchy as defined in the Waste Framework Directive (2008/98/EC, 2008) – evolved to a stronger focus on waste prevention, material recuperation and recycling (e.g. glass, paper, metals). Despite increasing attention to prevention and sustainability, total municipal solid waste (MSW) generation in the EU25 has raised from about 150 million tons in 1980 to more than 250 million tons in 2005 and is forecasted to reach 300 million tons by 2015 (ETC/RWM, 2007). Increased MSW generation combined with the growing problem of natural resources depletion, makes the transition to Sustainable Materials Management (SMM) crucial.

Sustainable Materials Management comprises the reframing of materials cycles and waste management concepts, targeting closed loop systems (Jones et al., 2013). Traditional landfilling (i.e. discarding materials on dumps or landfills) cannot be part of SMM as it opposes the idea of a fully closed material cycle. The novel concepts Enhanced Waste Management (EWM) and Enhanced Landfill Mining (ELFM) intend to integrate landfilling of waste in a sustainable context. In EWM, prevention and reuse/recycling become even more important, while landfilling is no longer considered *a final solution*. Instead, landfills are considered *temporary storage places awaiting further treatment* or also *future mines for materials*. Enhanced Landfill Mining represents an iterative valorization approach, targeting both new and old landfills. Waste valorization is its use as material or the conversion into energy or fuels, with particular focus on environmental indicators and sustainability goals. It is covered by the greater objective of loop-closing. Enhanced Landfill Mining offers the opportunity to select the most suitable moment to valorize – as materials (Waste-to-Product, WtP) and/or as energy (Waste-to-Energy, WtE) – certain waste streams, depending for instance on the state of the technology. The non-recyclable fraction needs to be stored again in

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such a way that future mining is possible. Additionally, the 'Enhanced' in ELFM incorporates the goal to prevent the emissions of CO_2 and pollutants arising during the energy/material valorization processes (Jones et al., 2013). Therefore, sustainable WtP and WtE technologies are greatly needed. The present paper reviews WtE technologies using (pre-processed) MSW as input.

Waste-to-Energy is the process of recovering energy, in the form of electricity and/or heat, from waste. In the past, waste incineration was a technology to reduce the volume and destroy harmful substances in order to prevent threats to human health. Nowadays, waste incineration is almost always combined with energy recovery. The importance of the energy recovery part has increased over time. Denmark and Sweden have been leaders in using the energy generated from incineration for more than a century. In 2005, waste incineration produced 4.8% of the electricity consumption and 13.7% of the total domestic heat consumption in Denmark (Kleis and Dalagar, 2007).

Table 1 gives an overview of the most relevant types of waste and waste derived fuels. Hogland et al. (2010) and van Vossen (2005) estimated that the amount of landfill sites across Europe is between 150,000–500,000 containing a significant amount of MSW. Municipal solid waste is a heterogeneous feedstock containing materials with widely varying sizes, shapes and composition. If the MSW is used 'as received' as input to WtE processes, this can lead to variable (and even unstable) operating conditions, resulting in quality fluctuations in the end product(s). In addition, the more advanced thermochemical treatment technologies require an input feed with a sufficiently high calorific value in order to obtain high process efficiencies. For these reasons, refuse derived fuel (RDF) – a processed form of MSW – is often used as input to WtE systems (Klein, 2002). In general, the process of converting MSW into RDF consists of shredding, screening, sorting, drying and/or pelletization in order to improve the handling characteristics and homogeneity of the material. In case the MSW is excavated from landfill sites, the preprocessing step should be carefully matched to the excavated waste properties in order to obtain a high quality RDF. The main benefits of converting MSW to RDF are a higher calorific value, more homogeneous physical and chemical compositions, lower pollutant emissions, lower ash content, reduced excess air requirement during combustion and finally, easier storage, handling and transportation (NETL, 2012). Therefore, a trade-off between the increased costs of producing RDF from MSW and potential cost reductions in system design and operation needs to be found.

The focus in this paper is on available technologies for thermochemical treatment of (calorific) waste streams. The scope is limited to technologies that have been commercially proven in a full-scale plant, or that have at least demonstrated their viability through pilot plant testing. This review summarizes the technological approaches that have been developed, presents some of the basic principles, provides details of some specific processes (more emphasis is put on new advanced technologies, such as plasma technology) and concludes with a comparison between the different technologies, stressing factors affecting their applicability and operational suitability. The evaluation criteria are based on environmental impact, energy efficiency, material recuperation and system operation (e.g. flexibility in dealing with input variation). Hence, this review constitutes the base for selecting best available technique(s) for energetic valorization of specific calorific waste streams. Focus is on MSW, possibly processed into RDF as the majority of advanced thermochemical technologies require a homogeneous process input. Furthermore, a closer look is taken at technologies offering the added benefit of recovering materials – in addition to energy – from the waste feed. In the Waste-to-Product (WtP) concept, waste treatment by-products are used to manufacture valuable (i.e. saleable) coproducts.

Table 1
Different types of waste and waste derived fuels (EIONET, 2012; Lupa et al., 2011; Wagland et al., 2011; Zevenhoven and Saeed, 2003).

Fuel type	Definition
Fuel	Energy carrier intended for energy conversion
Municipal Solid Waste (MSW)	Waste generated by households (may also include similar wastes generated by small businesses and public institutions), e.g. paper, cardboard, metals, textiles, organics (food and garden waste), and wood
Commercial & Industrial Waste (C&IW)	Waste derived from commerce and industry, e.g. packaging, paper, metals, tyres, textiles, and biomass
Refuse Derived Fuel (RDF)	Fuel produced from MSW and/or C&IW that has undergone processing (i.e. separation of recyclables and noncombustible materials, shredding, size reduction, and/or pelletizing), has an input-driven specification
Solid Recovered Fuel (SRF)	Comparable to RDF but considered more homogeneous and less contaminated, is market-driven due to tighter quality specifications
Automotive Shredder Residue (ASR)	Complex mixture of plastics (rigid and foam), rubber, glass, wood, paper, leather, textile, sand plus other dirt, and a significant fraction of metals

2. Waste valorization: boundary conditions

2.1. Bottlenecks

Nowadays, sustainability and its conciliation with the waste management system are hot topics. However, despite the various technologies available for waste valorization, a large number of issues remain unaddressed (Stehlík, 2009).

The environmental aspect including the emissions of pollutants and greenhouse gases, is of particular interest. Waste streams often consist of diverse types of materials, originating from a number of different sources. These raw materials may contain elements such as chlorine, sulfur and heavy metals that could affect the quality of the products formed in the waste treatment process (e.g. syngas, bottom ash, fly ash, digestate, vitrified slag). Consequently, special abatement technologies need to be used to reduce the content of pollutants in the products generated and/or in the emissions to air, water and soil. Evidently, these stringent measures come at a price.

Another bottleneck is the economic feasibility of ELFM which depends strongly on the development of innovative technologies with high WtE efficiencies (Van Passel et al., 2013). These new technologies need to prove their economic viability prior to full-scale implementation. Energy efficiency is an important system indicator used for comparison with conventional, well-established technologies. A lack of data (both experimental and theoretical) often hampers such a comparative study.

An urgent need exists to gain modeling expertise in the field of waste valorization processes. A validated system model facilitates system design and optimization, in addition to reducing the need for experimental work. Numerical experiments can be used to predict operating conditions when scaling up or down and as such to define optimal operating windows. Furthermore, the suitability of various feedstock can be assessed.

A basic prerequisite for waste treatment processes is the adequate characterization of materials contained in the available waste streams. Characterization data give an indication of the