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# Waste to energy – key element for sustainable waste management

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ABSTRACT

Human activities inevitably result in wastes. The higher the material turnover, and the more complex and divers the materials produced, the more challenging it is for waste management to reach the goals of "protection of men and environment" and "resource conservation". Waste incineration, introduced originally for volume reduction and hygienic reasons, went through a long and intense development. Together with prevention and recycling measures, waste to energy (WTE) facilities contribute significantly to reaching the goals of waste management. Sophisticated air pollution control (APC) devices ensure that emissions are environmentally safe. Incinerators are crucial and unique for the complete destruction of hazardous organic materials, to reduce risks due to pathogenic microorganisms and viruses, and for concentrating valuable as well as toxic metals in certain fractions. Bottom ash and APC residues have become new sources of secondary metals, hence incineration has become a materials recycling facility, too. WTE plants are supporting decisions about waste and environmental management: They can routinely and cost effectively supply information about chemical waste composition as well as about the ratio of biogenic to fossil carbon in MSW and off-gas.



## 1. Introduction

Waste management practices have evolved over many centuries. While in the beginning, hygienic considerations were on top of the priority list, the rapidly rising amount and complexity of wastes became main issues of waste management in today's affluent societies. In parallel to the economic development, waste management went through several stages to reach the high technological level that is observed today. Sophisticated collection systems, paired with efficient separation processes, allow high recovery and recycling rates. Additionally, a large fraction of municipal solid waste (MSW) is treated in waste to energy (WTE) plants, and most toxic organic wastes are destroyed in hazardous waste incinerators. In view of high and increasing recycling rates and of growing investments into prevention measures, the question arises, what the main function of thermal processes in modern waste management is. Is incineration still necessary and appropriate to fulfill waste management goals, or are other and better means available?

The objective of this introductory paper is to investigate the role thermal processes play for sustainable waste management. In a first step, the total turnover of materials in modern societies is summarized, because this anthropogenic metabolism determines the wastes that have to be taken into account by any waste management system. Next, the goals of waste management, which are crucial for the design of management strategies, are discussed. The question is addressed how these goals can be reached, and which contributions processes such as WTE can provide. Emphasis is laid on the following topics: energy, materials, costs, and social acceptance. The capacity of WTE to contribute to a recycling society is investigated by assessing the potential to supply energy and secondary materials from wastes.

A unique characteristic of this paper is the material balance approach: Waste management and all corresponding treatment processes are considered as input–output systems that have to observe the requirement of the law about the conservation of matter. This ensures a holistic view, affirming that valuable as well as hazardous substances and energy are taken into account, from entering waste management until disposal in final sinks. Also, additional features of WTE are taken up such as the application of incinerators for analytical purposes (waste composition, fraction of biogenic carbon in waste input). Finally, reasons are summarized why WTE is an indispensable part of every sustainable waste management system.

This introduction focuses mainly on MSW incinerators (grate furnaces and fluidized bed combustion) and does not cover all available thermal waste treatment processes. Technologies such as gasification (cf. Arena, 2012), pyrolysis (Malkow, 2004) and

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plasma arc (Pourali, 2010) treatment are discussed in other papers of this special issue on thermal waste treatment. However, most aspects that are considered in the following paragraphs are independent of the type of thermal treatment, and the conclusions hold true for a wide array of thermal treatment technologies.

## 2. Waste as a product of the metabolism of the anthroposphere

The sphere where human activities take place – the anthroposphere – can be looked at as a living organism with inputs, stocks and outputs. To operate this metabolism, materials are imported from the earth's crust or synthesized from precursors, and are utilized over a certain time. Like any living organism, the anthroposphere sets off materials. These are on one hand emissions to water, air and soil, and on the other hand waste products generated by the use of consumer products and the replacement of investment goods. Hence, waste management controls a large fraction of the output of the anthropogenic metabolism. In order to design and plan waste management systems, the metabolism of the anthroposphere must be known. Without this knowledge, neither future amounts of wastes nor its compositions can be anticipated. In particular the stock of materials in long living goods is of primordial importance, because this stock comprises the largest amounts of bulk materials, and of hazardous materials, too.

The evolution of civilization goes hand in hand with a growing per capita turnover of materials. During prehistoric times, primitive men had a total throughput of about 6 t/capita and year, consisting mostly of food, air, and water, and a few kilograms for tools and clothing. In contrast, a modern citizen requires about 86 tons per capita and year just for the activities in his private home and for transportation (cf. Table 1).

If larger system boundaries are taken into account, considering all materials that are required to sustain urban life in a city (public and private infrastructure such as buildings for administration, education, sports, culture and leisure; roads, public transport; industry, service industry, trade, and commerce), the material turnover increases to about 200 tons per capita and year. An actually larger amount of material flows results if the total turnover is regarded, including mining and production processes and their respective tailings and wastes.

Even more striking is the growth in material stocks: While the per capita belongings of primitive men amounted to less than 100 kg, the stock of his modern counterpart is about one thousand times larger and amounts to more than 300 tons in his private home (including transportation infrastructure), and even 400 tons if the total urban metabolism is considered. The bulk of this stock consists mainly of mixtures of sand, gravel, and stones (concrete, bricks, other building materials), metals (iron, aluminum, zinc, copper), plastics, and wood. In addition, many metal compounds and thousands of organic substances are comprised in the stock to ensure certain functions.

For waste management, the stock is important because it represents the future waste. Materials in the stock cannot be prevented, they already exist and will eventually become obsolete. Thus, the understanding of stock dynamics is important for early recognition of waste amounts and compositions. Fast growing economies such as some Asian countries still have a comparatively small material stock which is now rapidly filled up. For these countries, input into the economy is much larger than the output, thus to establish a recycling market for long living materials is difficult due to the lack of wastes for recycling. It will take several decades until the large amounts of steel and construction materials come to their end of life status and enter waste management and recycling. In contrast, mature societies with a highly developed infrastructure and lower growth rates are more likely to have a waste output that can be compared to the primary supply input. For these countries, recycling can provide a major part of the commodities needed in the market.

For both types of metabolism – fast growing or mature – it is a fact that all materials that are brought into the system at one point in time will turn into waste. The only exceptions are dissipative emissions during the life time of the material (e.g. $CO_2$, or products of weathering, corrosion, and erosion), and certain materials of very high cultural value that are preserved "forever". Thus, it is important not only to know the mass of the stock, but also its composition.

The content of materials in the anthropogenic stock changes constantly and is as dynamic as the mass of the stock. While most materials are inorganic and potentially well suited for recycling, many organic substances are also contained in the stock. These organic materials comprise degradable substances such as cellulose (wood) as well as refractory compounds such as PVC (polyvinylchloride). The bulk of these substances, in particular polymers such as PET (polyethylene terephthalate) or PP (polypropylene), are of no health concern, but some are hazardous and are regulated as so called POPs (persistent organic pollutants) by the Stockholm convention. Today's anthropogenic stock contains substances that are out phased by the Stockholm convention, and thus are highly restricted in their use; due to their hazardous properties, they cannot be put on the market today as recycling products. Alternative solutions are required.

The stock of hazardous organic materials is large, and amounts globally to millions of tons. Because products often contain POPs, such as the flame retardants polybrominated diphenylethers (PBDEs) in plastic materials, the mass flows of materials containing POPs are huge. This is also the case for certain heavy metals that are added to polymers: in order to improve properties such as resistance towards degradation by UV-light, temperature, chemicals, and microorganisms, heavy metals like lead, zinc, tin, antimony and others are used as additives for plastic materials. The stock of PVC for instance holds large amounts of cadmium that – in the past – has been used as a stabilizer in the range of 1–10 g Cd per kg of PVC.

Although there is abundant data about the individual production and consumption of goods and substances, there is no compre-

**Table 1**
Per capita material flows through private households in affluent societies (based on data from Baccini and Brunner, 2012).

| Activity | Input [t/c.y] | | Output [t/c.y] | | | Stock [t/c] |
|---|---|---|---|---|---|---|
| | Total | Water fraction | Solid waste | Sewage | Off gas | |
| To nourish[a] | 5.7 | 1.0 | 0.1 | 0.9 | 4.7 | <0.1 |
| To clean | 60 | 60 | 0.02 | 60 | 0 | 0.10 |
| To reside | 10 | 0 | 1.0 | 0 | 7.6 | 120 + 1[b] |
| To transport | 10 | 0 | 1.6 | 0 | 6.0 | 280 + 2[b] |
| Total | 86 | 61 | 2.7 | 61 | 19 | 300 + 3[b] |

[a] Including air for breathing.
[b] Change in stock [t/c.y].