1 Introduction

1.1 State-of-the-art waste disposal concepts

In most European Countries waste disposal basically relies on landfill. However, with the implementation of the European Waste Landfill Directive the disposal of untreated waste is or will be omitted in the near future. With the implementation in June 2005, some European countries ran into significant capacity problems. Germany is one example, as waste treatment capacities are still insufficient. As a result, waste has to be temporarily stored. Other European countries still have some time to develop and improve their current waste management systems. Nevertheless the lack of environmental-friendly disposal capacities is and will be an enormous challenge in the next decade.

In most developed countries, incineration, with energy recovery in the form of electricity and/or useful heat, and the utilisation/landfill disposal of the solid residues, is one of the principal elements of integrated management systems for municipal solid waste (MSW). Commonly used are grate firing systems with capacities ranging from 50,000 up to 500,000 Mg/a. Some European countries, such as Germany and the Netherlands, have significant incineration capacities installed. In Germany, the available incineration capacity was approx. 18 Mio. Mg/a in the year 2006 (see Fig. 1-1) including facilities currently under construction.

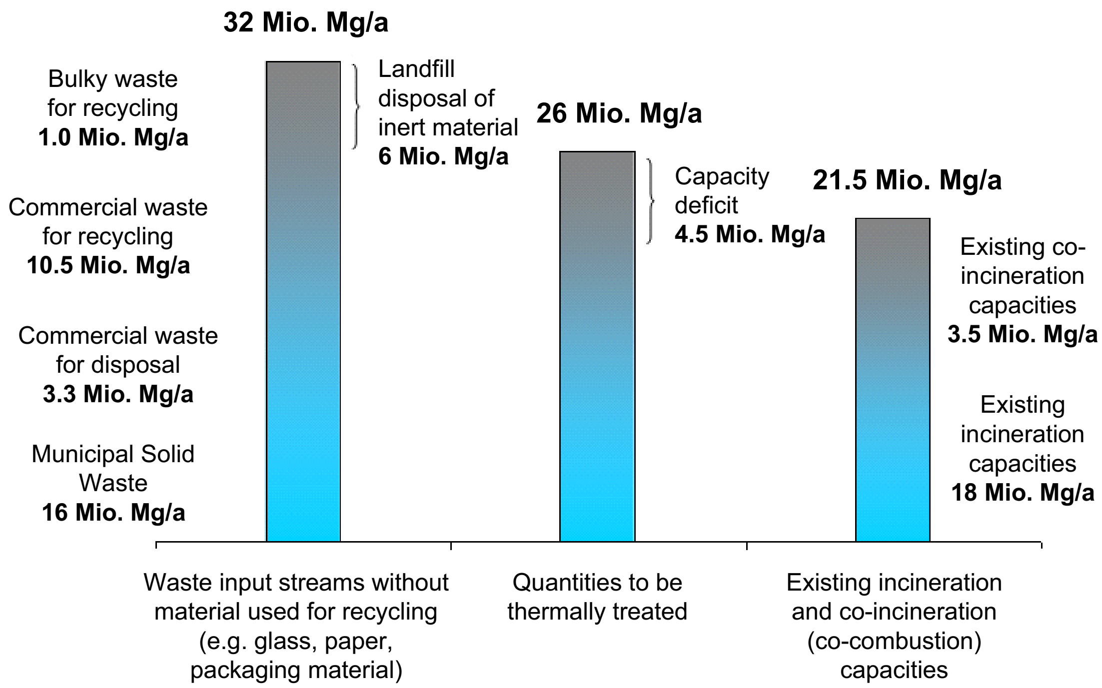

Fig. 1-1: Waste management scenario (Germany) and quantities for the year 2006 [1]

[1] PROGNOS AG, VGB PowerTech, 10/04, (2004)

In addition to incineration, approx. 3.5 Mio. Mg/a of waste are currently co-incinerated, primarily in industrial furnaces such as lime- or cement kilns, but also in industrial processes like smelters, where they partly replace valuable fossil resources. In order to prevent misunderstandings, these waste materials do not consist of untreated MSW, but of selected mono fractions with considerable energy content. Taking incineration and co-incineration capacities into account, approx. 21.5 Mio. Mg/a can be thermally treated. Nevertheless the total waste input stream does not consist of MSW only. Considering all relevant waste streams (including commercial waste) without materials used for recycling up to 26 Mio. Mg/a have to be thermally treated, thus resulting in a capacity deficit of some 4 to 5 Mio. Mg/a in the year 2006 [1].

Incineration processes, however, have been subject to increased capital and operating costs due to the improvements - required by legislation - in their environmental performance. To overcome missing capacities and economic deficits other technologies are sought. As already mentioned, co-incineration is a technically feasible and short-term available solution, which is commonly applied in industrial processes. The co-incineration of pre-treated waste materials in thermal power plants is a further step - offering high-efficient waste-to-energy conversion - and could be considered as an emerging market in the future.

In this context, the production of fuels from waste materials suitable for utilisation in thermal power plants is a challenging development. Contrary to industrial processes like kilns or smelters, the technical demand upon such waste-derived fuels is considerably higher. With the availability of new and reliable automatic sorting technologies such as near-infrared detection and separation (NIR), their production has become technically feasible and economically attractive [2]. The idea behind this concept is to pick valuable materials such as mixed plastics from the raw waste stream and convert them into a combustible form. Therefore, the production process includes further mechanical process steps such as crushing, classifying, drying and ferrous/non-ferrous separation. The long-term operational effects and environmental compatibility of such waste-derived fuels - in the following referred to as Solid Recovered Fuels (SRF) - are currently under development and demonstration.

Going beyond conventional incineration or co-incineration, advanced concepts refer to different technological approaches such as gasification and pyrolysis processes, or the combination of different process steps, e.g. gasification followed by combustion. Despite of the projected benefits and advantages of such technologies, the results achieved in industrial scale were often negative and economical unattractive [3].

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[2] Th. GLORIUS: „Erfahrung mit Produktion und Einsatz gütegesicherter Sekundärbrennstoffe – RECOFUEL“, 11.Fachtagung Thermische Abfallbehandlung, München, 14-15.03.2006, ISBN-10: 3-89958-198-9, (2006)

[3] Siemens/KWU: „Keine Akquise in Deutschland“, Entsorga-Magazin 5, S. 121, (1999)

The combination of separate facilities is a further approach to provide economical and environmental solutions in the future. An example for an innovative combined process is the so-called UPSWING process. UPSWING is the acronym for Unification of Power Plant and Solid Waste INcineration on the Grate, describing the combination of a conventional grate firing system with a power plant both on the steam- and the flue gas side. The concept was developed by the Forschungszentrum Karlsruhe, Germany, and patented 1998-2003 [4]. However, it has to be emphasised that the UPSWING process is not realised up to now, neither in demo- nor full-scale application.

The UPSWING concept was recent subject of the European Research Project UPSWING (ENK5-CT-2002-00697), which was successfully finished in 2006. Based on the results of this project, the present thesis focuses on this new and promising process, its environmental, economical, and operational advantages being compared with other available technologies such as conventional waste incineration and co-incineration.

The following descriptive part will give a more-detailed insight of the relevant processes, further discusses the demand for alternative waste disposal concepts, and concludes with the methodology used in this thesis.

1.1.1 Municipal Solid Waste Incineration (MSWI)

The typical system for MSWI in Central Europe is the so-called European mass burner, a facility which incinerates the waste on the grate without prior treatment. Often, waste incineration is referred to as “mono-combustion”, although the term “incineration” fits better to the grate firing concept. Anyway, the chemical energy of the waste is released as heat in the combustion process and transferred to the boiler system. Modern boilers recover more than 80% of this heat. The steam can be utilised in different ways such as district heating purposes, production of electrical power, direct utilisation in industrial processes, or a combination of the mentioned utilisation paths.

MSWI has relatively low electricity generation efficiencies, resulting from the poor quality of MSW as a boiler fuel and the relatively low steam parameters achievable, due to concerns about excessive corrosion rates of high temperature boiler components. In case of power generation, modern plants reach an average electrical efficiency of 18%, while modern plants can reach up to 25%. Optimum efficiency is achieved by a combination of power and heat utilisation (combined heat and power, CHP). Using CHP, energy recovery in the range of 70 to 75% becomes possible [5].

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[4] H. HUNSINGER, S. KREISZ, H. SEIFERT, J. VEHLOW: “Verfahren zur Beschickung der Verbrennungseinheit eines Kohlekraftwerks“; DP-OS 19 723 145 (10.12.1998), DP-PS 19 723 145 (8.8.2002), EP-PS 59 804 147 (15.5.2002), JP-PS 3 392 424 (24.1.2003), IL-PS 132 336 (18.12.2003); (1998, 2002, 2003)

[5] E. DIRKS: „Praxishandbuch Abfallverbrennung – Technik und Betrieb thermischer Behandlungsverfahren“, Herrentor Fachbuchverlag, ISBN 3-00-005535-5, (2000)

1.1.2 Co-combustion of Solid Recovered Fuels (SRF)

Co-incineration (or co-combustion) of pre-treated waste-derived fuels such as SRF describes their co-utilisation in industrial furnaces or power plants as a supplement fuel. The intention is to replace a certain amount of the regular fossil fuel (coal, oil, gas), mainly because of economic reasons. In respect to the closed combustion system of a power plant, where coal is combusted and not incinerated, the term “co-combustion” will be applied for SRF, accordingly.
Complying with the emissions and air quality control directives, co-combustion of SRF can be an efficient and low-cost form of energetic and material exploitation. The high biomass content of SRF (usually > 50%) is an additional means to use a substantial potential in a highly-efficient and cost-effective way in power generation, thus making a lasting contribution to CO_2 emission reduction and resource saving. Nevertheless, co-combustion processes do not provide secure control of a number of the pollutant species present in the waste stream, and particularly of the heavy metals and the halogens. Hence, the investigation of this potential disadvantage becomes one of the primary objectives of this thesis.

1.1.3 Combined processes

An early concept realising this principle was the so-called “Satellite Combustion”, developed by the German Company “Hölter” together with the former German Engineering Company “Steinmüller”. Hot flue gases of a waste incinerator were directly transferred into the boiler of a power plant. The main problem of this concept is that all pollutants are transferred to the power plant process. Disturbance of the power plant process, e.g. by exceeding emission limits, increased corrosion problems (potentially induced by chlorine), or deterioration of power plant residues, could be expected.

The UPSWING process can be considered as a subsequent improvement of the Hölter Process. The UPSWING process includes partial flue gas cleaning of the waste flue gases prior to injection into the coal boiler. As a consequence, the risk of negative effects on the power plant process should be omitted. Furthermore, the steam produced in the boiler system of the waste incinerator is included in the steam circuit of the power plant. As a result, increased efficiency of waste-to-energy conversion can be expected. As the focal subject of this thesis, the process and its boundary conditions will be discussed in chapter 1.3.

1.2 The demand for alternative waste disposal concepts

The European Landfill Directive (1999/31/EC) sets strict rules on landfill disposal of untreated MSW in the EU countries and forces a reduction of the biodegradable quantities disposed off to landfills up to 35% of the amount produced in 1995 in the coming decade. More environmentally friendly waste management options are promoted under the framework of the European Waste Strategy (1996), which lays down the hierarchy of waste management policy as follows: (1) Prevention of waste; (2) Recovery (material over energy); and (3) Final disposal.

This hierarchy must be applied with certain flexibility and be guided by considering the best environmental solution taking into account economic necessities and social requirements. Where environmentally sound preference should be given to material over energy recovery, although in certain cases preference can be given to energy recovery. Considering the application of a preferable option a clear definition is still required in most member states.

Therefore, it is necessary to point out the environmental benefits of thermal waste treatment with heat- and energy recovery. The concept comprises not only the protection of human health and environment, but is also capable to conserve fossil fuels by energetic utilisation of residues and waste. This aspect leads to an issue with increasing importance: Energy recovery from waste and residues can significantly contribute to climate protection by avoidance of organic emissions from landfills (e.g. methane) and reduced CO_2 emissions by replacing fossil fuels. Furthermore, approx. 50% of MSW can be attributed to as biomass, leading to an additional benefit in terms of CO_2 emission reduction. The utilisation of waste is therefore fully complying with the requirements of the European Directive 2001/77/EC on the promotion of electricity from renewable sources.

Considering the global development of population and energy consumption (see Fig. 1-2), the future importance of energetic utilisation of waste becomes obvious. Despite of all efforts to safe energy and to improve efficiency, worldwide energy consumption will increase dramatically, especially in developing and emerging countries.

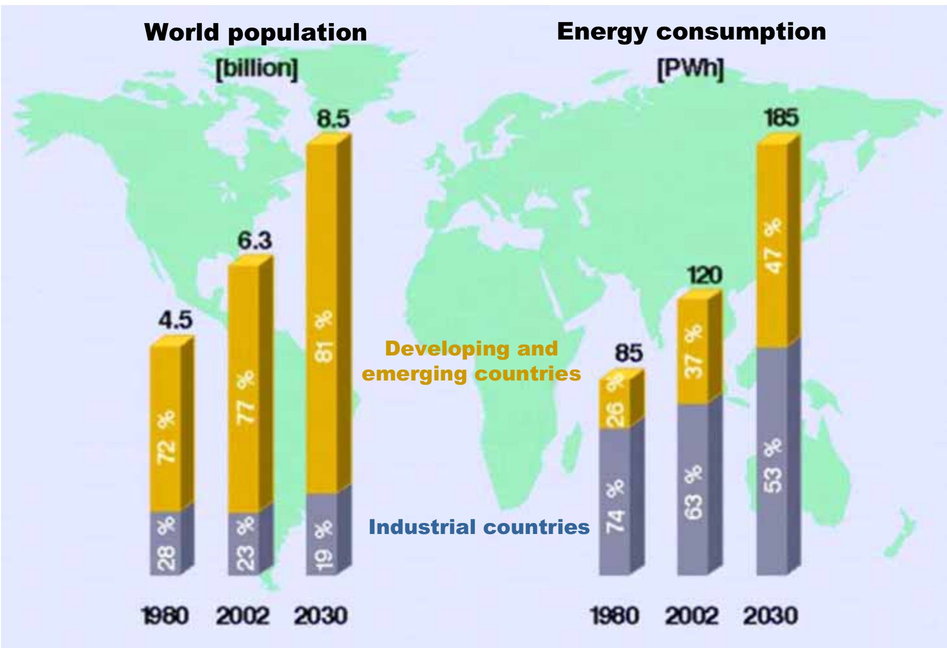

Fig. 1-2: Forecast of world population and energy consumption [6]

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[6] International Energy Agency (IEA), Forecast of world population and world energy consumption, (2002)

However, the disproportion between developing and industrial countries will remain. For the time being 25% of the world population consume approx. two-thirds of the total energy supply. The utilisation of waste for heat- and electricity production can significantly contribute to the reduction of necessary energy imports. In this context more efficient and sustainable waste treatment policies and technologies become gradually necessary within the EU and worldwide. In view of these demands, the UPSWING process was developed as an advanced waste treatment concept.

1.3 UPSWING as an advanced waste treatment concept

The UPSWING process, describing the integration of a waste incinerator on the flue gas and steam sides to a large coal-fired boiler, has been developed to overcome the economical deficits of conventional MSWI while maintaining its environmental advantages [7][8]. A schematic overview of the UPSWING process is given in Fig. 1-3, covering the waste-to-energy section, the partial flue gas cleaning concept, as well as the integration of both steam- and waste flue gas to the power plant.

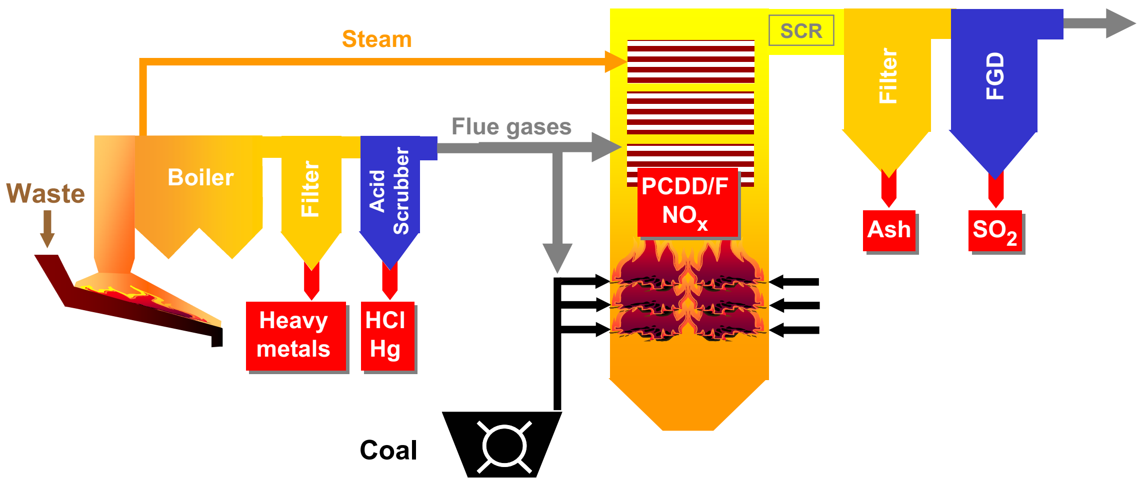

Fig. 1-3: The UPSWING concept

The waste-to-energy section consists of a grate firing and boiler system comparable to those utilised in modern MSWI. This is an important aspect, as reliable technology is available on the market, which can be used without the need for further research- or technological development. The steam produced by the waste is forwarded to the boiler system of the connected power plant. Hence, increased steam parameters can be achieved and its expansion in the generator unit of the power plant leads to higher electrical efficiency. Furthermore, the waste flue gases - partially cleaned - are injected into the combustion chamber.

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[7] J. VEHLOW, H. HUNSINGER, S. KREISZ, H. SEIFERT: „UPSWING - Kombination von Abfallverbrennung und Kohlekraftwerk“, In: Schriftenreihe des Fachgebietes Abfalltechnik Universität Kassel (Hrsg.: Urban, A.I.), 67 – 82, Kassel, Germany, (2003)

[8] J. VEHLOW, H. HUNSINGER, S. KREISZ, H. SEIFERT: “UPSWING - A novel concept to reduce costs without changing the environmental standards of waste combustion”, IEA Bioenergy Joint Task Seminar, Tokyo, October 28, (2003)

1.3.1 Flue gas integration and partial flue gas cleaning

The idea behind the partial flue gas cleaning concept is to keep critical substances away from the power plant process, thus limiting environmental and operational disadvantages. The partial flue gas treatment system is based on de-dusting of the waste flue gases using conventional bag-filter systems (BFS) or electrostatic precipitators (ESP). The major part of critical heavy metals is removed with the fly ash. Acid components like HCl, HBr and HF, imposing significant risks for boiler operation, are removed in an acid scrubber, which is part of the partial waste flue gas treatment process. The partially cleaned gas, which still contains SO_2 and NO_x as well as gaseous PCDD/F and other organic pollutants, is introduced to the power plant process. The remaining gaseous PCDD/F is totally destroyed inside the combustor. NO_x and SO_2 will be reduced to acceptable levels by the air pollution control system (APC) of the boiler.

1.3.2 Steam integration

Steam integration refers to the utilisation of the waste energy in the turbine/generator set of another plant (e.g. combined cycle turbine). A comparable approach was realised in Mainz, Germany, by company Martin GmbH. Steam produced from MSWI (40bar and 400°C) is connected with a combined cycle natural gas turbine as shown in Fig. 1-4.

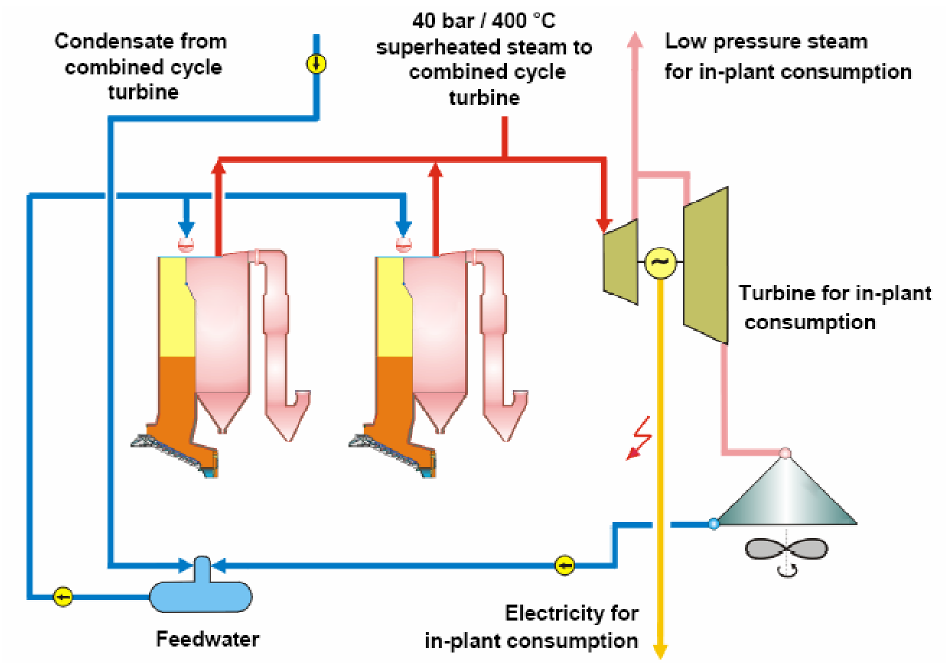

Fig. 1-4: Combination of MSWI and combined cycle gas turbine, Mainz, Germany [9]

Steam produced from MSWI (40bar and 400°C) is connected with a combined cycle natural gas turbine. The superheated steam produced is brought forward to a combined-cycle gas turbine process, where it is overheated and expanded in the combined cycle steam turbine. The condensate is returned to the MSWI feedwater tank. The MSWI plant is still equipped with a medium and low

[9] J. MARTIN: "Global use and future prospects of waste-to-energy technologies", Waste-to-Energy Research and Technological Council, Columbia University (USA), October 7-8, (2004)

pressure turbine in order to guarantee high operational flexibility. The combined electrical efficiency of this combined process was determined to be higher than 40%, which is far beyond conventional MSWI. A comparable concept was realised in Bilbao, Spain. Both examples show that steam integration is generally possible, although the efforts for integration to a coal-fired power plant in case of the UPSWING concept are expected to be significantly higher.

1.3.3 Expected benefits

The UPSWING concept basically relies on state-of-the-art technology; a development of new components is not required. Combination of the steam circuits of both facilities proposes higher net electrical efficiency in waste-to-energy conversion, leading to lower CO_2 emissions in electricity production. Furthermore, a reduction of the specific investment costs in comparison to a same-sized standalone MSWI can be expected. All factors should result in a lower gate fee per Mg (or tonne) of waste to be disposed of. In comparison to alternative waste-to-energy concepts, the UPSWING concept proposes the same stringent environmental standards as conventional MSWI. One of the major benefits of the UPSWING concept is the integration to existing power plants. Approx. 23.5% of the world energy consumption and 38% of the world energy production are covered by the utilisation of coal [10]. With this background the concept is especially favourable for those countries which largely rely on fossil fuels and lack of state-of-the-art waste treatment facilities, e.g. Poland, Romania, and Bulgaria.

1.4 Methodology

1.4.1 Problem definition and primary objective

The UPSWING concept is proposed as an advanced technical solution to solve economical deficits of conventional thermal waste treatment as well as environmental/operational deficits of alternative waste treatment concepts such as direct co-combustion. However, the UPSWING process is still a (theoretical) concept and not realised yet. A direct comparison is therefore not possible. Nevertheless, a method was sought which should allow exactly such a process comparison, and to qualify the UPSWING process as a potential option in a future thermal waste treatment scenario. This approach is discussed in chapter 1.4.2, with the initial idea to compare both UPWING and direct co-combustion and subsequently elaborate the advantages respectively disadvantages of the one or the other concept.

1.4.2 Approach and areas of concern

The question is now how to approach to such an ambitious task. Taking a look on the proposed benefits of the UPSWING concept, already discussed in the previous chapters and summarised in Fig. 1-5, may help to identify the relevant aspects, worth to be taken into consideration:

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[10] Gesamtverband des deutschen Steinkohlebergbaus, Steinkohle Jahresbericht, (2003)