MSc Program

Renewable Energy in Central and Eastern Europe

Can Waste to Energy Technologies Provide Energy Solutions for CEE?

An Analysis of Competitiveness.

A Master's Thesis submitted for the degree of

"Master of Science"

supervised by

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Affidavit

I,**Imre M. Schebeck**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Can Waste to Energy Technologies Provide Energy Solutions for CEE? An Analysis of Competitiveness.", 103 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

With the EU commitment to increase renewable energy by 20% by 2020 and reduce CO2 emissions by 20%, electricity production from renewable energy sources, so far largely neglected in the CEE Member States, has to be expanded. The investors' perspectives to invest in renewable energy in CEE are at the center of this analysis.

The core question which this paper attempts to ascertain is: Can biogas and waste -to-energy offer high rates of return to attract investments and contribute to efficient energy and environmental solutions in CEE? The main drivers for such investments are: feedstock availability and prices, robust technologies alternatives, and attractive feed-in tariffs. These drivers are assessed in detail.

The most important conclusions are: Municipal solid waste and sewer sludge are an increasing problem in all CEE Member States. These waste streams are a free feedstock. New processing technologies for anaerobic digestion and plasma-arc gasification can turn the waste problem into a highly attractive financial investment opportunity to produce a renewable energy with little or no carbon footprint.

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1 Introduction

Prior to the 1989/90 transition, centrally planned economies with a predominant reliance on heavy industry dominated the 10 CEE countries (Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia), which now have become member states of the European Union. Coal and nuclear generated energies were the predominant sources. With increasing need to replace technically obsolete coal fired power stations, energy security has become a major concern for the CEE countries. The recent gas crises have only exacerbated this concern.

For the next decade there will be a great push to establish new generating capacities. With the EU commitment to increase by 2020 renewable energy by 20% and reduce CO2 emissions by 20%, electricity production from renewable energy sources, up to this point, largely neglected, have to be expanded. The existing heavy reliance on coal generated energy presents these countries not only with an environmental problem but also with a great opportunity. Replacing these coal fired power plants with renewable energy provides an opportunity for earning carbon credits under the Kyoto agreement, thus providing an attractive source of finance for investors to expand into cleaner energy systems.

Expanding wind and solar energy is facing constraints in CEE. Suitable land is increasingly difficult to obtain, property rights to land are often uncertain and land prices for good locations are on the rise. Grid access is sometimes difficult to obtain and where it is available it can not handle peak loads generated by wind and solar energy. Resistance by communities and nature conservation groups, particularly to large wind parks, is on the rise, thus delaying investments and increasing investment costs. Where investors are confronted with high upfront risks, the potential investments in renewable energies loses their financial attractiveness.

The agriculture and forest production in most of CEE can provide a potentially large feedstock for biogas plants. Disposal of municipal solid waste, hazardous waste and sewer sludge is not only an ever increasing global environmental problem, but a problem of severe proportion and still largely unaddressed in all CEE. Waste is plentiful and ever rising. It is a free energy resource. It can provide an unlimited, free and sustainable feedstock for renewable energy. Thus, WTE could become an attractive energy solution.

1.1 The Core Objectives

The investors' perspectives to invest in renewable energy in CEE are at the center of this analysis. Their overriding objectives are to maximize their return and to minimize the possible risks associated with investments in renewable energy. From the perspective to minimize the risks of investments, wind and solar energy appear less attractive given the above mentioned problems. While without dispute, hydro-power plants of 10MW or less offer great investment opportunities in several CEE countries, they will not be considered in this analysis, since the permit process and environmental assessments can be complex and time consuming. Little attention has so far been given in all CEE countries to WTE. Agricultural and forest byproducts, municipal sludge and municipal solid waste are energy feedstocks which can be obtained free of charge and generate revenues through tipping fees. Little or no use has so far been made of these feedstocks in CEE, although they are an important alternative energy source to fossil fuels and could provide important contribution towards the reduction of CO2 emissions. This will be the primary focus of the Thesis.

The Thesis will examine if WTE can offer a high rates of return to attract investments and contribute to efficient energy and environmental solutions in CEE. From an investors point of view it will be essential to determine:

- What is the state of the art of new WTE technologies? Have they been proven to be operational beyond the research or pilot phase and without massive reliance on subsidies?

- How profitable are selected renewable energy investments in WTE projects in the CEE countries?

- Are these technologies financially viable to attract investments? Can they sustain without government subsidies in form of feed-in tariffs or EU grants?

1.2 Method of Approach

Extended literature review and an exchange with relevant equipment suppliers, economists, and investors are the underpinnings for this Thesis. The Thesis will assess for the new Member States of the CEE:

- The EU push for renewable energy;
- The role of renewable energy in electricity production;
- The potentially available supply of feedstock for biogas from agricultural, forest and byproducts;
- Assessment of sludge from waste water treatment facilities, municipal solid waste and hazardous waste as a potential feedstock for WTE ;
- The state of the art of new biogas and waste to energy technologies; and
- The financial profitability of proven, ready available new technologies for electric power generation from biogas and MSW and hazardous waste.

2 A Push for Renewable Energy Sources in CEE.

2.1 The EU Directives and Targets for Renewable Energy

In 1997, the European Commission established as a target that the share of renewable energy should reach 12% in total energy consumption by 2010 [1]. In the subsequent Directive 2001/77/EC, all member states adopted non-binding national targets for their share of electricity consumption to be met by renewable energy sources. For the EU-25 the overall 2010 target set the share of gross electricity consumption from renewable energy at 21%. These directives, combined with various incentives and regulatory schemes, have provided a major push to renewable energy in 10 CEE . With the present state of progress, the EU anticipates that the 2010 target for RES electricity can not be fully, but almost met.

In March 2007, the road for a more sustainable energy future was paved, when all 27 Member States adopted a mandatory target that by 2020 the share of renewable energy in total energy consumption must reach 20%. As of 2020, such reduction would translate into an annual reduction of fossil fuel demand of 2,931TWh, resulting in an annual CO_2 emission reduction in the order of

600 to 900 million tons [2]. This is an ambitious target since in 2005 the share of renewable energy was only 8.5% of total energy consumption.

Supporting the energy target is the EU goal to reduce CO2 emission by at least 20% by 2020. In order to provide the legislative underpinnings to achieve the ambitious 2020 energy targets, the European Commission passed in 2009 the Directive 2009/28/EC on the promotion of the use of energy from renewable energy source (RES), and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC [3]. The RES Directive addresses administrative and procedural barriers of authorization for renewable energy systems, grid access, and cost sharing of grid connections, among others.
The Directive also establishes for each Member State mandatory targets for the share of renewable energy in total energy consumption by 2020. The calculations for these targets are based on the 2005 share of these countries, plus an additional 5.5% and a GDP weighted adjustment. Table 1 below shows the mandatory targets for the member States of CEE. [4]

Table 1 Mandatory national targets set out in the RES Directive (2005 and 2020)

CEE Countries	Share of Energy from RES/Final Consumption of Energy 2005	Target for Share of Energy from RES/Final Consumption of Energy 2020
Bulgaria	9.40%	16.00%
Czech Republic	6.10%	13.00%
Estonia	18.00%	25.00%
Latvia	34.90%	42.00%
Lithuania	15.00%	23.00%
Hungary	4.30%	13.00%
Poland	7.20%	15.00%
Romania	17.80%	24.00%
Slovenia	16.00%	25.00%
Slovak Republic	6.70%	14.00%

Source: European Renewable Energy Council, Renewable Energy Technology Road Map, 2008

The EU assumes that, with growing support for renewable energy, the 2020 targets for RES electricity can be achieved, particularly since new technology breakthroughs in all fields of renewable energy are expected to take hold by 2020. The 2020 targets and the required annual growth rates to achieve these RES electricity objectives are presented in Table 2 below,

Table 2 Renewable Electricity Installed Capacity Projections

Type of energy	2002 Eurostat	2006 Eurostat	Annual growth rate 2002-2006	Projection 2010	Annual growth rate 2006-2010	Projection 2020	Annual growth rate 2010-2020
Wind	23.1 GW	47.7 GW	19.9	80 GW	13.8	180 GW	8.5
Hydro	105.5 GW	106.1 GW	0.2	111 GW	1.1	120 GW	0.8
Photovoltaic	0.35 GWp	3.2 GWp	73.9	18 GWp	54.0	150 GWp	23.6
Biomass	10.1 GWe	22.3 GWe	21.9	30 GWe	7.7	50 GWe	5.2
Geothermal	0.68 GW	0.7 GW	0.7	1 GW	9.3	4 GW	14.9
Solar thermal elect.	-	-	-	1 GW	-	15 GW	31.1
Ocean	-	-	-	0.5 GW	-	2.5 GW	17.5

Source: European Renewable Energy Council, Renewable Energy Technology Road Map, 2008

For the CEE countries power generation from renewable sources (hydro, biomass and wind) has shown only a modest growth between 1996 and 2006, growing from 67TWh to 77.2TWh respectively. Hydro accounted for nearly all of the power generation from renewables. Prior to 2003 biomass and wind energy were nearly negligible, but their installed capacity and production started to grow significantly thereafter. In 2006 the breakdown for renewable power generation stood at 93% for hydro, 6% for biomass and as little as 1% for wind. [5]

Remarkable has been the nearly tenfold increase of biomass generation between 2002 and 2006, jumping from nearly 500GWh to 4,500GWH respectively. This growth has been concentrated predominantly in Poland, Hungary and the Czech Republic, whereas in the other CEE countries biomass generation has been insignificant [6]. Over the same period wind power generation increased sevenfold, from 61MW to 435MG, although this is still a low generation level. No comprehensive data are available after 2006, but the fact that many new wind power generation project reached maturity, underlines that the wind power generation capacity expanded substantially. Like biomass, wind power generation is concentrated predominately in Poland, Hungary, the Czech Republic, Estonia and Latvia. In Bulgaria, with one of the best wind power potentials in CEE, substantial investments in wind power generation have only recently been carried out [7]. Annex I provides more detailed country data on electricity production and the importance of renewables.

Up to 2020 the European Commission estimates that the share of renewable energy in the EU's total electricity production could increase significantly as shown in table 3 below.

Table 3 Contributions of RES to Electricity Consumption

	2005 Eurostat TWh	2006 Eurostat TWh	2010 Projections TWh	2020 Targets TWh
Wind	70.5	82.0	176	477
Hydro [2]	346.9	357.2	360	384
Photovoltaic	1.5	2.5	20	180
Biomass	80.0	89.9	135	250
Geothermal	5.4	5.6	10	31
Solar thermal elect.	-	-	2	43
Ocean	-	-	1	5
TOTAL RES	504.3	537.2	704	1370
Total Gross Electricity Generation EU27 (Trends to 2030-Baseline) * (Combined RES and EE) **	3320.4	3361.5	3568	4078 3391
Share of RES	15.2%	16.0%	19.7%	33.6-40.4%

These figures are based on integrated growth rate projections. EPIA (European Photovoltaic Industry Association), believes that the Photovoltaic figures could be much higher if the development of the industry continued similar to the previous years. EPIA estimates that in 2020 350 GWp of Photovoltaic could be installed. EUBIA (European Biomass Industry Association) believes that the installed capacity for electricity generation from biomass could be in the order of 70 GW by 2020 if certain conditions are met, such as higher promotion of co-firing through incentives for utilities and for biomass production. ESTELA (European Solar Thermal Electricity Assocation) foresees the installed capacity of Solar Thermal Electricity in the range of 30 GW by 2020. As far as the geothermal sector is concerned, it must be noted that the Eurostat figure for 2006 does not take all geothermal technologies into account, which affects the entire calculation of the respective growth rates.

Normalised according to the formula proposed in the RES Directive

Source: European Renewable Energy Council, Renewable Energy Technology Road Map, 2008

Up to 2020 the European Commission estimates that the share of renewable energy in the EU's total electricity production could increase significantly as shown in the table 3 above.

The European Renewable Energy Council estimates that in case the EU can meet its energy road map, the share of renewable electricity can reach as high as 33 to 40% of total electricity production.

3 Sources, Characteristics and Availability of Biogas Feedstock in CEE

Depending on the technology employed a wide variety of feedstock lends itself for the production of Bioenergy. Three main sources of potential feedstock in CEE will be discussed in this chapter: biomass from agriculture and forestry production and their waste by-products; sludge from municipal waste water treatment plants; and municipal solid and hazardous waste. The sources and characteristics of these feedstocks will be assessed as well as their potential availability for commercial energy production. Mining of landfills which can provide a potential source for biogas, but will not be discussed. Since feedstock is the largest cost component for energy production and determines ultimately the costs of energy and the long-term profitability of the investment, it is a *sine qua non,* an essential condition, to keep its cost to a minimum. What makes feedstock from waste so attractive is its negative costs from the avoidance of dumping fees at land fills, although some costs will incur for feedstock preparation. In general, if feedstock is not priced at low prices, electricity from biogas can not be sold competitively and indirect or direct subsidies are required. Since from an investors point of view, no government can provide a long term guarantee for the level or duration of subsidies, it is imperative to make any investment decision without reliance on subsidies and/or grants, and to negotiate long term contracts for the provision of low cost feedstock.

3.1 Biomass

Biomass is a renewable energy source, in solid, liquid or gas form that can provide various forms of energy to be used in heating, cooling, electricity and transport. Bioenergy is CO2 neutral, since all CO2 emitted through combustion has already been stored beforehand during the plants' growth. The term Bioenergy comprises the technical means by which biomass is produced, converted and used. The great advantage of biomass, as opposed to wind and solar energy, is that it can meet both baseline and peak energy demands.

3.1.1 Sources of Biomass

There is a wide variety of biomass raw materials which in turn differ greatly in their physical and chemical composition. Moisture, ash content and ash composition of biomass are critical specifications for the performance of the various energy systems. For combustion of biomass the most critical factor is the moisture content, since it determines the caloric value. The moisture content ranges from 40-60wt% for fresh forest or industrial wood chips to 10-30wt% for waste wood. For illustration, the heating value of pellets with 8% moisture content have a LHV (lower heating value) of 17MJ/kg; log wood after 3 years of drying with 20% moisture shows a LHV of 14.4MJ/kg and wood after felling with 55% moisture has only a LHV of 7.1MJ/kg. [7]

To meet the ambitious EU goals for bioenergy by 2020 will require expanding the reliance of biomass feedstock from the present dominance of forestry and wood industry by-products to dedicated high yielding energy crops.

Wood pellets or briquettes from saw dust of wood industries and from forest by-products have gained an increased importance. Pelletization has drastically reduced moisture content and improved energy efficiency and plant operation. Densification also reduces transport costs and required storage capacity and improves storage life. With the exception of straw, the bulk and moisture problem have not been solved for other agricultural residues. The only draw back of pellets is their increased price as a result of energy costs for densification.

A greatly underutilized biomass resource throughout most of Europe,with the exceptions of Sweden and Finland, are forest residues. Accounting for environmental and biodiversity factors of forest management, the European Biomass Association estimates the harvest potential for forest residues within the EU at about 140 million m3, however at best less than 5% of that potential is presently used. Within CEE, Poland stands out with the largest reserve of unutilized forest residues (including stem wood), followed by Latvia and Hungary. [8]

Table 4 Available Felling Residues and Stump/Root Biomass

Country	Available Residues from felling(million m3/yr.)	Available Residues of Balance(milliom3/yr.)	Felling residues volume of stump wood available (million m3/y)
Czech Republic	3.2	1.5	0.5
Estonia	0.6	0	0.1
Hungary	0.7	1.2	0.1
Latvia	1	1.5	0.2
Lithuania	0.7	1.1	0.1
Poland	3.6	2.9	0.6
Slovakia	0.3	1.3	0
Slovenia	0.3	1.3	0

Source: European Biomass Association

Forest residues in CEE are underutilized because of extraction and transport cost, which frequently exceed the value of these residues for energy production. However in recent years new harvesting excavators and off road transporters have been developed to make the collection, bundling, on site chipping and subsequent transport from forest thinning, forest slash (waste wood after logging), stumps and roots cost effective. As a result of these competitive solutions forest residues have gained a price advantage over industrial wood chips (pellets and briquettes).

Dedicated biomass energy crops still play a minor role in agricultural production in Europe. Statistic of total acreage devoted to these crops in EU-27 is hardly existent; estimates are in the range of only 50 to 60thousand ha. The key characters of ideal Biomass energy crops are: perennial production, dry harvest, high dry matter yields in the range of 3 to 30 t/ha, high heat value, low or no fertilizer need, and low production costs. The most promising plants for solid biofuel production are miscanthus, canary grass and other reeds which are planted in a 12 to 25 years cycle and harvested annually. Willow, poplar and black locust are planted once every 20-39 years and harvested every 2 to 8 years. Energy production per ha for Miscanthus and reeds over 500GJ/ha, can reach nearly 1 1/2 times higher production than for poplar and willow, the most widely planted biomass energy crops. The key parameters for these crops in terms of yield, heating value, moisture and ash content are presented in table 6 below. [9]

Table 5 Comparisons of Technical Properties of Biomass Energy Crops

Crops	Dry mass yield	Lower heating value	Energy production per ha	Water content at harvest	Ash content
	[tDM/(ha year)]	[MJ/kgDM]	[GJ/ha]	%	Weight %
Straw	2 - 4	17	35-70	14.5	5
Miscanthus	8 - 32	17,5	140-560	15	3.7
Hemp	10 - 18	16.8	170-300	n/a	n/a
Willow	8 - 15	18.5	280-315	53	2.0
Poplar	9 - 16	18.7	170-300	49	1.5
Giant reed	15 - 35	16.3	245-570	50	5
Reed canary grass	6 -12	16.3	100-130	13	4
Switchgrass	9-18	17	n/a	15	6
Black locust	5 -10	19,5	100-200	35	n/a
Wood	3 - 5	18,7	74,8	50	1-1,5

Sources: AEBIOM "European Biomass Statistics 2007"; N.El Bassam "Energy plant species"; M J Bullard and others "Biomass and energy crops"[10]

There are several factors which have prevented a rapid expansion of these biomass energy crops. Foremost is the economic factor. Farmers are reluctant to commit farm land to a 12 to 20 year cycle for planting willow, poplar or Miscanthus, not knowing how prices for bioenergy crops will compete with traditional annual food crops in years to come. The need for specialized planting and harvest equipment and high costs for planting, harvesting and transport are further cost barriers which make these plants not cost competitive to traditional farm crops. Unlike the agricultural and forest residues which are byproducts of primary products and where pricing is based only on the added costs of excavation and transport, the pricing for the dedicated energy crops must cover the full costs of land, planting and maintenance of the crop as well as the required processing and transport. At present this potential feedstock is not price competitive with other forms of feedstock.

3.1.2 Potential Supply of Biomass Feedstock

Great variations are found among the CEE countries on the existing and potential supply and costs for biomass feedstock. Annex II provides a detailed analysis of the biomass potential in the CEE countries. It shows that the highest biomass potentials and the lowest costs are found in Poland, Romania and Bulgaria. Significant potential exists to tap the largely unused agricultural residues and waste products. As the CEE countries adopt modern, sustainable agricultural practices which will bring about higher productivity of food crops, a substantial portion of land presently used for food crops can be freed and used for a sustainable production of energy crops. The most attractive crops are those with low energy costs for planting and harvesting. However, investors will have difficulties to fully realize this potential as long as the authorities in these countries fail to address issues of the supply chain and market risks. Foremost is the security of the feedstock supply, its procurement price, and transport logistic. Like all agricultural production, biomass yield is determined by year to year variations in weather which can result in high fluctuations of available supply, quality and price. This risk is hard to mitigate as long as there is not a functioning market for feedstock and the creation of buffer stocks. Compounding this risk are the economics of scale of bioenergy technologies and the logistics of feedstock supply. An inherent problem is that most available technologies for bioenergy production show relatively poor economic performances at small scale plants. In contrast, large scale plants, providing economies of scale with associated low production costs for electricity, suffer from the logistical risk and high transport costs of procuring the necessary feedstock at a continuous basis from the predominantly small scale agricultural holdings in most of CEE. In the long term the goal should be a more distributed use of available biomass for electricity production, but this will depend on future technology improvements for smaller scale electricity production as well as substantial investments by the grid operators to provide grid access throughout these countries. With sharp rises in commodity prices for wheat and corn since 2008, land previously used for biomass production moved increasingly into grain production. Biomass prices have reached the order of about Euro 40/t, thereby reducing the financial incentive for this feedstock and the financial profitability for new biogas plants.

4 Feedstock from Waste

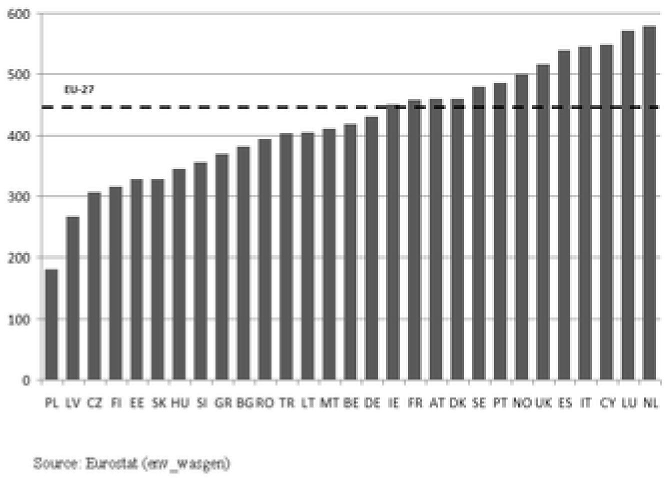
Sharply in contrast to the purchasing price and availability of biomass feedstock, are feedstock from waste, which are more than abundant, and do not suffer from the logistical problems of timely and sufficient procurement and more importantly they are available at no costs; instead their use as feedstock generates tipping fees. Under the EU Directive biogas produced from sewerage treatment plants via anaerobic digestion or electricity produced from the organic fraction of MSW is considered a renewable energy and contributes to a reduction in greenhouse gas emissions. [11] Therefore, the problems of waste can be turned into an attractive opportunity for renewable energy production.

The range of potential waste feedstocks is broad, including: municipal solid wastewater, hazardous waste, residual sludge from water treatment plants, food waste, food processing wastewater, dairy, pig and poultry manure, seafood processing wastewater, yard wastes, and residues from dairy processing, vegetable canning, potato processing, breweries, sugar and paper production. While many of these waste feedstocks, such as dairy, pig and poultry manure, food waste etc. offer great biogas potential in CEE, it is the dispersed nature and small scale livestock holdings in CEE which make these feedstocks only attractive for small plants. For large plants the most attractive feedstock for energy production is municipal solid waste and hazardous waste and sludge from waste water plants. This section will therefore focus on these feedstocks.

4.1 Waste Generation

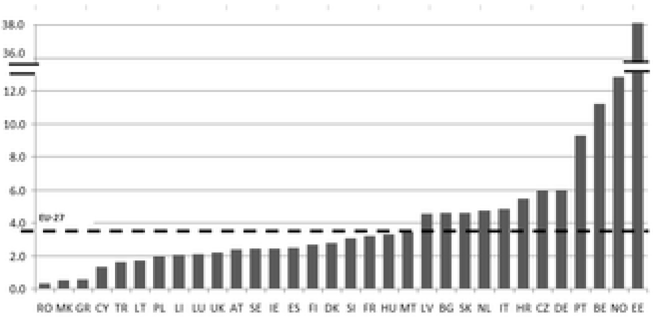
For the EU, but particularly for the new members in the CEE countries, reliable waste statistics are hard to obtain. For 2008 Eurostat estimates about 2.6 billion tones of waste was generated in the EU 27, of which some 101 million tones or 4 percent constituted hazardous waste. Relative to population, the total amount of waste was over 5,300/kg/per capita. The municipal solid waste (MSW) generation in the EU 27 is estimated at around 524 kg/person/year. This average hides significant differences within the EU. It ranges from around 565 kg/per capita in the EU-15 Member States to only 397kg in the 10 accession countries of CEE. Waste volumes have been growing as fast or faster than the economy: between 1998 and 2008 municipal waste grew by about 7 percent, faster than GDP. Smaller, but important waste streams are also growing: hazardous waste generation increased by 13 percent between 1998 and 2002, whilst GDP grew by 10 percent.[12] The projected growth scenarios for waste are troublesome. For the period 2005-2020, municipal waste is projected to grow by 22 percent in the EU15, whereas, the new EU12 have a projected growth of 50 percent. Over the same period, even higher rates of up to 60 percent growth is projected for the Czech Republic, Hungary, and Slovakia. [13] The waste produced by households in the EU 27 is around 450kg/capita, ranging from 180 kg/capita in Poland to 578 kg/capita in the Netherlands in 2008. All the CEE countries are well below the EU average. (Note: In contrast to household waste, MSW includes not only household waste, but all other waste collected by the municipalities and the amount is therefore higher than household waste). [14]

Figure 1 Waste Generated per Household 2008



Source: Eurostat

Figure 2 2008 Hazardous Waste in percent of Total Waste



Source: Eurostat

4.2 Waste Management and EU Directives

As more waste is generated in the EU, effective waste management, cultural reforms, and technological processes gain in importance to deal with the growing waste problem and the associated environmental problems. Excessive waste generation is a symptom of inefficient use of resources, and recovering materials and energy embedded in waste can help use resources in a better way. Waste and recycling policies are therefore a cornerstone of EU environmental protection efforts. In the 1970s, the first issue addressed by the EU environmental legislation was waste. The Waste Framework Directive, Directive 75/442/EEC, of 1975 establishes the guiding principles for waste management in the EU. However, the 1975 policy framework has been criticized for being too fragmented and inefficient. In 2008, the environment ministers from the 27 EU countries approved a new Framework Waste Directive with tougher recycling targets and provisions to burn waste for energy as part of a five-step prevention hierarchy.

The management of hazardous waste is regulated by the Directive 91/689/EEC. Safe shipment of all forms of waste is regulated by the 1993 Regulation 259/93. Landfills and incineration requirements are covered in the1983 Directives on incinerators, Directive 2000/76/EC, and in the 1993 Directive on landfills, Directive 99/31/EC. Specific waste streams are addressed in special legislation, such as sewage sludge (86/278/EEC).

The key to address the waste problem is imbedded in the waste hierarchy adopted by the EU, which is a “priority order” and not a “guiding principle” for governments and local authorities. The agreed five-step hierarchy, which codifies the different options for managing waste from 'best' to 'worst' from an environmental perspective, includes:

- Waste prevention and minimization is the first priority, but it will require major cultural changes for both industry and consumers. The idea is to reduce the production of waste to the minimum level consistent with economic sustainability. Particular priority should be given to minimizing the hazardous components of waste, and certain hazardous materials may need to be eliminated entirely from the waste stream.
- *Re-use of the product* is putting objects back into use so that they do not enter the waste stream. This may require industrial redesign of products as well as a consumer acceptance of the practice.
- *Recycling or composting* is the one most commonly understood by the consumer and the industry. This covers materials for recycling, composting and recovery of energy from waste. An integrated approach that incorporates all these options is the preferred option.
- *Recovery* (including energy recovery by incineration,) The 2008 Directive on Waste now considers "energy-efficient waste incineration" to be a recovery operation rather than a disposal, as originally proposed. This provision places incineration at a higher position in the waste hierarchy.
- *Safe disposal* in a landfill as a last resort. – From an environmentalist perspective, this is the least attractive waste management.

4.2.1. Implementing the EU Directives in the CEE Member States

In 2004 an EBRD (European Bank for Reconstruction and Development) review estimated that compliance with the EU Directives will demand substantial investment costs by the 10 new CEE Member States, as seen in the table below.

Table 6 Estimated EU Compliance Costs in Waste Sector (Investment Costs)

Country	€ millions(1)	€ millions(2)	€ millions(3)	Cost/Capital€ inhabitant(4)
Bulgaria	671	2477	2,150-3,000	80-340
Czech Republic	3800	1152	1116	110-370
Estonia	698	698	n/a	485
Hungary	4400	454	n/a	45-435
Latvia	259	343	n/a	105-140
Lithuania	325	364	n/a	89-100
Poland	3695	3695	4000	95-105
Romania	2788	2568	5971	115-180
Slovak Republic	1205	892	2,0084	165-370
Slovenia	1600	1073	n/a	540-808

(1) DSAE paper "Development of Implementation Strategies for Approximation in Environment". Brussels, June 1998.
(2) "Economic Instruments and Environmental Policy in CEE" J.Jantzen TME,Hague September 1999.
(3) Publicly available estimates in CEE countries- www.eurowaste.org
(4) Halcrow & Partners Ltd, (1999) Provision of Technical Assistance in the Approximation of Waste Management Legislation in the Slovak Republic.

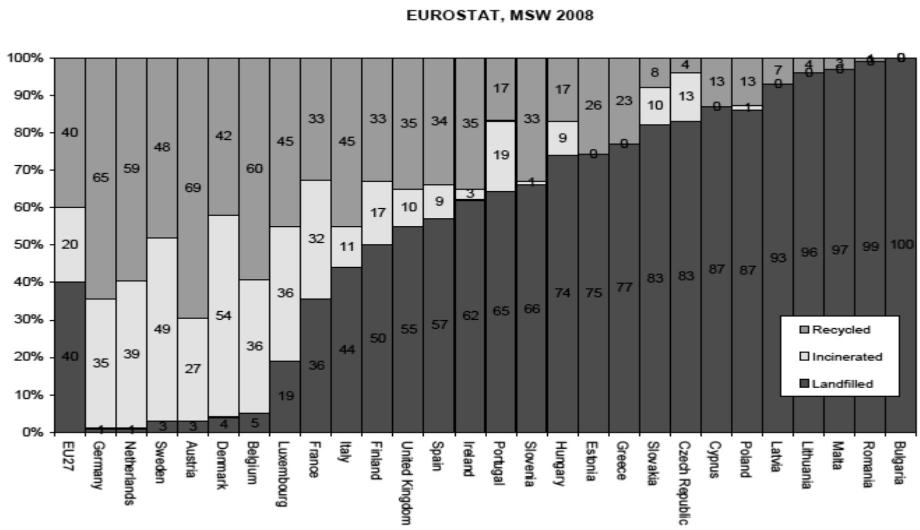
Source: EBRD,Municipal and Environmental Infrastructure Operations Policy, 2004[15]

In response to the EU objectives and the associated staggering investment needs of the CEE Member States, the EU's Structural Fund and the Cohesion Fund for Environment Programme provide grants during 2007-2013 for waste and water infrastructure, and for integrated waste management [16]. These funds will be discussed in a later section.

4.3 Municipal Solid Waste Disposal

EU-wide statistics on waste treatment are available only for MSW, which represents about 14% of total waste produced. At present, 49% of total EU municipal waste is disposed of through landfill, 18% is incinerated and 27% recycled or composted. There are wide discrepancies between Member States as seen in the graph below. Among all CEE countries, the predominate disposal method is landfilling. Bulgaria landfills more than 90 percent of municipal waste, others like Poland 65 percent. As compared to Germany with nearly 1 percent, the CEE countries' performance is dismal. While the proportion of recycled municipal waste has been increasing in the CEE counties, this has been offset almost completely by an increase in municipal waste generation. Incineration is slowly increasing, but has gained so far only importance in the Czech Republic, Slovakia and Hungary.

Table 7 2008 MSW Management Practices among EU Member States



Source: Eurostat 2008

Within the EU-15 member states, the general trend since the introduction of the Landfill Directive is a reduction in the number of landfill sites. (The only countries that have permitted new landfills, since the introduction of the Landfill Directive, are Finland, Greece, Ireland, Portugal, the Netherlands and the UK) . In the new EU12 nearly all waste was landfilled until 1990, a situation which has changed only slowly. While Slovakia, Slovenia and Hungary reduced their landfills until 1995, this trend reversed from 1995 to 2001. Since 2001, the Czech Republic could decrease landfills, while in Poland the landfill rate fell only after 2006[17]. Projections up to 2020 show a continuous decline in landfill to about 34 percent [18].

While data on waste in general is difficult to obtain for CEE, the situation is even worse when it comes to data on landfills sites and costs of disposal (gate fees and taxes). Some of these landfills receive both municipal and industrial waste, and in some cases even hazardous waste. Only a small fraction of the landfill sites comply with EU standards. A key challenge is consolidation, e.g. the closure and the concentration on an optimum number of sanitary landfills.

Table 8 Landfill Sites in CEE Member States

Country	Total Number of Landfills	Population (million)
Bulgaria	124 controlled (9meet EU standards)	8.2
Czech Republic	161	10.3
Estonia	351 (221 operated)	1.45
Hungary	725	10.1
Latvia	565	2.46
Lithuania	800*	3.7
Poland	998	38.7
Romania	257	22.5
Slovak Republic	141	5.4
Slovenia	6	2

*including contaminated sites and liquid waste reservoirs

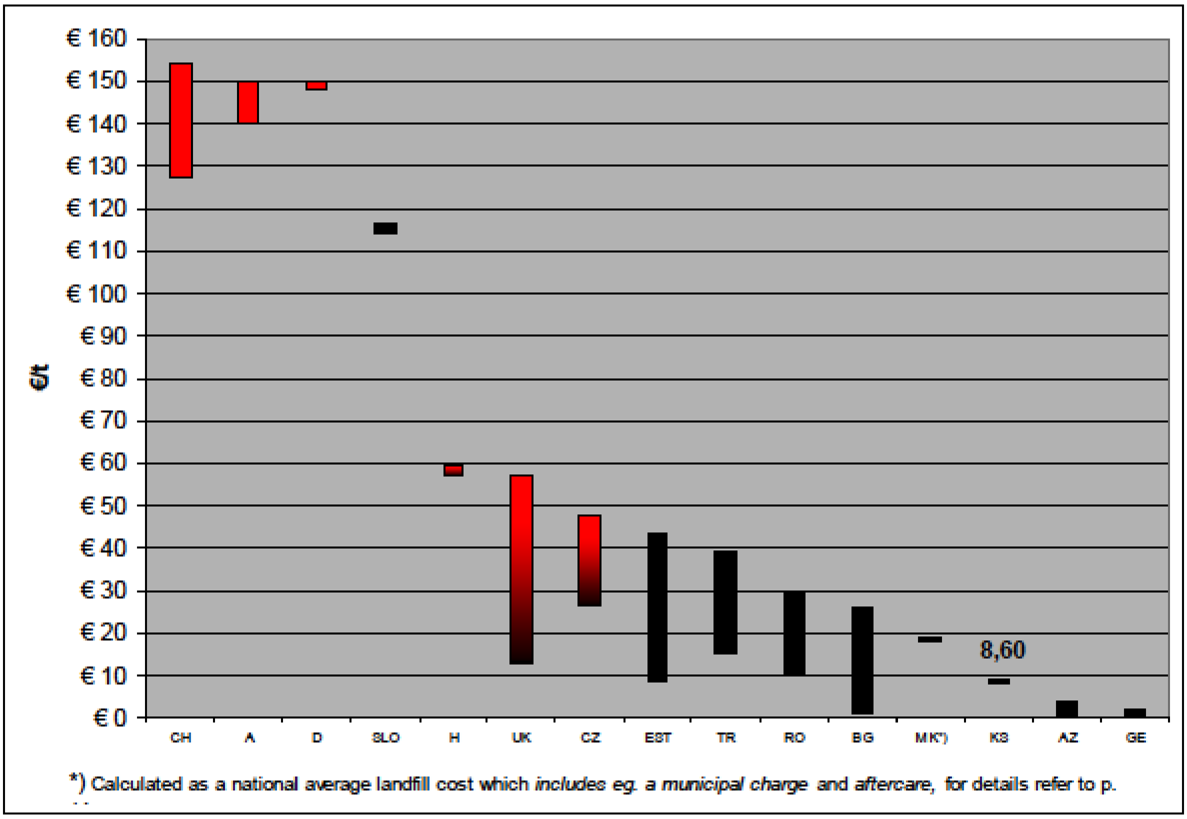
Source: EBRD: Municipal and Environmental Infrastructure Operations Policy, 2004.

A massive trend towards regionalization of waste landfills was observed by the EBRD in all CEE Member States, resulting in the closure of many small local landfills and the emergence of fewer large landfills at the regional level [19]. Illegal landfills are prevalent through out CEE member states, but no comprehensive inventory exists. These landfills operate for obvious economic reason to avoid the gate fees at regulated landfills. The 2004 EBRD Report assessed that the CEE member states have plans or strategies in place in order to achieve compliance of existing sites with the EU Landfill Directive, including the closure of sites. By the 2009 dateline of the Landfill Directive this process was only partially advanced, still leaving some 1,600 sub-standard landfill sites in existence. Since delays in the construction of new "replacement" landfills in many CEE countries are the main cause, dateline extensions were granted in 2009 for Bulgaria (December 2014),Poland (December 20111) and Romania (July 2017). Member States were also obliged to reduce by 50 percent the 1995 volume of biodegradable waste going to landfill by diverting it towards recycling and energy recovery. Since, among the CEE countries these targets were not achieved by Bulgaria, Czech Republic, Latvia, Lithuania, Poland, Romania and Slovakia, a 4 year extension was grated. [20].

4.3.1 Disposal Costs for Landfilling

Disposal costs for landfilling (consisting of gate or tipping fees plus environmental taxes and VAT) of MSW are high in most EU 15 and encourage the divergence from landfill to composting, recycling and to non-thermal and thermal waste disposal methods. For most of the new EU 12 Member States this is not the case. According to the above cited EBRD study "willingness to pay" and affordability issues are the main constraints for higher disposal costs in CEE countries. Comparable and consistent data for MSW and hazardous waste disposal costs for the CEE countries are not available, a problem which is largely attributable to the fact that landfilling falls under the domain of municipalities and local authorities. The best available estimates for a limited number of countries are available from a 2007 study presented below.

Figure 3 MSW Disposal Cost Ranges (excluding Taxes and VAT) in Selected Countries



* Note: Bars in red include pre-treatment charges and/or incineration charges.

Source: IPA Energy and Water Consulting, Landfill Benchmark Study, March 2007. BC International Inc., Global Plasma Gasification Technology Assessment, May 2007 [21][22]

The best single country data available are for the Czech Republic. In 2010, the basic price for landfill disposal of non-hazardous waste is Euro 34/t, a tax of Euro 10/t plus 19% VAT. The basic charge for hazardous waste is Euro 62/t, a Euro164/t hazardous risk tax plus 19% VAT. The Ministry of Environment anticipates introducing rate hikes for hazardous waste in 2011 to reach Euro 80/t base price, Euro 215/t for hazardous risk tax plus VAT.[23]

4.4 Waste Water and Sewage Sludge

Residual sludge from waste water plants is an abundant and renewable resource. In 2009 about 10 million tons dry matter (DM) sludge was produced in the EU, of which only 1.2 million tons DM were accounted by the new 12 member states in CEE and this is a reflection of the poor state of water treatment facilities and/or the lack of these facilities [24] The main disposal methods are composting and subsequent use on agricultural land or disposal in landfills. Pre-treatment of sludge before landfilling is rarely applied [25]. With increasing environmental and health concerns and the introduction of the EU Sewage Sludge Directive 86/278/EEC,untreated sludge can no longer be used on agricultural land or disposed in landfills, while the application of treated sludge (biological, chemical or heat treatment) is permitted under the Directive. Several countries (Austria, Belgium, Germany, Netherlands) have long banned sludge disposal all together, because of health hazards and soil contamination with heavy metals. With the Landfill Directive 99/31/EC, landfills of biodegradable waste will be banned in all 27 EU member states by 2018. In non of the CEE Member States is sludge incinerated, or after a drying process co-fired with coal in caloric power plants or cement factories. [26] These disposal methods are only of minor importance in the accession countries where landfill is still the predominant choice followed by agricultural use (see Table below).

Table 9 Disposal of Sewage Sludge in Accession Countries as Percentage

Member State	Year of Data	Agriculture	Landfill	Incineration	Other
Bulgaria	2006	40	60		
Czech Republic	2004	45	28		26
Hungary	2006	26	74		
Poland	2000	14	87		7
Romania					
Slovenia	2006	>1	50		49
Slovakia	2006		17		83

Source : European Commission, DG Environment, Environmental, Economic and Social Impacts of the use of Sewage Sludge on Land, 2009.[27]

In most CEE countries waste water treatment is inadequate, sometimes non-existent, or lacking EU standards. However, the production of sludge in the new accession countries will increase markedly by the 2018 dateline of meeting EU standards for treatment of wastewater and sludge. To cope with the enormous investment needs, the priority focus is on settlements above 2000 inhabitants, which will exclude about 20% of the population in CEE. [28]

In urban areas the main causes of water pollution are organic wastes, nitrogen and phosphorous compounds, as well as suspended solids from municipal sewers and to a lesser extend industrial pollution. Where municipal waste water plants are in place, they are overloaded, poorly maintained, and many times by-passed. Large enterprises in CEE countries, which used to pre-treat waste water before discharging it into the municipal sewer, tend to discharge without treatment in an attempt to safe costs. The high phosphor and heavy-metal content and pharmaceutical contaminations of sludge endangers its use in agriculture.[29][30][31]

So far only few countries have made use of sludge as a feedstock for AD plants. One exception is Bulgaria, where an international concession was granted for the new Sofia waste water treatment plant. Waste water management is in the hands of city councils and municipalities and they lack mostly the funds to invest in AD plants [32]. While Bulgaria and Romania have no AD biogas plants, Latvia has one facility in Riga and Lithuania has 2 plants. [33] Of all the CEE Member States, Poland is with 73 sewage digester plants the most advanced, although their installed capacity of 14MW remains small [34]. Romania has 1 plant using sludge as feedstock and there are several small plants in Slovakia. Slovenia has 6 small plants producing 2MW and 3 new plants in Ljubljana, Maribor, and Celje are to start operations. [35]

5 Electricity Feed-in Tariffs from Biomass, Landfill Gases, Sludge and Waste

Feed-in tariffs are an essential element in the wider support scheme to advance the EU wide objectives to raise the production of electricity from renewable energy sources. It is equally recognized, however, that feed-in tariffs alone will not ensure that the CEE countries' electricity targets from renewable energy are met. Also important in this wider support scheme are efficient and independent regulators, barrier-free grid access, and efficient, non corrupt permission and license procedures. It is through such leveling of the playing field, that feed-in tariff policies provide investors with an essential risk minimizing element for their investment.

Annex III provides a detailed overview of the most current feed-in tariffs for all CEE Member States for electricity generated from biomass, landfill gas, sludge, and waste. With the exception of Poland and Romania, all CEE countries have feed-in tariffs in place. The basic principles of the feed-in tariff system are that utilities and grid operators have a legal obligation to provide renewable energy procedures with a fair,non-discriminatory access to the grid and to buy any renewable energy from producers at a guaranteed, favorable per kWh price over a specified period of time. Electricity generation projects for renewable energy installations have all high upfront investment costs and do require a reliable, stable long-term revenue stream in order to secure finance at a reasonable cost. Well-designed feed-in tariffs must be sufficiently high to provide a reasonable return to investors and are proven to be one of the most effective instruments to attract investments for renewable electricity projects.

In the case of Poland and Romania, a quota scheme with guarantee prices and Tradable Green Certificates (TGC) is in place. Studies have shown that such a system is far less attractive to investors. They have also shown that where a system of mandatory quotas and TGC are used the price for renewable energy is higher than in countries with feed-in tariffs. [36]

As shown in **Annex III**, in recent years, many of the CEE countries have introduced tariffs which are differentiated by source of feedstock, technology, and generation size of the plant (electricity or CHP). Hungary differentiates the feed-in tariff also by time of day (peak, valley or off-peak). Particularly for biogas technologies, where the differentiation of economies of scale are great, Bulgaria, Hungary, Latvia, Slovakia and Slovenia are offering higher feed-in tariffs for small plants and lower tariffs for large plants, thereby leveling the playing field. It makes smaller producers cost effective and does not over-compensate larger plants which already benefit from economies of scale. Slovenia provides a fixed feed-in tariff and a variable premium. Some countries provide feed-in tariff for all renewables and others, like Lithuania, only for the most cost effective energy technologies. In Bulgaria, Czech Republic, Hungary, Slovakia and Slovenia landfill and sludge gases receive feed-in tariffs below those for other biogas. Although incineration and/or cogeneration of waste receives a lower feed-in tariff than biogas (Hungary, Slovakia), it is highly profitable, because of the off-set revenues from tipping fees which are saved at the landfills.

6 Waste to Energy

MSW management practices, such as source reduction, recycling, and composting, prevent or divert materials from the waste stream. Other practices address those materials that require disposal, such as landfills and combustion. A rapidly growing industry addresses, however, how to convert waste to a sustainable energy source. The term waste-to-energy (WTE) refers to any waste treatment that creates energy from any waste source into electricity and/or heat. Traditionally the term referred to incineration of garbage combined with heat recovery to make steam which can be used for district heating, electricity production or CHP. Today, WTE technologies encompass a broad range of technologies, that convert various waste feedstocks. Advanced WTE technologies produce biogas, syngas, biofuels and hydrogen.

6.1 Waste to Energy Conversion Pathways

There are basically four categories for Waste-to-Energy processing: Anaerobic Digestion, Incineration, Gasification and Pyrolysis, and Plasma. These processes compete in the market with each other. In recent years innovative advances in technology development of WTE processing have occurred in the fields of Anaerobic Digestion (AD) and Plasma. For many years AD was only a solution for small-scale processing of organic feedstock, and Plasma technology remained in R&D testing for processing MSW and hazardous waste. Both of these technologies have matured and are now considered as viable commercial applications for large scale WTE processing. It is for this reason that the emphasis of this section is on AD and Plasma technologies. Incineration, Gasification and Pyrolysis are important in their own right but are only mentioned to complete the overview.

Incineration is the total thermal degradation of a substance with sufficient oxygen to oxidize the material completely at high temperatures, usually 1,000°C, to carbon dioxide and steam, leaving only a small amount of residual ash. The overall process converts almost all of the chemical energy in the material into thermal energy, leaving no unconverted chemical energy in the flue gas and very little unconverted chemical energy in the ash. Incineration offers the least expensive alternative to waste processing. Although the environmental impact is significantly lower than coal-fired plants or landfills, the issues of air toxic emissions and residual toxic ash sent to landfills is a growing concern. The attempt to significantly reduce furan and dioxin emissions, has been a focus of the industry[37]. Investments in air pollution control are costly and economies of scale require large facilities (350k/t/a to 900k/t/a), thus resulting in long hauling distances, huge collection and sorting facilities with adverse environmental and financial impacts.

The EU Directive 2000/76/EC on Waste Incineration sets stringent operational conditions, technical requirements and emission limit values for plants incinerating and co-incinerating waste. This Directive covers any incineration facility dedicated to the thermal treatment of waste including the oxidation of waste or by pyrolysis, gasification, or plasma processes insofar as the substances resulting from the treatment are subsequently incinerated. Under the EU Integrated Pollution Prevention and Control (IPPC) Directive (Directive 2008/1/EC), the current options facing incineration plants are to install the required pollution control technology such as flue gas cleanup or combustion alternatives or operate at low loads and postpone pollution control installations to safeguard their bottom line. All incineration plants need full compliance by 1 January 2016.[38]

The many EU regulatory issues facing incineration today combined with increasing health and environmental concerns by the public, make incineration a controversial and expensive operation. Emissions are not the only source of pollutants and ash residue must be considered. MSW generates ash, representing about 10% by volume and 25%-35% by weight of the waste incinerated. The principal environmental concern of the public regarding incinerator ash is that when ash is disposed of in a landfill, the metals and organic compounds can leach (dissolve and move from the ash through liquids in the landfill) and migrate into ground water or nearby surface water. In addition to possibly contaminating water supplies, incinerator ash could also affect human health through direct inhalation or ingestion of airborne or settled ash.[39] The WTE incineration offers effective bulk volume reduction of MSW and electricity generation. It is an effective short-term alternative to landfills but not a sustainable environmental solution.[40] Incineration is the largest single competitor to all plasma gasification, but since they are under increased regulatory control, the costs of plasma gasification represent a cost effective option.

Gasification is the partial thermal degradation of a substance in the presence of oxygen, but with insufficient oxygen to oxidize the material completely. A gas such as air, oxygen, or steam is used as a source of oxygen and/or to act as a carrier gas to remove the reaction products from reaction sites. Systems usu

750°C and the by-products are gas (methane, hydrogen, and carbon monoxide) and a solid residue (consisting of non-combustible material and a small amount of carbon). The process does not convert all of the chemical energy in the fuel into thermal energy but instead leaves some of the chemical energy in the syngas and in the solid residues.

Pyrolysis is the thermal degradation of a substance in the absence of added oxygen, at temperature, typically from 300°C to 800°C. Oxygen is not present (or very minimal oxygen) except for oxygen already present in the waste material. The main product is syngas (e.g. carbon monoxide, hydrogen, methane and some longer chain hydrocarbons including condensible tars, waxes and oils) and a solid residue (consisting of non-combustible material and a significant amount of carbon). The overall process generally converts less of the chemical energy into thermal energy than gasification. Since pyrolysis generally takes place at lower temperatures than for combustion and gasification, the result is less volatilization of carbon and certain other pollutants such as heavy metals and dioxin precursors into the gaseous stream. The benefits or detriments to this depend on the overall system capabilities but in general, any pollutant that is not volatilized will be retained in the pyrolysis residues and will need to be dealt with in an environmentally acceptable manner.

A minor variation of the process is a two-step pyrolysis-gasification system, with a separate pyrolysis process in front of the gasifier, but there is no plasma decomposition reactor. Waste is moved by screw action or by ramming through a tube that is heated externally called Tube Pyrolysers. Indirect heating is usually supplied by hot gases from the combustion of part of the product syngas or char. These pyrolysis systems are usually used as the first stage with a second stage gasification step to convert more of the combustible solids into syngas. To cope with the tar problem, they will operate with oxygen instead of air and supplement with natural gas to reach operating temperatures of 1,600°C-2,000°C and the resultant fuel gas from the gasifier is quenched by water in a subsequent stage. Price and operating costs are estimated to be high but pyrolysis systems are gaining support in Japan .

The final pyrolysis variation is fast pyrolysis where very small particle sizes are employed and pre-treatment is the most critical step in the process. Pyrolysis reactions are slower than gasification and combustion reactions so high temperatures, low moistures and very small particle sizes are used to accelerate the process.

In this system, the fine dry feed pyrolysis process takes place on contact with the hot metal surface of the reaction chamber. The advantage is a faster reaction and smaller reactor.[41]

Most gasification and pyrolysis processes have four stages: 1) Preparation of the waste feedstock, where waste can be in form of a refuse derived fuel or mixed waste which requires removal of recyclables and materials with no calorific value; 2) Heating the waste in a low-oxygen atmosphere to produce a gas, oils and char (ash); 3) 'Scrubbing' (cleaning) the gas to remove some of the particulates, hydrocarbons and soluble matter; and 4) Using the scrubbed gas to generate electricity and, in some cases, heat (through CHP). There are different ways of generating the electricity from the scrubbed gas – steam turbine, gas engine and maybe some time in the future, hydrogen fuel cells.[42]

6.2 Anaerobic Digestion and Advanced Anaerobic Digestion

6.2.1 Anaerobic Digestion (AD)

Next to incineration, anaerobic digestion is the most established WTE conversion in the EU. Thanks to attractive feed-in tariffs and support frameworks in form of grants, soft loans and tax incentives, Germany, Denmark and Austria experienced a rapid adoption of this renewable energy technology and today about 4,500 biogas plants are in operation producing both electricity and heat with gas powered generators. The ratio of power and heat generated is in the order of 35% to 65%, respectively, and depends on the technology and design of the plant. . These plants operate with various feedstocks, ranging from primary agricultural production to secondary production waste and all forms of organic waste including sewage sludge. So far, the CEE member states have seen only a modest development of AD plants. One should note that steadily rising prices for agricultural substrates in recent years have slowed the expansion of AD plants in recent years. Waste substrates are supplied against gate/tipping fees and may become the driver for future AD expansion both in the EU15 and the new CEE member states. At present, biogas produced from sludge contributes 19% of total gas production in the EU and shows a sharply rising trend.

Biogas is produced by means of the fermentation process of anaerobic digestion (AD). Organic matter is decomposed by various anaerobic microorganisms in the absence of oxygen, producing a mixture of methane and carbon dioxide, typically in the ratio of 6:4 (methane range between 50-

75% and carbon dioxide between 25-50%). The gas with a an approximate density of 1,2kg/m3, an average heating value of 4-7,5 kWh/m3, and an ignition temperature of 700ºC ,all dependent on methane content. The final composition of biogas is dependent on variables like feedstock used, chosen digestion system, temperature range used, and retention parameters set.

The reaction process can be seen in the chemical equations below

Figure 4 Reaction Biogas Process

$$C_6H_{12}O_6 \rightarrow 2\,C_2H_5OH + 2\,CO_2$$
(organic compound) → (ethanol) + (carbon dioxide)

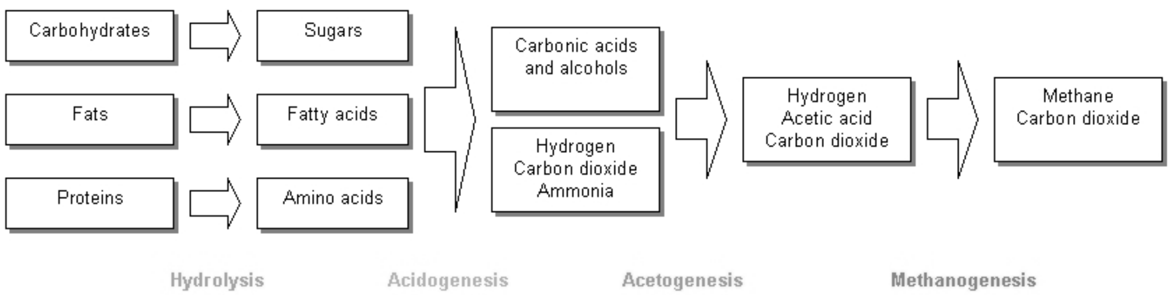
$$2\,C_2H_5OH + CO_2 \rightarrow CH_4 + 2\,CH_3COOH$$
(ethanol) + (carbon dioxide) → (methane) + (acetic acid)

$$CH_3COOH \rightarrow CH4 + CO_2$$
(acetic acid) → (methane) + (carbon dioxide)

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O$$
(carbon dioxide) + (hydrogen) → (methane) + (water)

Source: Wellinger Module 2 Process Parameters

Figure 5 Stages of Anaerobic Digestion



Source: Alex Marshall, Clarke Energy Ltd.[43]

As seen in the table above, the first step is **hydrolysis**, where enzymes break down large polymers, proteins are converted to amino acids, fats to fatty acids, and carbohydrates to sugars. This is followed by **acidogenesis**, where fermentation occurs and sugars, fatty acids, and amino acids all produce carbonic acids and alcohols, carbon dioxide, ammonia, and hydrogen. The third stage of **acetogenesis** continues to further break down volatile acids to acetate acid and hydrogen. The final stage of **methanogenesis** converts hydrogen and acetate to methane and carbon dioxide.

The widespread natural occurrence of methane bacteria demonstrates that anaerobic degradation can take place over a wide temperature range from 10°C to over 100°C and at a variety of moisture contents from around 60 percent to more than 99 percent.[44]

Table 10 Thermal Stage and Retention Times

Thermal stage	Process temperatures	Minimum retention time
psychrophilic	< 20 °C	70 to 80 days
mesophilic	30 to 42 °C	30 to 40 days
thermophilic	43 to 55 °C	15 to 20 days

Source: Biogas Handbook[45]

Both temperature and pH play critical roles in AD parameters in the desired production of methane. Sudden temperature fluctuations adversely affect the digestion process. Thermophilic process temperatures offer superior effectiveness compared to either psychrophilic or mesophilic thermal stages. Since the digester is full for only 15-20 days minimum retention time, but at high temperatures between 43 to 50ºC, pathogens are destroyed providing improvement in digestability and availability of substrates. Liquid separation is made easier as the degradation of solid substrates increases. However, there are drawbacks since there is a greater degree of imbalance due to a larger energy demand due to the increased temperature to remain in the thermophilic stage. This in turn can also cause risk of ammonia inhibition because of the high temperatures. A certain period of time should be maintained between the input of feedstock to the digester and the removal of digested materials. Based on the advantages of thermophilic digestion, an AD digester's best output would be to run at highload input or by shortening residence time to increase overall efficiency. Spikes in pH can occur at the point of shock loading, where non-acidified feedstock is added to the already digesting batch, leading to process imbalance. Biogas forms in the pH range from 6.0 to 8.5 (Wellinger). A pH outside these process parameters will halt methane production.

As seen in the table below, there remain trace amounts of hydrogen, nitrogen, carbon monoxide, saturated or halogenated carbohydrates, oxygen, and ammonia present in the biogas composition. This water vapor saturated gas can contain siloxanes and dust particles. During biogas combustion containing siloxanes, silicon is released and may combine with free oxygen or other elements in the combustion gas requiring cleaning downstream. AD produced biogas is carbon dioxide neutral, producing no more carbon dioxide than the raw material's own unassisted biological decomposition. From the AD process a medium heating value biogas mixture and a solid and liquid digestate are the outputs.

Table 11 Biogas Composition

TYPICAL COMPOSITION OF BIOGAS	
Methane	50-75 %
Carbon dioxide	25-50 %
Nitrogen	0-10 %
Hydrogen	0-1 %
Hydrogen sulphide	0-3 %
Oxygen	0-2 %
Ammonia	0-1%

Source: ADBA. The Anaerobic Digestion and Biogas Association[46]

Of importance for determining the energy yield, is methane, carbon dioxide, and water vapor content of the biogas. In turn, the potential methane yield for a certain substrates is determined through the proportions of carbohydrates, fats, and proteins as seen in Table 12. The potential biogas yield is determined by the basic composition of the substrate. Gas yields of different substrates will vary based on the combination of these proportions as seen in Table 13

Table 12 Substrate Methane% Yield

Substrate	Max. methane yield [Wt.%]	Max. methane yield [m³/t ODM]
Carbohydrate	27	370
Fat	72	998
Protein	42	585

Source: European Energy Manager.IHK [47]

Table 13 Gas Yields for Substrates (ODM)

Cattle liquid manure	200 m^3 methane/t ODM	20 m^3 biogas/ m^3 liquid
Pig liquid manure	300 m^3 methane/t ODM	30 m^3 biogas/ m^3 liquid
Poultry manure	250 m^3 methane/t ODM	40 m^3 biogas/ m^3 manure
Sewage sludge	300 m^3 methane/t ODM	5 m^3 biogas/ m^3 sewage sludge
Biowaste	250 m^3 methane/t ODM	100 m^3 biogas/ t biowaste
Old fat	720 m^3 methane/t ODM	650 m^3 biogas/ t old fat
Cut grass	480 m^3 methane/t ODM	125 m^3 biogas/t cut grass

Source: European Energy Manager.IHK [48]

The heating value or the calorific value is calculated by the amount of heat released during the decomposition of a certain amount of substrate. Measurement is in units of energy per unit of the substrate: MJ/kg. The calorific value of sewage sludge depends on the amount of organic matter in the dry solids (DS). [49]

6.2.2 The Anaerobic Digestion Process

The number of anaerobic systems provider in the market is numerous, even more numerous are the concepts offered to configure the digestion process. To date, various technologies for processing are on the market for biogas production from AD. Organic industrial waste from food processing, the organic fraction from MSW, sewage sludge, agricultural manures, and energy crops are processed through AD. The processing of sewage sludge has undergone significant R&D and has seen dramatic increases in biogas methane content availability. Different processes to increase calorific value by adding 'green bags' to the digestion process, or steam to the fermenting batch in the digesters, or by biogas upgrading through cleaning processes, have all been developed to take advantage of the full potentials of the AD process.

Despite these complexities, the basic process parameter to distinguish are:

- temperature (mesophilc versus thermophilic digestion);
- moisture (wet versus dry digestion)
- number of process steps;one stage versus two-stage versus multi-stage digestion
- continuous versus discontinuous systems;
- single feedstock versus codigestion
- pre-treatment

Mesophilic versus Thermophilic digestion:Mesophilic digestion occurs in the range of 35ºC-40ºC. Thermophilic digestion occurs in the range of 50ºC -55ºC. Anaerobic digestion that uses the mesophilic range is more stable and uses less heat input than a thermophilic process. However, thermophilic digestion does show a greater biogas yield, as more energy is removed from the feedstock. Sterilization is increased as well, where in mesophilic digestion bacteria can still be an issue. The total energy balance must be taken into account. Since thermophilic digestion requires a greater power input to reach desired range, the biogas output must be greater than the input needs. The majority of presently installed capacity is still mesophilic, largely because of low heat requirements,, although thermophilic plants have been sharply rising in later years.

Wet digestion versus dry digestion: Wet digestion is preferred when using substrates with a dry mass content lower than 15 %, whereas dry digestion is used with a substrate having a dry mass content between 20 and 40 %. This classification determines the design and type of the digester used. Wet digestion is usually applied to manure and sewage sludge biogas processes. In contrast, dry digestion can be used to ferment food waste, solid municipal organic waste, feedstock high in nitrogen, energy crops, and solid animal manure, with a high straw content. In the case of wet digestion, single-stage AD plants, operating with a flow through process are usually used. In the two-stage process, a pre-digester is placed before the main digester.

Number of process steps:single-stage, two-stage, and multi-stage digestors. In the later process the process of hydrolysis, acid formation, and methane formation are separated. The two former processes are the most common technologies in use today. Single-stage digesters are distinguished by no special separation of the different process steps (hydrolysis, acidogenesis, acetogenesis, and methanogenesis). All process steps are conducted in one single digester. The two-stage digesters, as the name applies, use an added digester for processing continuous feed systems where digestion will occur at a slower rate, but still producing around 20% of the total biogas.

Continuous or discontinuous systems: The digester used is determined by the feedstock applied and sets the parameters regarding filling procedure intervals. The mode of feeding can be one of continuous or discontinuous (batch)feed. Continuous feed systems benefit mostly liquid substrates. Caution must be used in preplanning so the digester is large enough to contain all substrate pumped into the digester during the full cycle. The fresh substrate and an inoculant, a microorganism to speed up the digestion process, are added. In order to increase the overall temperature, the material is aerated for one to two days. The substrate is pumped at regular intervals into the digester and remains for a retention time of between 10 to 40 days depending on waste composition. During the following two or three weeks the substrate is anaerobically degraded, at first with an increasing daily gas production. After approximately 10 to 14 days, gas production decreases again and plateaus producing about half of maximum biogas production.

Discontinuous or batch systems used for plant solids have seen an increase in agricultural biogas plant use for improved rates of production. They are operated normally in groups of 4 digesters to compensate the decrease in gas formation. It takes up to 3-4 weeks before gas is produced slowly and the process can take up to 4 months. The combination of fermenter and holding tank in one is another form of discontinuous feed design. These storage systems are slowly filled with fresh substrate. This system's advantage is the low costs of production. High heat losses and unsteady gas formation rates can be drawbacks to this process. The finished digested substrate, called digestate, is pumped out of the digester into storage tanks. The biogas produced is stored, conditioned and used for energy generation.

Single feedstock or Codigestion: Not long ago, anaerobic digestion (AD) was a single substrate and single purpose treatment. The process of co-fermentation, also referred to as co-digestion, developed after documenting that different substrates anaerobically digested together brought about a better stabilization in gas quality. The co-digestion provides an improved nutrient balance leading to an increased digester performance and a significant higher biogas yield. It has been discovered that AD as such becomes more stable when the variety of substrates applied at the same time is increased. [50]

Incorporating co-digestion of a high methane producer like manure or sewage sludge with minor amounts of other substrates low in moisture content like aggregate wastes, particulate materials, floating wastes or other materials with difficult fermenting capabilities alone, can benefit the process, overall biogas yields, and fertilizer quality.[51]

When additional substrates are added, they behave differently and can cause damage to internal parts of the digester like blocked pipes or sediment accumulation within the digester. Therefore pretreatment of these substrates is critical to speed up retention time and prohibit downtime due to adaptation. Premixing before digestion of the substrates requires additional equipment, but improves digestion. Monitoring the measurement of the daily co–substrate flow, the daily biogas production, as well as pH- and biogas composition play key roles in gas quality control and plant efficiency.

The increase in costs for digester equipment required for pre-treatment and digester upgrading of some co–substrates can be too expensive for small scale biogas plants. Such plants are more or less confined with co-digesting substrates that demand minor pre-treatment or no treatment at all. Large-scale centralized farm digesters, industrial applications or municipal sewage sludge co-fermentation plants can meet these additional requirements.

There are different digester designs, some require the substrate to be mixed mechanically during digestion, while other designs take advantage of mixing the substrate with a hydraulic pump or thermally heating during fermentation. Pneumatic mixing by circulating biogas through the decomposing substrate mixture has also been developed. Decomposition in the vessel is designed to withstand pressure buildup and provide conditions ripe for the presence of bacteria for anaerobic digestion to take place.

6.2.3 Processing Technologies

Much attention has gone to the development of processing technologies to improve the AD of sewer sludge, manure, slurries and solid waste by making the substrates more accessible to the anaerobic bacteria, speeding up the overall process flow, improving the methanogenic potential and decreasing the amount of waste disposal. These pre-treatment technologies aim to increase the biodegradabilty of cell walls and bring about a better accessibilty for enzymes. This enhancement of biodegradability can be accomplished by different pre-treatment methods:

- Mechanical methods to break down solids by grinding of the solid particles and thereby releasing cell compounds and enlarging the surface areas for enhanced biodegradation;
- Ultrasonic disintegration;
- Chemical methods using mineral acids or alkalies;
- Thermal hydrolysis to break down a large fraction of solids into less complex molecules,
- Enzymatic and microbial methods, and micro-organism stimulation where organic compounds, like amino acids act as agents in bacteria growth and methane production.

With the exception of the thermal hydrolysis, where the sludge is sterilized by high temperature and pressure differences cause the cooked cells to open, all other per-treatment processes bring about a disruption of the cellmass. Thermal hydrolysis has proven to achieve a better biodegradabilty through a process by which sludge is heated to 130-180 C for 30 minutes at corresponding vapour pressure. Through the hydrolysis water is freed from the cells, thus changing the viscocity of the sludge and permitting a higher load in the digester feed and a more stable process. Dewaterabilty could be increased by 60-80% with a hydrolysis at 165-180ºC and a 10 minute treatment instead of 30 minutes previously used. [52

Increasing the methane yields by improving the bio-degradability of sludge has received much attention. In 1978, methane yield increases between 14-57% were obtained by Haug et al. with

mesophilic digestion after a pre-treatment at 100-175 C for 30 minutes. In 1992 Li and Noike found the best conditions for sludge pre-treatment to be achieved at 170 C for 60 minutes. With this pretreatment a mesophilic digestion was feasible with a retention time of only 5 days, while bringing about a 60% efficiency of COD removal. [53]
In 2008, the most thorough and systematic review of existing technologies for sludge treatment was carried out by Entec UK Ltd. for the Thames Water Utilities Ldt. In order to assess their future sludge treatment strategy and investment program for a new facility at Bran Sands, Thames Water Utilities looked for a robust technology, which was commercially proven, and which can achieve the objectives of increasing the renewable energy recovery from sludge digestion, minimize the solids and reduce the carbon footprint.

From an analysis of 34 established and emerging technologies it emerged that meeting the above objectives would require a process consisting of thermal hydrolysis, AD and cake dewatering. Thermal hydrolysis scored the best because of its: 1) high Volatile Solid Destruction; 2) high energy recovery; 3) best dewaterability; 4) highest removal of nitrogenous material; and 5) thermal drying of the digestate without need of fossil fuel because of improved dewaterability and higher gas production. If pelletized this dried product could be further recycled as fuel. [54]

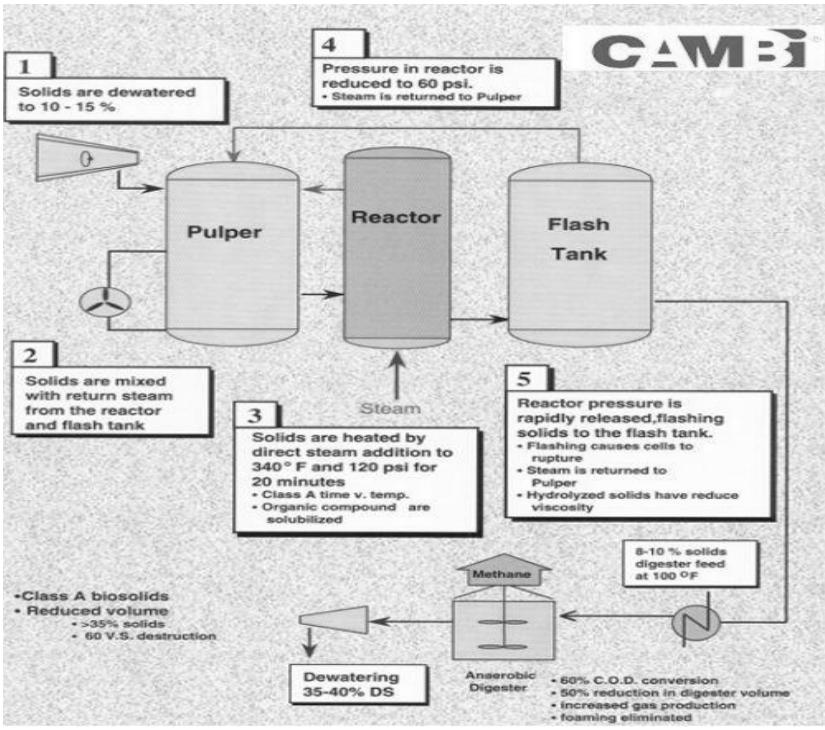
There are several manufactures in the market for thermal hydrolysis. The Cambi, a Norwegian company, and France's Biothelys process by Veolia lead the way. Based on the Entec evaluation, Thames Water Utilities Ltd. selected the Cambi Thermal Hydrolysis Process (THP) for the new plant at Bran Sands. Because of its application for the CEE countries the Cambi technology and its experience in Bran Sands will be discussed in detail below.

6.2.4 Advanced anaerobic digestion (AAD) and the Cambi Process

Sewage sludge as a substrate for biogas production is an important focus today as it is on a sharp rise throughout the world. An ever increasing waste problem, stringent policies for waste disposal, and the drive for WTE, coupled with the advancement of research in sewage sludge decomposition and improved gas yields, have made the development of low-cost solutions a mandate as well as an economically viable process.

Cambi THP Process: The Cambi process consists of a thermal hydrolysis pre-treatment process. The Thermal Hydrolysis Process (THP) which Cambi has patented, treats municipal and wastewater treatment sludge and bio-waste before it is put through anaerobic digestion. Before the hydrolysis process begins a steam is injected from a steam generator fired with biogas. This avoids clogging and unplanned shut downs of heat exchangers. The steam is released and used for pre-heating another vessel..Thermal hydrolysis disintegrates the raw substrates cell structure and dissolves proteins into a more prepared and easily digested feedstock for gas production. This allows the digester vessel to be doubled in the amount of dry solids since the disintegration process produces a more liquid sludge. Since greater biodegradability is attained using this process, more raw gas can also be produced. Greater dewaterability is also achieved, as much as 40% of total dry solids. All pathogens and odors are eliminated by this thermal pretreatment at 165°C for 20-30 minutes. It produces a stabilized bio-solids product that can convert more organic matter into gas in the AD process ,a pathogen-free bio-solids fertilizer of high quality or fuel pellets for further energy use.

Figure 6 Cambi Thermal Pre-treatment Process



Source: Cambi. Technology for Enhanced Anaerobic Digestion Of Municipal and Industrial Sludge. [55]

Figure 6 above illustrates the Cambi process flow. Cambi uses this process flow technology as an add-on or retrofit to treatment sites already in use, performing all aspects of site planning and building. The process, all operated in a batch process, entails a mixed pre-heat tank, up to five reactor vessels, and a flash tank. The feedstock or sludge substrate is dewatered in the process to the range of 16%TS (total solids), before it is then transferred to a pre-heat tank. After dilution with digesting sludge, the thermally treated solids are pumped into the digester, with a 8-10% TS range for the digester feed. After this, digested solids can be further dewatered reaching the 30-37% range. [56]

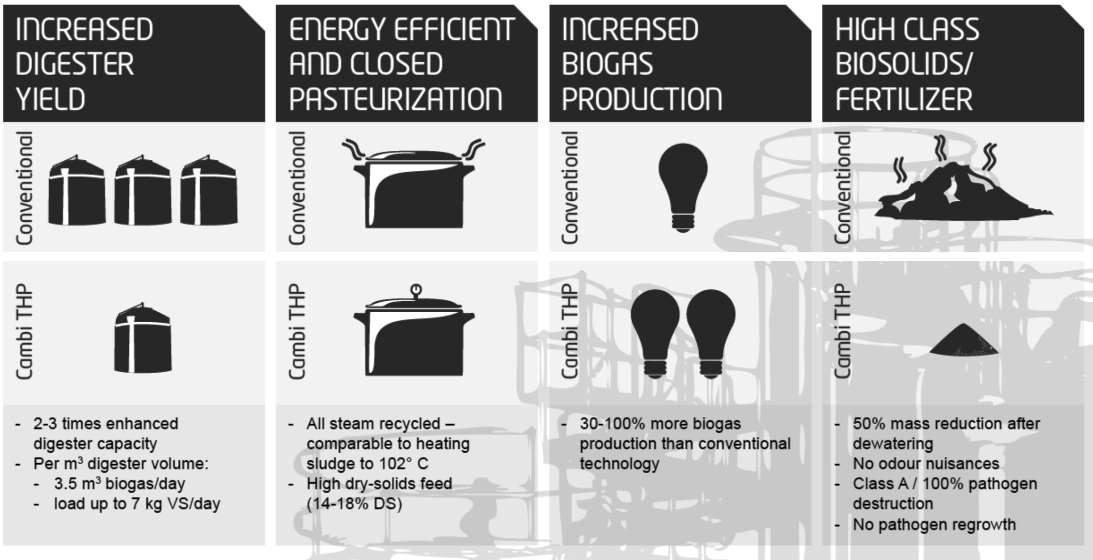
Table 14 Before and After Cambi. Plant (1600t dry solids/year) Naestved (DK)

	Before hydrolysis	After hydrolysis	Change
Biogas production (62-65% CH_4)	306,000 m^3/yr	504,000 m^3/yr	+65%
Post digestion dewatering	18% TDS	29% TDS	+61%
Cake	5,750 tonnes/yr	2,830 tonnes/yr	-51%

Source: Cambi Presentation IFAT2010, Sept. 13-16,Munich,Germany.[57]

Cambi's process has advantages over conventional anaerobic digestion as seen in the diagram below by using thermal hydrolysis in a two-stage fermentation process. When the process is undertaken in a conventional digester a wide range of micro-organisms slowly disintegrate the substrates. Since substrates are heated under pressure (6 Bar) at 165ºC in the Cambi process, it occurs much more rapidly. More of the biodegradable feedstock is thereby made available for conversion into gas. If the net additional gas energy production equals or exceeds the greater parasitic load from the hydrolysis stage then the overall process is a success. In so doing, Cambi THP has been shown to produce 30-100% more biogas production than conventional AD and significantly reduces the cost for end product disposal because of a volume reduction of about 50%. The end product is safe (free of pathogens) and odor free.

Figure 7 Cambi THP vs. Conventional AD



Source: Technology for Enhanced Anaerobic Digestion of Municipal and Industrial Sludge. Cambi

The Cambi process, discussed above, and used successfully on a large scale by Northumbrian Water in Bran Sands,UK is a case in point. This plant has been fully operational for nearly 2 years. The turn key contract costs for design, construction and commissioning the new plant were GP 33 million. The treatment center of Northumbrian Water Bran Sans has been processing sludge since 1998. Before the introduction of the Cambi pre treatment process, the facility used gas and electrical power to dry the incoming sludge. This process used an abundant amount of power to dry its 40,000 tds/yr sludge feedstock. Pellets were the output for fertilizer for agriculture. While the old plant remains as a back-up, the Cambi pre- treatment process has taken over full operation to produce power and reduce more than 500,000 tons of sludge, from the domestic and industrial sector, to approximately 60,000 tons [58]. The raw sludge is made into a sludge cake, and is pressed to remove water at the smaller sites before transport to Bran Sans. By so doing, the volume is reduced before transporting saving excessive transport costs and the treatment on site at Bran Sands becomes more efficient.

Table 15 Power Changes in MW

Process	Power before changes (MW)	Power after changes (MW)
Electrical energy input	1.96	0
Natural gas energy input	17.47	1.4
Total energy input	**19.43**	**1.4**
Biogas produced and used	0	11.5
Engine heat recovery	0	2.0
Energy used in the process	13.14	As required
Waste heat	4.33	6.2
Electricity produced and used	0	1.96
Electricity exported for use elsewhere on site	0	2.74

Source: Peter Caldwell.3rd European Water and Wastewater Management Conference 22nd -23rd September 2009[59]

This significant reduction in volume is followed by a substantial reduction in total energy input, from 19.43MW needed to only 1.4MW of power needed to run internal processing. The overall process also minimizes the natural gas needs for the production of steam for the THP process, capturing 2MW of thermal energy to replace the natural gas use in the THP process. The site also exports 2.74 MW of electrical power. Cambi's process is providing all energy needed for processing. The plant produces 4.7MW of energy from four Jenbacher CHP engines, using 1.96 MW for on-site use. Substantial reductions in carbon footprint are achieved, with a reduction of CO2 emissions by 69,440 t/year. The possibilities of co-digestion with other wast streams could be in the near future at the Bran Sands facility, as research has demonstrated that an increased methane yield from co-digestion is possible [60]. Therefore, it is necessary to calculate the influence of adding sewage sludge to other high-energy substrates and review the resulting new mixed products according to sludge type, dry residual content, amount, and composition. [61]

Research is ongoing at The Technical University in Lodz, Poland as well as at Lund University in Sweden, on the co-fermentation of sewage sludge with the organic fraction of MSW (OFMSW). Findings have indicated a higher methane yield is present when co-fermentation is used with sludge. Since sewage sludge has a higher nitrogen content than OFMSW, and OFMSW has a higher carbon content than sludge, their co-fermentation results in a higher methane production of that produced by the single substrate alone. The operational feasibilty of these findings awaits evaluation on a commercial scale.

Prior to the development of the Cambi technology, the processing of sludge was energy intensive. The Cambi technology opens a new approach to turn an ever increasing sludge problem into a new opportunity to produce a renewable energy from a free feedstock. With major investments in waste water treatment plants forthcoming in all CEE countries, the robust Cambi technology can largely contribute to energy production and to reducing the rising waste problem.

6.3 Plasma Arc Technologies

The following section will address:

- A brief description of the plasma history.
- The principle physical nature of the core process to set reference conditions for later technology discussions.
- Identification and description of competing plasma technologies.

Plasma History

The origin of plasma arc technology started in the metal industry in the late 1800's to provide extremely high heat applications. The 1950's saw the development of many materials processing applications using the plasma arc heaters. Working at low power levels of 10-20 kW, processes were developed for the cutting and welding of metals and for plasma spraying of metal and refractory powders to form protective coatings and surface treatments of metals. During the 1960's, plasma arc heaters were developed at power levels of 500 kW up to 35 MW for aerospace materials testing. This led to many high power applications for materials processing, particularly heating of molten steel in continuous casting tundishes (pouring vessels) using 1-4 MW plasma heaters. The 1970's and 1980's saw expansion of the plasma technology into industrial cutting and welding techniques and the beginning of pilot industrial plants for different applications ranging from the chemical industry to the metallurgical industry and to the waste industry.

For over 30 years, engineers throughout the world have been trying to convert refuse derived fuels (RDF) into a gas that can be suitable as a fuel in a gas engine or gas turbine and thereby enhance the efficiency with which the thermal energy in waste is converted to electricity. In the late 1980's and early 1990's, there was a notable surge in pilot plants for Waste-to-Energy (WTE) from Municipal Solid Waste (MSW) and Hazardous Waste (HW) in Australia, Germany, Italy, Japan, Norway and the USA. The successes of these plants were limited and most were decommissioned

for numerous reasons such as: technology not refined; regulatory limits not met; inefficiencies in production techniques; unplanned delays; and, original economic model not well understood.
Commercial plasma gasification facilities have only gained traction in Japan, thanks to generous subsidies. Japan has three plants in operation: a 166 ton-per-day pilot plant in Yoshi, co-developed by Hitachi Metals Ltd. and Westinghouse Plasma Corp., which was certified in 2000; a 165-ton-per-day plant in Utashinai City, completed in 2002; and a 28 ton-per-day plant commissioned by the twin cities of Mihama and Mikata in 2002. EnviroArc, which owns exclusive rights to the Pyro Arc process technology, operates since 2001 a waste-to-energy plant, based on tannery waste in Norway. Until mid 2010, PlascoEnergy Group operated a plasma-arc waste demonstration plant in Ottawa, Canada, at the Trail Road Landfill, which had to be closed because of not meeting emission standards. Advanced Plasma Power operates its Gasplasma process plant in Swindon, England, since 2006 [62]. There is a certain degree of overlap between these technologies. The distinct characteristics of some of these plasma processes will be discussed later.

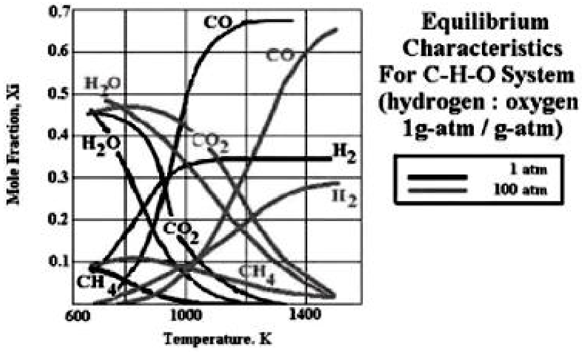
The Core Process

Plasma is called the 4th state of matter after solid, liquid and gaseous states of matter. It can be achieved either by high temperature or by lowering the pressure and is obtained at sufficiently high energy densities. The plasma systems used in all the processes of interest are based on high temperature plasma. Plasma is an ionized gas consisting of molecules, atoms, ions, electrons and photons. Plasma arc heaters are electrical resistance heaters with electrically conductive, partially ionized gas between two electrodes, providing a resistive element. When plasma arcs occur in the natural environment, they occur as sudden lighting discharges. Plasma arc heaters provide a continuously controlled electric arc discharge. The discharge can be controlled by magnetic and mechanical means, but the key design feature is the controlled feed of the gas to the arc environment. The gas can be reducing (hydrogen), oxidizing (oxygen) or inert (argon). The core temperature of the plasma arc can range from 4,000ºC to 20,000ºC. The working temperature depends on gas flow rates and heater design. The high temperature of the arc and the working gas plus the heat transfer at the arc root area result in heat fluxes about 10-50 times higher than standard oxygen fuelled flames. The high energy content of plasmas compared to that of ordinary gases or even the highest temperature combustion flames offers unlimited potential for its use in a number of significant modern industrial applications and is the key to its success.[63]

Among the WTE technologies gas plasma arch technologies are ideally suited for treatment of all kinds of waste. The process of thermal plasma assisted WTE uses plasma torches to convert waste (i.e. presorted MSW, hospital waste, all kinds of hazardous waste, railroad ties, industrial waste, sludge, digests from AD plants, liquid wastes, waste from paper and lumber mills, etc.) into a clean hydrogen-rich syngas and a vitrified material. Other processes have been unsuccessful in their attempts to clean syngas of the tars and other contaminants that can foul gas engines/turbines or block their filter systems.

The plasma arc process has shown its effectiveness in a high efficiency "cracking" of these tarry substances, which then reform into a syngas of high quality and consistency. Also, what distinguishes the plasma arc technologies from other WTE processes is a low or negative greenhouse gas footprint as compared to energy generation from fossil fuels. In addition, the extremely high temperatures from the plasma arc heater offer two distinct advantages over any known alternative technology. It allows for the complete decomposition of the highly toxic halogenated organic compounds and provides a higher heating value of the produced syngas gas than competitive processes.

Figure 8 CO & H2(syngas) only Molecules Remaining after Plasma torch



Source:Brazilian Journal of Physics[64]

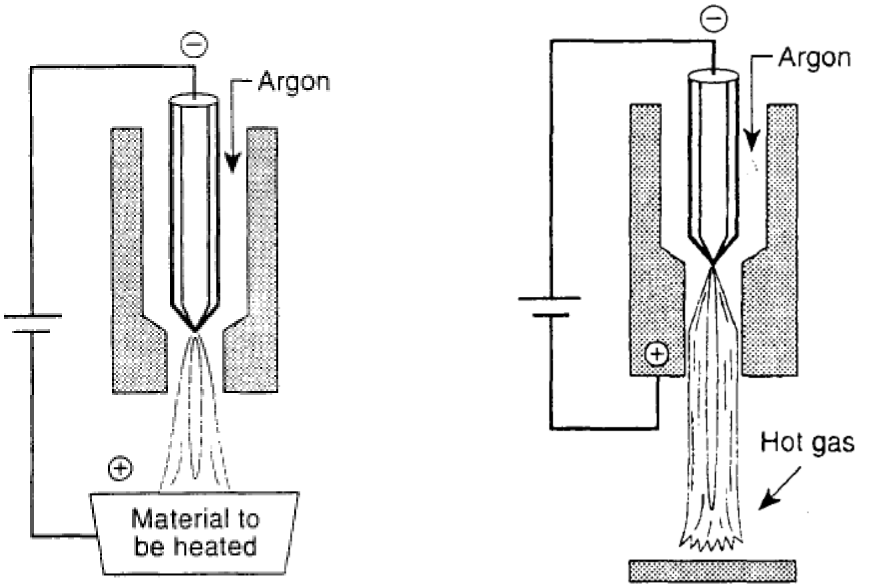
DC or AC electricity can be used to generate plasma, however, for Refuse Derived Fuel (RFD) DC is preferred. Most plasma heaters use direct current with either "non-transferred" or "transferred" arcs generated by DC electric discharge. Plasma systems can be based on non-transferred or transferred arcs:

- **Non-transferred** arcs use gas as the only working resistive element. The arc is transferred directly to the work area with resistive heating of both the gas phase and the work area. Non-transferred arc heaters are useful to heat the gas phase, such as gas phase reactors and for counter current solids, such as gas contact in shaft heaters, smelters (cupolas) and reactors (blast furnaces). These work typically with water-cooled cylindrical electrodes and operate up to 2,000 amperes and 6,000 volts with high flow rates of a reactive gas.
- **Transferred** arcs are useful for bulk heating of solids and melting where the gas phase is not the principal reactant but can be used as an inert shield. The gas flow rates are usually very low and can be important for controlling vapour phase reactions. These operate at up to several thousand amperes and only a few hundred volts. The work piece (material to be heated) is one electrode and the gas phase electrode is the other. [65]

Plasma graphite 'arc' systems and plasma 'torch' systems are the two main types of plasma gasification technologies used for Refuse Derived Fuel (RDF). Plasma graphite 'arc' systems were developed for the steel industry and have either two torches with opposite polarity or one electrode within the chamber with the return electrode housed within the lining. In plasma 'torch' systems, an arc is struck between a copper electrode and another electrode of opposite polarity or with a bath of molten slag. A plasma torch consists of two tubular metal electrodes and looks like a large welding torch. A high voltage current ignites the plasma. It is fired from the end of the downstream electrode in a "plume", destroying anything in its path.

Figure 9 Plasma Torch Types

Transferred Plasma-arc Non-Transferred Plasma Arc



Source: An Electric Energy Tool for High-Temperature Material Processing. EPRI Center for Materials Production.1991[66]

Graphite *arc* plasma processes, like those found in non-transferred applications, are more advantageous than *torch*, transferred applications. Since there is no water cooling needed as with plasma torches up to 32% of the energy output can be saved, which would otherwise be used to cool the torches. The non-transferred plasma arc design has capacities of up to 150MW as seen in the steel industry; whereas plasma transferred torch designs have a maximum limit of 2MW. The upfront capital costs for graphite arc designs are far less, around one tenth of that of torch designs which are in the range of Euro 1.5 -2.5 million.[67]

What makes plasma arc technologies so attractive in the field of WTE, is not only the environmental impact of reduced CO2 emissions and little or no landfill requirements, but more importantly its superb electricity conversion from waste. Table below shows the net electricity to grid ratios per ton of MSW processed with plasma arc technologies as compared with competing WTE conversions, based on general available industry data from U.S., European and Japanese sources. The plasma arc advantage is clear: a 816kWh net electricity generation from 1 ton of processed MSW, which translates to a 50% net electricity gain over incineration.[68]

Table 16 Municipal Solid Waste-to-Energy Thermal Process Comparison

Process (1)	**Net Electricity to Grid (kWh/t MSW (2)**	**Plasma Advantage**
Plasma Arc Gasification	816	---
Conventional Gasification	685	20%
Fixid Fluidized Bed Technologies		
Pyrolosis & Gasification -Thermoselect Technology	685	20%
Pyrolosis -Mitsui Technology	571	40%
Incineration -Mass Burn Technology	544	50%
(1) 300-3,600 TPD of MSW; (2) Steam Turbine Power Generation		

Source:EFW Technology Overview, The Regional Municipality of Halton, Submitted Genivar, URS, Ramboll, Jacques Whitford & Deloitte, Ontario, Canada, May 30, 2007

Three Competing Plasma Technologies

In the following section an attempt will be made to review and analyze three plasma systems of companies using plasma technology processes for RDF: AlterNRG/ Westinghouse, Plasco, and Advanced Plasma Power (APP). These companies have gone beyond the research phase and have demonstrated that their systems are operational. Of course, there are many other plasma companies and systems on the market, they have not passed the R&D stage and will not be discussed here.

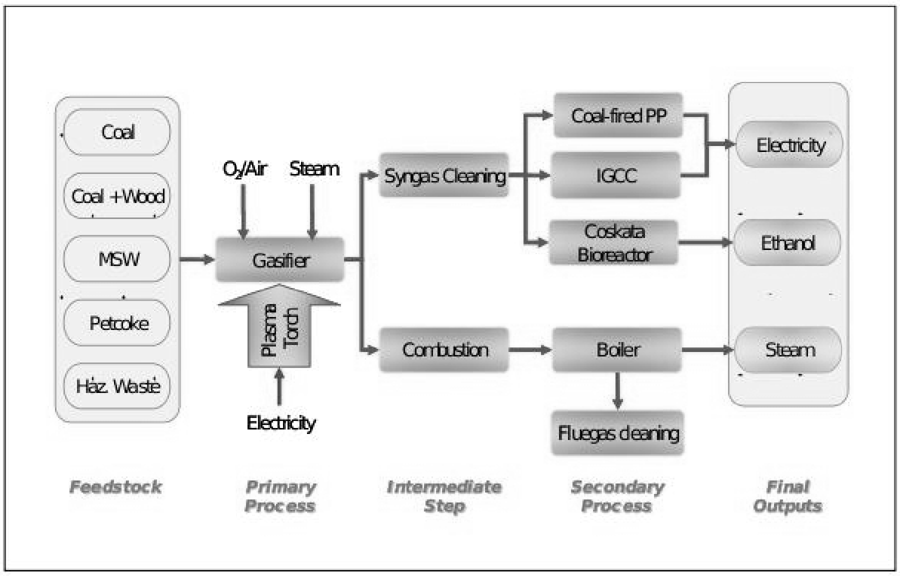
Alter NRG/Westinghouse Plasma

The technology was developed by Westinghouse with half a century experience in R&D, plasma torch sales and engineering support. Alter NRG acquired the technology in 2007 and shifted the focus to MSW.

The Alter NRG/Westinghouse Process

The process is a non-transferred single stage plasma-assisted torch gasification, producing a syngas that is treated by up to six plasma torches that are located at the gasifier's bottom. Non-shredded feedstock is put in the one step gasifier,vaporizing all waste into syngas. Metallurgical coke (Met coke),a carbon material produced by the destructive distillation of various blends of bituminous coal, is fed into the gasifier with the MSW feedstock to provide a sufficient environment for the production of vitrified slag from the inorganic materials present. Alter NRG's use of single stage plasma gasification for RDF requires a large amount of power to convert the RDF to syngas making it not an economical process. The syngas requires further cleaning downstream if it is to be used for anything other than immediate combustion. [69]

Figure 10 Alter/NRG Conversion Process



Source Juniper Independent Waste Technology Report. The Alter NRG/ Westinghouse Plasma Gasification Process.2008[70]

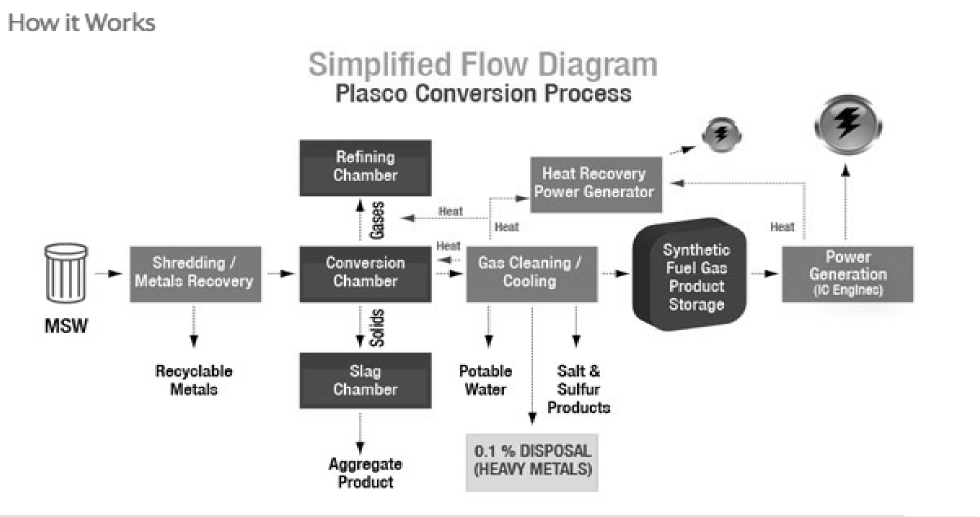
Plasco

Plasco uses traditional gasification techniques with plasma torches in a one stage, non-transferred plasma gasification process.

The Plasco Process

In the pre-processing system the metal content and materials with high reclamation content are separated before the MSW enters the shredder. In order to ensure stability of the syngas, a Consistent Carbon Feed stream enhances the shredded material with old tires, plastics, and waste with know heating value. A conveyer system under nitrogen pressure (to prevent syngas from entering) feeds the material to the converter unit. In the primary chamber of the converter the material is gasified with heat recuperated from the syngas refining chamber. The product leaving the gasification chamber contains carbon monoxide, hydrogen and tars together with untreated carbon and enters the refining chamber where the catalytic reaction of the plasma graphite arc breaks down the hydrocarbon chains into their elements to form a clean syngas. By adjusting the process of air fed into the converter, the temperature and the volume of CCF added to the MSW stream, the quality of syngas can be controlled. The next step is a recuperator where heat is recovered for the gasification process and for electricity production via a heat recovery steam generation system. The syngas is subsequently sent for cleaning to a Gas Quality Control Unit before its combustion for electricity in 13 Jenbacher engine generators of 2 MW each. Engine efficiency is at 38 percent. Heat recovery steam generators attached to all Jenbacher engines as well as 8 process waste heat boilers deliver steam to a 7 MW steam turbine for electricity production [71].

Figure 11 Plasco Conversion Process



Source: Review of Plasma Arc Technology, Mott MacDonald.2008[72]

Plasco built a demonstration plant in Ottowa with the aim of processing 85t/day of MSW. In Oct. 2008 Plasco started delivering power to the grid. In May 2010 the Ottawa Chronicle reported that Plasco had to shut down its operation, since for over 1 ½ years its engines managed only a running time of 85 hours, predominantly because of consistent problems of not keeping exhaust level pollution below the regulatory limits [73]. In October 2008, Plasco proposed a plasma plant for

Port Moody, Canada in 2008 with a capacity of 400t/day, using 4 modular facilities each with a 100t/day capacity; a design based on the their Ottawa Trial facility. From 1 ton of energy waste (pre-sorted MSW spiked with shredded tires), they estimated a net energy output of 1.2 MWh in a combined cycle operation. This proposal was dropped by the city council of Port Moody because of concerns whether Plasco can meet air quality standards and by communities who feared a WTE plant will hamper efforts of recycling and waste reductions.[74]

Advanced Plasma Power (APP) uses its trademark Gasplasma process, a non-transferred two-stage system classed as energy recovery rather than wastisposal, on refuse derived fuel (RDF) and refined biomass, to produce two end products: syngas rich in hydrogen and a vitrified recyclable material. The Gasplasma technology was developed by Tetronics Ltd and APP. Tetronics has been one of the leading international manufacturers and suppliers of High Temperature DC Plasma arc technology since 1964. APP is based in Swindon, Wiltshire, England and founded in 2005. A Gasplasma demonstration plant in Swindon operates since 2007, processing 75 kg/h successfully over 4 years under continuous operation. What makes APP's process unique is simplicity of design: it combines three different, well proven, technologies from well established technologies: fluidized bed gasification, separate plasma arc treatment, and a power island with gas engines to provide highly efficient power generation and heat, with over two-thirds of total power produced exported to the grid. [75]

The APP Process

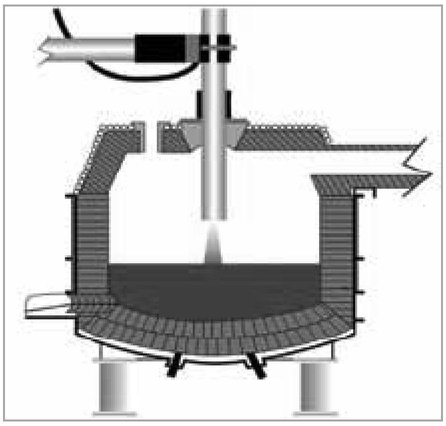
After recyclable materials are separated in a front-end fuel preparation and materials recycling facility (MRF), an air preheater is used to bring the gasifier system up to its operating temperature using a natural gas burner and a high-pressure fan. Air is heated and then blown into the gasifier raising the temperature to approximately 700ºC. The gasifier is 9 meters high with an internal diameter of 3 meters. The presorted feedstock is introduced into the gasifier slightly above the fluidized sandbed, until the process becomes self-supporting, at which time the gas burner input is then reduced before being turned off.

In a normal operating situation, the gasifier bed of sand is fed inputs of steam and oxygen that are injected at the base of the bed to fluidize the sand and to maintain a starved air atmosphere within the gasifier. The syngas then leaves from the top of the gasifier. A small percentage of the input material filled with soot, ash, and solid chars, is removed from the base of the bed and transferred to the plasma converter.

The plasma converter is a refractory lined chamber 3 meters in diameter and 2.5 meters high. The carbon electrode and its control equipment is aligned in the center of the roof and as syngas is introduced, it is forced to swirl around the chamber allowing the time for the gas to be exposed to the high temperatures and intense ultra-violet light of the electrode arc before exiting from a refractory lined duct for further processing.

The soot, ash, and solid chars are also treated in the plasma converter, becoming a molten product which is continually removed, cooled, and processed into a recyclable aggregate, called Plasmarock and useable as a building material or construction aggregate material. It is glass like substance and not leach-able. [75]

Table 17 Cross-section through APP Plasma converter



Source: APP Company brochure

The hot syngas exits the converter at approximately 1,200ºC. It is then cooled in a water tube heat exchanger to reduce the temperature to 200ºC. During this process, energy is recovered in the form of low pressure steam, a proportion of which is used in the gasification process. The syngas flows to a particulate filter that has reacting agents metered into the gas stream to enable capture of sulfur based compounds and metals.

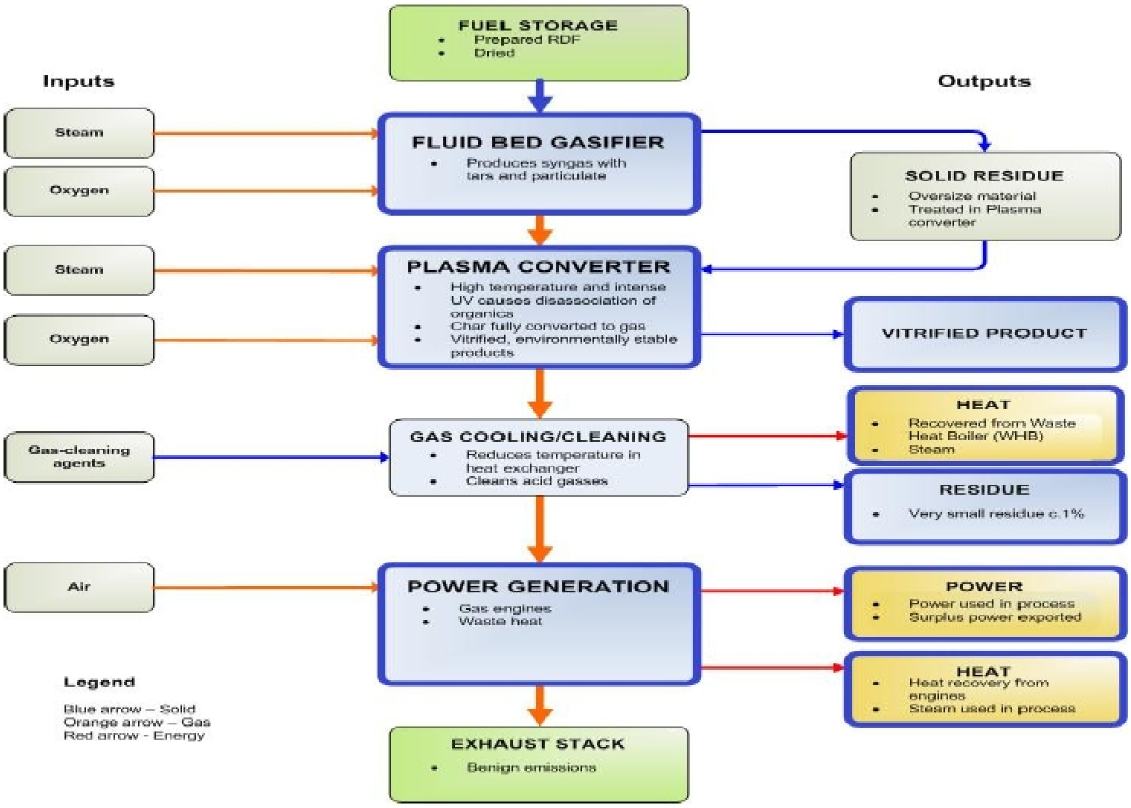
The subsequent reacted materials are captured as contaminated dust, allowing the syngas to pass through. The syngas travels through a vertical packed tower that has a strongly alkaline acid solution. The acidic components in the gas are reacted and are neutralized in the solution, leaving a cool, clean fuel gas for the gas engines. This achieves electrical generating efficiencies of 35-40%, considerably higher than found in a straight gasification process of a small steam cycle power plant of around 20%. [76]

Before the gas is sent to the engines, a small proportion of the cooled, low-pressure, clean gas is diverted and compressed at high pressure to provide buffer storage capacity. The storage facility allows for the fluctuation of energy demands from the gas engines. The syngas flows into the Jenbacher gas engines at a constant pressure, with the required rate matched to demand.

The power is routed to the internal distribution system for the conversion process itself and the balance is sold to the distribution grid system. Heat is recovered from the engine exhausts and converted to steam. This steam is combined with the steam recovered from the syngas cooling system process. It is used either for additional power generation or for export as process steam or hot water to a district heating system.

About one-third of the total electricity generated is used to power the plant and two-thirds can be fed into the grid. Finally, engine exhausts are combined into a single, low impact stack for discharge, meeting all European Emission standards. This process has high rates of power output and electrical efficiency, with virtually zero residues and very low emissions, producing a valuable and recyclable aggregate, accomplished within a small plant that can handle any waste close to the source at a highly competitive cost.

Figure 12 APP conversion process



Source: http://www.advancedplasmapower.com

Intellectual Property Law and trade secrets protect design and detailed process information. Based on public records and interviews with LGE Executives, some significant differences between the APP process and other plasma processes emerge:

- APP's non-transferred two-stage Gasplasma system is built with proven technology components.
- The extreme high temperatures from the plasma arc heater achieves complete decomposition of all toxic halogenated organic compounds.
- Conventional fluid bed gasifiers convert organic waste material into a syngas (40% hydrogen, 40% carbon monoxide and the balance consisting of methane, ethylene, carbon dioxide and small amounts of nitrogen). This syngas is contaminated with tars, solvents and solid soot, char and ash particles. In contrast, APP's process with its extreme high temperatures of the plasma jet dissolves the complex hydrocarbons of tars and soot into

basic molecules. Not only makes this the cleaning of syngas easier and less costly, it also increases the net energy conversion, since the long hydrocarbon chains are broken down and added to the fuel instead of being scrubbed off by filters as it is the case in competitive processes.

- Unlike incineration, conventional gasification or pyrolysis, the APP process converts the inorganic matter to a vitrified, reusable residue. Other conversions, such as incineration, conventional gasification and pyrolysis produce significant volumes of toxic ash, chars, and tars which have to be deposed of at high costs.
- The high grade syngas is used in a gas engine or turbine and achieves electric generating efficiencies of 35-40%, sharply in contrast with steam cycle power plants which convert about 20% of the feedstock into power.
- APP's advanced conversion technology (ACT) process produces little to no polluting gases or emissions as seen in the table below, sharply in contrast to power plants, incineration or landfill and other plasma arc processes. The table also shows the highly negative carbon footprint per ton of MSW when processed with Gasplasma. With only 1.5% of input volumes designated for landfill, Gasplasma has one of the highest diversion rates from landfill. Noteworthy, is its negative carbon footprint from a low environmental impact plant. [77]

Table 18 GasPlasma Environmental Impact Data Versus Incineration and Landfill

	GHG Emissions	**CO2 Emissions**
Gasplasma	-341 kg CO^2/MWh	-543 kg CO^2/t MSW
Incinerator	230 kg CO^2/MWh	120 kg CO^2/t MSW
Landfill	430 kg CO^2/MWh	325 kg CO^2 / t

Source: APP

Summary

Plasma applications in the fields of municipal, commercial, industrial and hazardous waste treatment generate from the organic fraction of the waste streams renewable energy. These technologies meet or exceed the current and projected emissions and landfill requirements in the EU for their respective applications. With regard to WTE alternatives, plasma treatment is by orders of magnitude 20 to 50% more efficient in converting MSW to electricity than competing technologies. Moreover, it is more robust and versatile than traditional incineration, especially where the particles (ash, fly ash, metal dust) cannot be worked upon efficiently in any other way than landfilling with its detrimental environmental consequences..

Chemical treatment and non-plasma systems still generate and/or leave huge volumes of hazardous disposables for additional transportation and landfills. Hence fundamentally, these technologies can only be considered as volume reduction techniques and certainly not as permanent solutions to problem mitigation. With plasma there exists the fundamental alternative of complex molecular disintegration and destruction, yielding a high energy syngas for power production plus a condensed and vitrified, non-leach able, practical usable construction type of a material or product, all this without any significant wastage of funds, energy, time or space. [78]

The more recent alternatives for general MSW application such as mechanical and biological treatment systems (MBT) and advanced thermal systems (gasification and pyrolysis), may still require additional processing for the landfill for their eventual waste by-product.

7 Financial Profitability of Investments in Waste to Energy Projects

The Drivers

The main legal drivers for investors to invest in WTE projects in CEE are:

- The EU Council Directive 99/31/EC on Landfill. [79]
- The EU Council Directive 86/278/EEC covering sewer sludge and waste water treatment. [80]
- The EU Directive 2006/12/EC on waste. [81]
- The abundance of waste in a resource constrained world is increasingly being recognized as a “ free” feed stock for renewable energy. The sharp increase of agricultural commodity prices and its subsequent spill-over to prices for biogas feedstock is supporting this trend.
- The emergence of new technologies in the fields of ADD and plasma arc have proven to be operational.

- The EU Directive 2009/28/EC on Renewable Energy [82], combined with attractive feed in tariffs for WTE in some CEE countries.

- The EU Structural and the Cohesion Fund for Environment Programme provide grants during 2007-2013 to new CEE member states for waste water infrastructure and integrated waste management. [83]

Table 19 Attractive Feed-in Tariffs for Electricity from Biogas from Anaerobic Digestion, Sewer and Waste & 2007-2013 EU Grant Allocation for Water, Sewer and Waste Infrastructure and Management

Country	Feed-in Tariff Euro cents/kWh	EU Operational Program Environment Allocations 2007-2013 In Euro millions		
		EU	National Government	Total
Bulgaria	<5MW 10.12	1,339	312	1,651
Czech Rep.	12.7	777	137	914
Hungary	Average 8.17	2,218	391	2,609
Poland	9.2	3,990	705	4,695
Romania	5.5	3,711	724	4,435
Slovakia	12.87	485	86	571
Slovenia	6.65	531	93	624

Source: EU Operational Programme Environment 2007-2013 [84]

Attractive Technologies

From the above analysis two attractive technologies emerge for waste to energy

- The Advanced Anaerobic Digestion based on thermal hydrolysis of the Cambi process; and
- The plasma gasification based on the Advanced Plasma Power technology.

An attempt will be made to assess the potential financial profitability of these two technologies - each based on different, most abundant and sustainable waste feedstock: one is sewer sludge from wastewater treatment plants, and the other is MSW and all forms of hazardous waste. Since very little data on capital expenditures, operational costs and profitability of these technologies is in the public domain, this analysis is not conclusive and provides only a rough indication of the potential

profitability for an investor in these technologies in CEE.
Some of the underpinning capital expenditure (CAPEX) data were derived from internet sources, company publications, interviews and discussions with key decision makers of these technologies. In this respect much gratitude has to be expressed to the CEO, the CFO and the Vice-President of Projects of Leveraged Green Energy LLC, who were gracious to share their valuable experience and key operational data of the new plasma technology. Without their help this analysis would not have been possible.

Innovations and Flexibility in Project Funding

Preconditions for investments for WTE projects, next to the creation of a Special Purpose Company (SPC) to manage the project, are efficient technology options, a secure and uninterrupted feed stock supply, and a secure power-purchase agreement. Furthermore, a favorable regulatory policy including guaranteed and preferential feed-in tariffs for renewable energy from waste sources provide a strong incentive. The financing strategy for all of these projects will require innovation and flexibility to provide investors and lenders with the necessary risk mitigation. A strategic partnership between the SPC and feedstock suppliers (e.g.. municipal waste water treatment plants in the case of biogas to energy projects, or with MSW collection companies in the case of gasplasma to energy projects) in the form of equity participation will eliminate the risk of feedstock interruptions. Equally important are Public/Private Partnerships by the SPC with municipalities, which would be a precondition to obtain access to grant funding from the EU Structural or Cohesion funds.

To optimize the profitability of the investment, a SPC wants to take maximum advantage of emission reduction units under the Kyoto Protocol. The Joint Implementation (JI) Projects agreements between the Republic of Austria and Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Romania, and Slovakia, regulate the purchase by Austria of Certified Emission Reduction credits (1 CER is equivalent to 1 metric ton of carbon dioxide) from project implementation in jointly agreed priority areas. Among the defined project types are projects using renewable energy sources and waste management measures which contribute to avoidance of greenhouse gas emissions in particular through energy recovery and use. For Austria, the management of the JI

Programme rests with the Kommunalkredit Public Consultant. For JI projects of Annex I countries (developed countries signatories to the Kyoto Protocol), which are implemented under Track 2 regulations of the Kyoto Protocol and the Marrakech Accords, the CER credits will be issued for verified emission reductions. [85]
The CERs are traded within the EU Emission Trading System. With the present recession in Europe, the CER prices are down and in 2010 the range is about Euro 18 to 20/tCO2. In a recent report the Society General estimates that the CERs could languish at about Euro 20/tCO2 up to 2020 based on current EU emission targets [86]. For projects meeting the JI Programme requirements, the CERs gain particular importance not only as an annual revenue, but more importantly when they are pre-sold (at a discount) for up to 5 years in advance (on the spot market of one of Europe's climate exchanges or over the counter), since the proceeds can be applied as a quasi equity contribution to the SPC.

Risk mitigation for both investors and lenders is an important aspect of project finance in emerging markets of CEE. It can best be achieved through insurance with MIGA (a part of the World Bank Group, Washington D.C.) or other insurers such as OeKB. MIGA will ensure eligible projects in the CEE against losses arising from: currency transfer restrictions (would not be called for EU member states); expropriations; war and civil disturbances; breach of contract; and non-honoring of sovereign financial obligations. MIGA's charge for underwriting such insurance is determined by coverage and country risk. Insurance coverage can be obtained for up to 15 years. MIGA's advantage for investor is a reduction of the risk-capital ratings for projects and thereby helps investors to: (1) access project finance from banks and (2) lower the banks borrowing costs. [87].
Possible tax credits and grants funding from the EU Structural or the Cohesion Fund could provide strong additional financial incentives at a time when long term project finance is hard to obtain from banks because of the prevailing financial uncertainties in the markets.

Keeping construction, procurement of services and goods, estimated completion dates and cost estimates for plant construction under control is a sine qua none for successful project implementation. A common road used by private investors is reliance on turn-key solutions as well as performance bonds, and completion guarantees from suppliers, contractors, and sub-contractors. Generally all new technologies are based to some extend on existing technologies for which equipment was already built and tested. Procuring, as much as possible, proven off-shelf equipment for component parts of new technology applications can substantially reduce the engineering and procurement costs for new plant designs.

7.1 Biogas Sludge Waste to Energy

Driven by the various EU Directives and supported by funding from the EU Structural and Cohesion Fund mentioned previously, major constructions of new waste and sewer water treatment plants will have to be carried out by municipalities in all new 12 EU member states. In addition, the past disposal practice of untreated sludge on agricultural land or in landfills, sometimes in from of liquid waste disposal, will have to be abandoned. Most municipalities in the CEE countries will be stretched financially to undertake these enormous investments, since they will have to mobilize first their own financial contribution for the proposed investment before they can access the EU grant contributions. These circumstances offer an opportunity for investors in combined advanced anaerobic digestion (ADD) and CHP plants to turn the municipalities' sewer sludge liability into a profitable asset by taking advantage of ample free feedstock, attractive tipping fees, and carry the clean up process of the sewage treatment investments a major step forward, by producing renewable energy.

The issue of decentralized versus centralized ADD & CHP plants is complex and has various aspects. Most sewage treatment plants to be constructed in CEE will serve population centers of 2000 and above [88]. Transporting dewatered sludge to centralized ADD&CHP plants entails transport costs for municipalities and creates CO2 emission. Investing in small, decentralized ADD&CHP plants will overcome these problems and may be desirable from the viewpoints of governments or municipalities, but it is certainly not attractive for an investor who seeks foremost a high return on equity and a risk mitigation for the investment by a streamlined licensing process, an available power purchasing agreement in conjunction with grid connection, a short construction period, and a streamlined management for the investment. Decentralized plants would only compound the risk elements and are therefore not attractive. In addition, project financing, already difficult to obtain, is even more difficult for small projects. All this argues and supports centralized, large plants which can fully utilize economies of scale and have proven to be economically and financially viable. The Cambi process, discussed above, and used successfully on a large scale by Northumbrian Water in Bran Sands,UK is a case in point. This plant has been fully operational for more than one year. From the plant data available in public domain, an attempt is made to construct a financial model for a similar plant processing annually 40,000 tDS (tons dry solids) untreated sludge from waste water treatment plants under conditions prevailing in the Czech Republic. [89]

The Czech Republic has been chosen for this investment proposal because of very attractive feed-in tariffs, good grid connections, government's commitment to a waste management policy and ample available grant funding from the EU Operational Programme for Environment. Further assumptions used are straight line depreciation over 20 years. Following accounting rules, depreciation and amortization provisions are not considered for leased equipment or for plant assets financed by grants. By using MIGA insurance cover it is assumed that project financing can be obtained at favorable rates. These insurance costs are accounted within the OPEX. Two scenarios are presented: one where the SPC holds all equity and does not rely on EU grant funding and one, where the investors in the SPC form a Public/Private/Partnership with the local authorities or municipalities and thereby gain access to EU grant funding.

Table 21 Proposed Investment Case of Advanced AD of Sewer Sludge in the Czech Republic

	Financing without EU Grant	Financing with EU Grant
Cost of Infrastructure and Equipment	44.5 million	44.5 million
Cost of Engines (4x Jenbacher engines 320)	3.5 million	3.5 million
Cost of Permits, engineering, development fees, other cost	5.0 million	5.0 million
Cost of land	1.0 million	1.0 million
Total CAPEX(1)	**54.0 million**	**54.0 million**
Financing Plan		
Equity	20.2 million	20.2 million
Leased Equipment	3.5 million	3.5 million
Debt	30.3 million	15.3 million
EU Grant		15.0 million
Total	**54.0 million**	**54.0 million**
Annual Operating Revenues		
Tipping Fees for 40,000t DS (dry solids) @ Euro 225/t **(2)**	9.0 million	9.0 million
CER Credits (69,440t/year) @ Euro 20/t	1.4 million	1.4 million
Electricity Exported 2.74MW/803h @ Euro 13,9 cents/kWh**(3)**	3.1 million	3.1 million
Total	**13.5 million**	**13.5 million**
Annual Operating Costs (4)	**4.1 million**	**4.1 million**
Annual Operating Profit	**9.4 million**	**9.4 million**
SG&A Expenses **(5)**	**0.13 million**	**0.13 million**
EBITDA	**9.3 million**	**9.3 million**
Depreciation and Amortization	**2.3 million**	**1.5 million**
EBIT	**7.1 million**	**7.8 million**
Interest Expense @ 8%	**2.4 million**	**1.2 million**
EBT	**4.7 million**	**6.6 million**
	ROE 23%	**ROE 33%**

1) Major Data source: Aker Solution E&C Ltd; Northumbrian Water Sewage Treatment Works; and Graham Neave, Advanced Anaerobic Digestion: More Gas from Sewage Sludge. www.waste-management-world.com.[90]
2) Landfill of hazardous waste used to be the preferred disposal method which is being phased out with EU Directives. The alternative to landfill is incineration at Euro 270/t plus 19% VAT. Tipping fees for DS sludge is assessed at landfill disposal prices in this calculation. 2010 landfilling disposal cost are Euro 194/t plus VAT 19% in 2010. source: Ministry of Environment Ceska Republika.[91]
3) Plant generates 4.7 MWe from 4 Jenbacher engines. 1.96MW are used internally and 2.74MW can be supplied to the grid. Source Aker Solution E&C Ltd.
4) Assumed at 8.5% of total cost of plant equipment
5) SG&A expenses assumed at 12.5% of operating profit

7.2 Gasplasma From MSW and Hazardous Waste Streams to Energy

Like in the case of the AAD investment, the Czech Republic has been chosen for the proposed investment in Gasplasma, since the investment drivers are most attractive. Very important is the commitment of the Czech Republic to implement the EU Directives from Landfills to Waste, which is best reflected in its waste management plan and its policy to use the price mechanism to regulate waste generation and disposal alternatives. About 3 million tons of hazardous waste is generated per year, about 8% of total waste. There are 29 incineration plants and 6 cement kilns treating hazardous waste. Of the 240 landfills (capacity 93 million m3) there are 28 for hazardous waste (capacity 10 m3). In 2010, the basic price for landfill disposal of hazardous waste is Euro 62/t plus Euro 164/t for hazardous waste charges plus 19% VAT. The Ministry of Environment anticipates to introduce rate hikes for hazardous waste in 2011 to reach Euro 80/t base price plus Euro 215/t for hazardous charges, plus VAT. [92]

APP is now in the process of scaling-up the successful Swindon plant to a commercial 150,000t/year MSW plant, which, after recycling and drying of the residual waste, delivers around 90,000t of RDF for plasma gasification and can produce a gross output of 16.5MW, diverting 97% of the original feedstock away from landfill environment. To bust energy production, new J624 2-stage turbocharged Jenbacher engines could be used, thereby increasing output by about 10 %, from 4 MW to 4.4 MW. These engines offer an electrical efficiency of 46.5 %, an increase of about 2 percent over previous models.[93] Fichtner Consulting and Engineering conducted a detailed due diligence for the technology and plant design in September 2010, which verified and validated the feasibility for the proposed scaled-up plant.

The assessment also validated that the Gasplasma technology provides a clean syngas for direct use in a gas engine to produce electricity. The physical footprint of the proposed plant is less than 8,000m2 with a stack height of approximately 25m, thus allowing APP to fit into industrial sites where other processes are too big [94]. A scaling-up process of this magnitude entails inevitable uncertainties, however these risks should be less of an issue, since the Gasplasma process with its principle and proven components is already working in Swindon.

A preliminary financial feasibility for such a plant under conditions applying in the Czech Republic is presented below. A detailed analysis of cash flows and internal rates of return was not possible, since needed detailed data of plant operation are protected by intellectual property rights. Plant data sources (CAPEX, OPEX) were obtained from APP's website, by the Stantec Report "Waste to

Energy, A Technical Report of Municipal Solid Waste Thermal Treatment Practices, Final Report, August 27, 2010" [95], and from discussions with officials of Leveraged Green Energy LLC. The Stantec Report estimates the median reported CAPEX at Euro 960/per ton of prepared RFD processed annually by plasma (+ or – 40%) and the median OPEX at Euro 90/ per processed RFD ton (+ or – 50%). Another source of information was the Surrey County Council "Review of Plasma Arc Technology", issued August 2008, which compared competing investment proposals from APP and Plasco for a proposed investment for a 100k/pa plasma plant. Further assumptions used are straight line depreciation over 20 years. Following accounting rules, depreciation and amortization provisions are not considered for leased equipment or for plant assets financed by grants. By using MIGA insurance coverage, it is assumed that project financing can be obtained at favorable rates. These insurance costs are accounted within the OPEX. Two scenarios are presented: one where the SPC holds all equity and does not rely on EU grant funding and one, where the investors in the SPC form a Public/Private/Partnership with the local authorities or municipalities and thereby gain access to EU grant funding.

Table 20 Proposed Investment Case of a Gasplasma Plant in the Czech Republic

	Financing without EU Grant	Financing with EU Grant
Cost of Equipment	62 million	
Engines	20 million	
Cost of Land	1 million	
Permits, infrastructure, development fees, other costs	5 million	
Total CAPEX	**88 million**	**88 million**
Financing Plan		
Equity	27 million	27 million
Leased Equipment 1)	20 million	20 million
Grants	----	20 million
Debt	41 million	21 million
Total	**88 million**	**88 million**
Annual Operating Revenue		
Tipping Fees for 150t/year plant 2)		
-MSW 75k @Euro 50/t	3.75 million	
-Liquids,Industrial,Hazardous waste 75k @Euro 240/t	18 million	
CER credits	1.5 million	
Electricity 11MW/7500 h @ 12.7 Euro Cents/kWh	10.5 million	
Sale of reclaimed metals and Plasmarock	2.4 million	
Total	**36 million**	**36 million**
Annual Operating costs 3)	**7 million**	**7 million**
Annual Operating Profit	**29 million**	**29 million**
SG&A Expenses 4)	0.5 million	0.5 million
EBITDA	**28.5 million**	**28.5 million**
Depreciation and Amortization	3 million	2.4 million
EBIT	**25.5 million**	**26 million**
Interest Expense @ 8%	3.3 million	1.7 million
EBT	**22.2 million**	**24.3 million**
	ROE = 82%	**ROE= 90%**

1) Consits of engine leasing
2) Ministry of Environment Ceska Republika.
3) Assumed at 8.5% of total cost of plant equipment
4) SG&A expenses assumed at 12.5% of operating profit

Given the limited data sets available for both investment proposals it was not possible to calculate the internal rates of return. Therefore, only the Return On Equity (ROE) is presented. The ROE is equal to the net income after tax divided by the shareholder equity. Because of complexity of the Czech tax rates regarding investments in renewable energy, the tax rates could not be obtained and the ROEs presented here are the net income before taxes divided by shareholder equity.

Nevertheless, the rates presented give a rough indication how profitable the investments are for the shareholders of the SPCs. The high profitability or ROE ratios for both investments have been achieved because both investments are highly leveraged in terms debt financing - a financing model commonly practiced.

Under conditions prevailing in the Czech Republic- a stable policy framework for renewable energy and attractive feed-in tariffs with ready power purchase agreements and grid access - the above financial analyses demonstrate that investments in a ADD plant and in a Gasplasma WTE plant can both be extremely profitable to the investors in the SPC. These investments will be robust even in the absence of EU/government grants. However, in both cases the ROEs are highly sensitive to the tipping fees, since they account for the largest source of annual operating revenues. With full implementations of the EU Directives landfilling will become increasingly more constrained and this should put upward pressure on tipping fees.

8 Executive Summary and Conclusions

1. With the EU commitment to increase by 2020 renewable energy by 20% and reduce CO2 emissions by 20%, electricity production from renewable energy sources, so far largely neglected in the CEE Member States, has to be expanded. Electricity production from hydro, wind and biomass and to a lesser extend from solar energy have shown a modest growth in the last decade. Renewable energy still plays a minor role in the total energy supply of the CEE countries, although substantial opportunities for renewable energy have so far been untapped.
2. Nearly all EEC member States have a wide range of greatly underutilized biomass resource for renewable energy. The highest biomass potentials and the lowest costs are found in Poland, Romania and Bulgaria. Large scale utilization of biomass feedstock in CEE is constrained by small farm holdings. An inherent problem is that most available technologies for bioenergy production show relatively poor economic performances at small scale plants. In contrast, large scale plants, providing economies of scale with associated low production costs for electricity, suffer from the risks of price fluctuation for biomass and of high transport costs of procuring the necessary feedstock at a continuous basis from the predominantly small scale agricultural holdings in most of CEE.

3. At the same time, the CEE countries confront an ever mounting problem of disposal of MSW and hazardous waste. The projected growth scenarios for waste are troublesome. For the period 2005-2020, municipal waste is projected to grow by 50 percent in the new EU12. Over the same period, even higher rates of up to 60 percent growth are projected for the Czech Republic, Hungary, and Slovakia.
4. Residual sludge from waste water plants is another waste problem. In 2009 about 1.2 million tons DM sludge were accounted by the new 12 member states. On a per capita basis this is still low compared to the EU 15 and reflects the poor state of water treatment facilities and/or the lack of these facilities. The present disposal route is landfilling. EU Directives to ban landfilling of sewer sludge and to expand the coverage of waste water treatment facilities in all CEE countries will exacerbate the problem of sludge disposal .
5. So far the prevailing opinion was that these waste streams are a problem. This thesis provides evidence that the waste problems can be turned around into an opportunity for generating renewable energy with little or no carbon footprint. Moreover,this feedstock entails no costs, it even generates revenues from the collection of gate fees.
6. From a broad review of available new technologies in the areas of AD and Plasma-arc, two technologies emerged which are robust and proven in WTE: the Advanced Thermal Hydrolysis by Cambi, Norway, and the Gasplasma process developed by Advanced Plasma Power in the U.K. Although both technologies are energy consuming, they are in a position to deliver the majority of their energy production to the grid. The Cambi process delivers 58% energy production, and Gasplasma about 66% energy production to the grid.
7. There can be no doubt, that the challenges for developing such new WTE systems in the CEE are formidable, since they are highly capital intensive. Alternative ways of finance and management are called for. This calls for a greater role of the private sector to fund necessary infrastructure in the energy and waste sectors which in many CEE countries are still considered a domain of the public sector. Various forms of Public Private Partnerships offer such alternative, but also a sole private sector involvement is an option. In both cases profit motivations would assure that financial and managerial resources are allocated effectively and investments completed in time.

8. A financial analysis was carried out for a THP and a Gasplasma plant under conditions prevailing in the Czech Republic. The Czech Republic was selected, because of its a stable

policy framework for renewable energy, attractive feed-in tariffs with ready power purchase agreements and grid access.

9. Sole private sector involvement in ownership/financing and a PPP in ownership/financing with EU grants were examined. In both sole ownership/finance cases preliminary financial analysis with limited available data indicate that the proposed investments in THP and Gasplasma plants in the Czech Repulic would be robust and highly profitable. In the case of the THP plant, a ROE of 23% can be achieved, and in the case of the Gasplasma plant the ROE reaches 82%. Both ROEs do not rely on EU grants, which could be obtained for such investments. This leads to the final conclusion that financially well structured investments in robust technologies in WTE projects are highly profitable and will attract private investments in CEE counties.

8.1 Outlook

1. As more Gasplasma plants for MSW become operational and reliable data enters the public domain, a detailed technical and financial analysis should be undertaken to determine the optimal size for these plants.
2. The Gasplasma processes requires at present about 1/3 of the total electricity produced for operating a plant. For the THP process this amounts to 42%. Research would be called for to assess technology possibilities to reduce the internal electricity requirements.
3. The incineration lobby's argument against Plasma arc processing of MSW are the apparently high investment and operational costs for such facilities. The average capital cost for a conventional incineration plant (exclusive of new EU requirements for emission upgrading) are in the order of Euro 40-50/t MSW processed versus Euro 960-980/t with plasma arc. As more data becomes available, both for investment costs for emission upgrading needs of incinerators, and for plasma arc investment and operating costs, an analysis should be undertaken to assess whether the substantial production of renewable energy from plasma arc facilities (>810 kWh/t MSW) can compensate for the difference in capital and operating costs and environmental impact.

4. A synergism between THP and Gasplasma needs to be explored, since the pellets produced by the THP process from the digestate can be used as an energy feedstock for Gasplasma. A definite assessment can only be made after detailed technical and financial data of these technologies becomes available.

9 Glossary

AAD	Advanced Anaerobic Digestion
ACT	Advanced Conversion Technology
APP	Advanced Plasma Power
CAPEX	Capital Expenditure
CEE	Central Eastern Europe
CER	Certified Emission Reduction
DM	Dry Matter
EBITDA	Earnings Before Interest,Taxes,Depreciation and Amortization
EBRD	European Bank for Reconstruction and Development
EBT	Earnings Before Tax
EU	European Union
Eur	Euro
kW	kilo watt
kWh	kilo watt hour
GDP	Gross Domestic Product
GHG	Green House Gas
GJ	giga joule
GW	giga watt
GWh	giga watt per hour
Ha	hectare
LGE	Leveraged Green Energy
LHV	Lower Heating Value
j	joule
m	meter
m2	square meter
m3	cubic meter
MIGA	Multilateral Investment Guarantee Agency
MJ/kg	Mega joules per kilogram (Energy density)
MRF	Materials Recycling Facility
MSW	Municipal Solid Waste

MW	Megawatt
MWh	Mega Watt Hour
MWe	megawatt electric
MWh	megawatt per hour
ODM	Organic Dry matter
OPEX	Operational Expenditure
PJ	Petajoule
PPP	Public-Private Partnership
RDF	Refuse Derived Fuel
ROE	Return of Equity
SG&A	Selling, General and Administrative Expenses
SPC	Statistical Process Control
RES	Renewable energy Source
t	Ton
THP	Thermal Hydrolysis Process
Toe	Ton Oil Equivalent
Tpd	Ton per day
Tph	Ton per hour
WTE	Waste- to- Energy
y	year

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Annex I

Electricity Production in the CEE Member States

This Annex draws upon information provided by the EuroObserv'ER and illustrates the limited role of renewables in each of the CEE Member States. It is an indication of the challenges the CEE countries confront in meeting the ambitious 2020 targets set by the EU. [96]

Bulgaria

Fossil and nuclear energy generated 91% of Bulgaria's electricity production in 2007. Hydro power is the predominant renewable electricity source and accounts for 8.4% of electricity. Next to hydro resources, Bulgaria's wind and biomass are substantial. While the exploitation of wind has taken off since 2005, biomass is still a largely unexploited electricity source.

Czech Republic

The share of renewable energy in total electricity production was 3.9% in 2007. The 2010 target set by the Czech Republic stands at 8%, but is unlikely to be met. Biomass, with over 2/3 from solid biomass, is a major source and accounted for 22.8% of renewable electricity production. Following a nearly 25% jump from 2005 production levels, electricity production from biomass, largely wood and waste byproducts from woodworking, amounted to 912 GWh in 2006.

Estonia

With a limited opportunity for hydro, Estonia depends for 98.8% of its electricity production on fossil energy. The share of renewables in total electricity production was 1.2% in 2007. Biomass has gained increasing importance and its share of renewable electricity stood at 30.8% in 2007. However, unattractive feed-in tariffs have slowed the development of renewable energy and do not provide the necessary push for renewables.

Hungary

In 2007**,** Hungary's electricity production originated with 91% from fossil and nuclear energy, while the share of renewables stood at 8.6%, thanks to biomass. With little wind and hydro, biomass is the predominant source of renewable energy, accounting for 90.8% of renewable production. Biomass from wood, mostly round wood, is the main feedstock, and is used predominately in co-fired coal power plants.

Latvia

About 59% of electricity production and nearly 39% of electricity consumption came from renewables in 2007. Hydro with 57.6% is the main source, while biomass accounts for only 0.5% of renewable electricity production. The EU target for 2020 calls for a 42 % share of renewables in total energy consumption.

Lithuania

Nuclear with 71.6% is the main source of electricity production in 2007. Renewable energy accounts for 7.6% of total energy production and its share in total energy consumption was less than 3% in 2007. Hydro is the main source of renewable energy (92.9%), while energy from biomass is negligible (0.7%).

Poland

Fossil fuels dominate Poland's electricity production (95%). The share of renewables in total production has reached 4.4% in 2007 and biomass with 2.2% has been the driving force in recent years, although wind energy has seen the most dynamic growth rates. With nearly 50% biomass holds the largest share in renewable electricity production. It is nearly entirely solid biomass and used in co-fired coal plants. With a 2020 EU target of 15% of electricity consumption coming from renewables, Poland is at present far removed from this target.

Romania

Close to three quarters of Romania's electricity production is generated by fossil fuels and nuclear power plants in 2007. The share of renewables in total energy production reached 26.3% and was met nearly entirely by hydro power (99.9%). Biomass contributes only 0.5% to total production from renewable energy sources. While solid biomass produced only 7GWh in 2007, the potential of this important feedstock for electricity and heat generation has so far not been exploited.

Slovakia

Slovakia's principle sources of energy production are nuclear and fossil fuels, which account for 83.5% of total electricity production in 2007. Its renewable electricity production was 16.4% and is sourced nearly completely from hydro power, with biomass and wind accounting for just 0.8%. Slovakia's 2020 EU target has been set at 14% of renewables in final energy consumption.

Slovenia

More than 75% of electricity production originates from fossil and nuclear power. Renewable energy, nearly entirely from hydro power, shares 22.5% of total electricity production in 2007. Biomass is the only other renewable energy and is in its infancy (120 GWh in 2007), contributing only 0.8% of total energy production. Slovenia plans to meet the 2020 EU target of 25% energy from renewables primarily from an expansion in hydro and to a lesser extend from biomass.

Annex II

Potential Biomass Feedstock in the CEE Member States

Existing and potential supplies and costs of biomass feedstock vary greatly among the CEE countries. CEE agricultural production systems show great inefficiencies and low yields. A recent study of different agricultural production scenarios in the CEE countries estimates a biomass potential in the range of 2-5.7 EJ. For this estimate biomass is defined to comprise of residues from agriculture and forestry, wood from surplus forest and from energy crops. The potential energy crop production is based only on land which is presently not used for food or fodder production. Yet, with the adoption of modern agricultural production methods, including pest control and high fertilizer inputs substantial land could be freed from food and fodder production, which in turn could make an estimated 44 million ha available for energy crop production with short rotation shrub willow.

Under this scenario it is estimated that the potential biomass supply could reach up to 11.7 EJ (where 85% is derived from energy crops, 12% from agricultural and forest residues and 3% from surplus wood). With the exception of the energy crops, the cost of the biomass feedstock is estimated at Euro 2/GJ. Whereas costs for willow biomass range from Euro 1 to 4.5/GJ under present production systems, they are projected to rise to Euro 1.6 to 8.0/GJ when advanced production systems are introduced and more marginal land is being utilized. [97]

In another study of the biomass potential, covering the EU 27 and Ukraine, production costs for first generation feedstock is estimated at Euro 5 to 15/GJ, for second generation feedstock from Euro 1.5 to 4.5/GJ, for agricultural residues from Euro1 to 7/GJ and for forest residues from Euro 2 to 4/GJ. The highest biomass potential and the lowest production costs are found for Poland, the Baltic States, Romania and Bulgaria. [98]

Based on a review of all available literature an attempt is made in this Annex to assess the existing and potential biomass potentials in each of the CEE Member States.

Bulgaria

Although agriculture and forests cover 90% of the territory, the resulting vast biomass potential remains underutilized. The 2020 EU target calls for a 16% share of renewable energy in total energy consumption. To push the utilization of Bulgaria’s biomass potential the government passed in 2008

a National Long-term Programme for Encouragement of the Use of Biomass for 2008-2020. [99]
The EBRD estimates the total biomass potential at 96.2 PJ/year, were biomass from forestry accounts for 44.4PJ, agriculture for 48.2 PJ and waste from industry at 3.6 PJ. While all this potential can not be used economically, Bulgaria's timber, paper and pulp industries, were at present residues are stored until decay, offer a great unexploited energy source [100]. An important energy feedstock for biogas could come from biodegradable waste and agricultural waste of which over 50% are dumped in landfills at present. No doubt, the farming structure, based on small farms, poses a problem for efficient large scale utilization of farm waste, but this should not rule out small biogas CHP plants at local farm or community level or next to landfill sites. The North Eastern Region (Provinces of Varna, Dobrich, Shumen, and Targovishte) offer the most promising potential for biogas from energy crops and waste from agricultural primary production and meat processing. The South Western and South Central Regions with the highest population densities (particularly Sofia and its surrounding area, the Provinces of Plovidic, Haskovo, Pazardzhik, Smolyan, and Kardzhali) have the greatest biogas potential from waste from food industries, sewage sludge and municipal waste. [101]
Despite existing and potential feedstock for biogas, no commercial biogas plant is in operation; only one small plant exists producing electricity, while about 5 are in various stages of preparation and construction since several years. Sewage sludge as feedstock for CHP will be used at the Kubratovo Digester Gas Plant of the municipality of Sofia which is presently under construction. [102]
A major constraint in the development of Bulgaria's biogas potential is the lack of a supporting legal framework. The Alternative Energy Sources and Fuels Act 2007 went into force without a regulatory framework for feed-in tariffs and tax incentives for biogas. [103]

Czech Republic

Biomass has great potential in the Czech Republic. Yet at present, only one-tenth of this potential is being used. Based on FAO statistic nearly 1.3 million hectares are not used for food production, of which about 0.8 million hectares were not cultivated at all. To a large extend these unused acreages could be used for the production of biomass. [104] The EBRD estimates that if only 0.5 million hectares were used for biomass this could provide about 18% of total energy generated. An additional unused resource is grass from fallow land, which could provide 1 million tons/year of biomass for biogas production [105]. District heating plants provides about 50% of household with energy. However, only 1/3 is installed for cogeneration, the rest is fired by coal. It is estimated that about 10,000MW of district heating has the potential to be converted to cogeneration with biomass. A huge market not explored so far. [105]

In 2010 the installed capacity of biogas plants is 93 MW, of which 17MW is provided by 60 waste water treatment plants. The Czech Biogas Association estimates that the agricultural biogas potential alone could provide 500MW. A major driving force is the Law for Reneable Energy which provides for highly attractive feed-in tariffs with a 15 year guarantee.[106]

Estonia

With 48% of its land under forest, wood-based biomass is predominantly the present and future source for renewable energy. However, there is a limitation on the expansion of wood-based biomass, since Estonia has already exceeded its sustainable felling volume of wood [107]. Better collection of forest byproducts and residues could sharply increase the supply of this feedstock, but this will require technological improvements to reduce the costs of extraction and transport. The wood industry is well developed and 95 % of its waste wood is already used for energy production Wood chips, pellets and briquettes production is a major industry and Estonia is a large exporter of this biomass. Underutilized biomass feedstock could be obtained from manure from farms (estimated energy potential 500GWh/year) and cultivations from 6000 ha wetland (reed, cattail). The EBRD estimates that biomass could produce nearly 2 ½ times the present energy production, reaching a magnitude of 34TWh/year. [108]

Hungary

Meeting Hungary's EU target of a 13% share of renewable energy in total energy consumption will pose a major challenge. Topographic limitations curtail new hydropower. While the potential for wind power is great, even after the massive expansion over the last decade, peak load problems of a weak grid structure limits its expansion. Biomass will have to become a major driver for renewable energy to produce base load . So far, however, energy from biomass has played only a minor role. Among the EU27, Hungary ranked 16th in terms of biogas production. With Hungary's large import dependency on Russian gas and its high 44% share of natural gas in total energy consumption, substituting natural gas by biogas is becoming a major issue for energy security.[109]

The EBRD estimates the biomass potential at 67PJ. Much of this can be derived from a more efficient use of forest waste and byproducts, since only 10% is used at present for energy production. Since nearly 40% of the annual wood harvest could be used for energy production, the potential for electricity and/or heat production is significant. Energy plantations are few, but their yield potential of 200-350GJ/ha/year is nearly twice the yield per ha of forest land. Hungary's agriculture (5 million ha farmland and 3 million ha forestry) has a largely untapped biomass resource and its total potential is estimated at 300-400 PJ/year. About 40-80 PJ/year could be derived from agricultural production and additional 90-185 PJ/year from agricultural byproducts. This biomass potential has not been fully used and when used, it is with low efficiencies. [110]

Hungary's farm structure is the primary constraint to a more efficient utilization of its biomass potential. With nearly 90% of all holdings are below 5ha, investments in biogas plants are not profitable. Despite attractive feed-in tariffs and EU grants covering 40-70% of investment costs, the small farm structure remains a constraint for on-farm biogas plants and only large scale industrial biogas plants characterize the scene. [111]

Under Hungary's New Program for Agricultural Development and the 2007 Hungarian Act on Electricity a large grant and subsidy program is available for biogas plants with a capacity from 250 to 500kW. At present 38 new biogas plants are coming off stream with a capacity in the range from 250kW to 2MW each [112]. The major beneficiaries of the subsidy and grant programs have been investors in large biogas plants, which are predominantly sited at large farms with average cattle holdings of 390 heads. Giving existing farm pricing and feed-in tariffs, energy feed crops are not financially attractive. In 2008 there were 45 biogas plants, of which 44 operated on agricultural waste products. The largest biogas plant based on agricultural waste and with a capacity of 2.5 MW is in operation since 2003 in Nyírbátor. There are also 14 biogas plants based on sewerage sludge from waste water treatment plants. At present, it is estimated that Hungary's total production capacity from biogas plants has reached about 10MW. [113]

Latvia

With nearly 45% of its land under forests, Latvia has a great potential for biomass which has not been utilized. Sawmill residues and about 12.5% of the annual wood harvest is used for heating. A strong export market for wood and demand by the pulp and paper industry put additional pressure on lumber prices, thus curtailing the use of solid biomass for power generation. The EBRD estimates that the mid-term power potential from biomass is 4.6TWh/year and an increased use of solid biomass in CHP plants can become the driving force for greater biomass utilization [114]. The utilization of bio-degradable waste products is still in its infancy. There are only 3 biogas plants in Riga and the surrounding area; two utilize landfill sites and one uses sludge from waste water. The first agricultural biogas plant has recently been completed in Vecauce. Biogas production from agricultural waste and byproduct face a logistical constraint of greatly dispersed farm holdings [115]

A major push for fuller utilization of the country's biomass potential came in 2007, when government passed the regulations on “Electricity Generation from Renewable Energy Sources”, which establishes the highest feed-in tariffs for biogas within the EU and provides for a 10 year purchase price guarantee (see **Annex III**).

Lithuania

The EU target for 2020 calls for a renewable share of 23% in total energy consumption. Because of topographic restriction the expansion of hydro is limited. With nearly 1/3 of the territory under forest, the potential solid biomass feedstock is estimated at 1.5 million ton, of which over 50% could come from better utilization and extraction of forest residues. Plant biomass offer a great potential to meet the 2020 target and it is estimated at 36.4PJ. About 50% of this potential could be derived from wood plantation crops, not to speak of a better utilization of Lithuania’s forest land. Straw is increasingly used as a feedstock for boilers (installed capacity is around 5 MW). From an annual production of 3.5-4 million tons, an estimated 10% or 400,000tons/year could be used as feedstock, which would equivalent to 132ktoe. Manure from animal waste, sludge and organic food waste offer an additional potential for biogas production, amounting to about 530 million m3/year [116]. While biomass has a great potential, only 3 plants are operating, producing 7.8 MW from landfill and municipal waste water plants. [117]

Poland

Among all CEE countries Poland has the largest potential for biogas production**.** With its large agricultural and forest land as well as wood industry it is anticipated that biomass will provide a major push for achieving the 2020 renewable electricity goal. The biomass potential is estimated at about 755PJ/year. Electricity production from biomass and waste (fuelwood, forestry residues, agricultural residues and surpluses) reached 2.8billion KWh in 2007. In recent years biomass is increasingly replacing coal in district, individual and industrial heating and in CHP plants. [118]

Nearly 3 million hectares have the potential to be used for energy crop farming. Forest residues and bi-products could be used more efficiently and the northern and western regions and the areas bordering Belarus offer the greatest potential. To reach the EU RES target Poland will have to install 1000 MW capacity for biomass fed generation. There are only 5 biogas plants based on agricultural waste, whereas landfills and sewage sludge from waste water facilities are increasingly being used as a source for biogas production, although their capacity remains still small. In 2009, 11 MW installed capacity came from 78 power plants with landfill gas and 73 sewage digester plants had an installed capacity of 14MW [119]. In 2010, the largest biogas plant with an installed capacity of 2.18MW started operation; it is based on residues from a distillery in Liszkowo. Large live stock farms would offer opportunity for biogas plants from manure, however, lack of know-how has made progress cumbersome. In over 100 landfill sites methane concentrations are estimated to be over 250 million m3 and their utilization offer a so far unexplored potential. To comply by 2015 with the EU Directives on Waste Water Treatment and Sludge, Poland has launched a major investment program for the construction or modernization of waste water treatment plants(mostly in areas below 15,000 population). It is under these circumstances, that the Polish government in its decree on expanding energy from renewables has placed biogas from sewer sludge as its top priority. [120]

Feed-in tariffs and the RES energy quota obligations for electricity distribution companies to purchase electricity from biogas establish the incentive system. However, the feed-in tariffs are low and the systems administration appears overly bureaucratic, thus providing little incentives for investors in biogas plants (see **Annex III**). [121]

Romania

The 2020 EU target of a 24% share of renewables in final energy consumption should be achievable. The main drivers in Rumania's expansion of renewable energy production will be small hydro and wind energy plants. The potential for biomass feedstock is with 7.5 million toe/year substantial and only about 45% is being tapped, so far nearly entirely for heat production. Forest bi-products and wood waste account for 1.7 million toe/year, agricultural waste for 1.9 million toe/year, and the rest are accounted for by biogas and household waste. The forest areas and the areas of the Carpathian and Sub Carpathian offer the best potential for solid biomass feedstock. Wood waste and saw dust from wood industries are not being utilized at the moment because of logistical and transport problems [122]. Most agricultural waste and energy crop potential is found in the South and South Eastern part as well as Western Plains around Timisoara. Agricultural waste from secondary production (300,000 t/y) and municipal waste (500,000 t/y) are great potential for Bukarest and in the Northern part of Romania. The highest concentration of solid municipal waste is in the Northern part and in the areas of Bukarest, Brasov, Constanta, Iasi, Cluj_Napoca and Craiova. The biomass potential alone is estimated at 88.4 TWh/year and could meet nearly 70% of Romania's 2020 EU target.[123]

During the communist regime Romania was a leader in biogas . Today none of these plants are in operation. At present two small pilot plants operate; one using animal manure and the other sludge from waste water. As Annex III shows, Romania's feed-in tariff for biogas and the supporting system of purchase obligations by the distribution companies are lacking the incentives required to give biogas the needed investment push.

Slovakia

Slovakia's availability of biomass feedstock is vast both from forests and agriculture as well as from wood industry waste. While the expansion into wind power is limited by grid constraints, and hydro power expansion is reaching its limit, the vast majority of renewable energy production is planned to come from biomass. Despite the wide use of forest waste for residential and district heating and electricity production, only about 10% of the biomass potential is being used at present. By 2020 the EBRD estimates that the biomass potential could supply about 1,300MWh [124]. Other estimates place the potential at 5 PJ. However, in 2010 there are only a few farm enterprises and a few sewage treatment plants with biogas plants. The greatest potential seems to be biomass from wood waste. About 2.3 m tons of wood waste is produced annually, with an implied energy potential of 27 PJ. But only 20% is used at present [125]. Biogas production has been neglected so far on the large agricultural holdings. About 700 farms, or 1% of all farms holdings, hold on average around 630 heads of cattle or 1,200 pigs and could obtain EU subsidies of 60% for biogas investment. [126]

For long, a major drawback for renewable energy development was the low Slovak feed-in tariff system. This system has been changed and offers attractive feed-in tariffs (see **Annex III**) and this should provide the necessary boost to biogas development.

Slovenia

With forest coverage over half of its territory, the biomass potential is large and has been estimated at 75 PJ, of which at present only 20PJ are used [127]. The EBRD estimates a wood harvest potential of 450 thousand dry tons from forests and 120 thousand dry tons from abandoned agricultural land. From 360 thousand tons of annual wood residues, only 230 thousand tons are being used. Forest residues provide about 359 th MW for the wood processing industries and to 4 district heating systems. Solid biomass is clearly a potential which has not been tapped fully and offers great opportunities. So far only 5MW are derived from biomass in CHP plants, but according to the National Energy Program an additional 5MW production could be added [128]. Only in 2006 biogas plants were started and now about 15 plants are in existence using manure, sludge from waste water and land fill gas, but their total capacity is only about 13 MW. Several larger plants for biomass energy are in various stages of development, among them a 7.2MW plant in Eastern Slovenia [129]. A strong incentive for investments in biogas energy was provided with the 2009 support system for feed-in tariffs (see **Annex III**). In addition, various government subsidies can provide up to 40% of investment costs.

Annex III

Electricity Feed-in Tariffs in the CEE Member States

Table 21 Electricity Feed-in Tariffs for Biogas,Sludge and Landfill Gas in Bulgaria

Electricity Technology Source	Euro Cents/kWh
Biomass <5 MW -from wood residues - from agricultural residues - from energy crops	 11.10 8.49 9.561
Biogas (from agricultural residues, animal waste, etc.)<5MW - installed capacity till 150 kW - installed capacity from 150 kW to 500 kW - installed capacity from 500 kW to 5 MW	10.12 9.29 8.45
Landfill Gas	4.6

Exchange rate: 1 EUR = 1,956 BGN

Sources: EREF (European Renewable Energy Federation), Prices for Renewable Energies in Europe: Report 2009, Edited by Dr. Doerte Fouquet. [130]*, Austrian Energy Agency, Energy in Central and Eastern Europe, http://www.enercee.ne* [131]

Table 22 Electricity Feed-in Tariffs for Biogas,Sludge and Landfill Gas in Estonia

Electricity Technology Source	Euro Cents/kWh	Duration of Support
From all RES	7.35 (as of 1.1.2010)	2010 for 12 years from the start of operation
CHP heat from RES	3.33	2010 for 12 years from the start of operation

Sources: EREF (European Renewable Energy Federation), Prices for Renewable Energies in Europe: Report 2009, Edited by Dr. Doerte Fouquet. , Austrian Energy Agency, Energy in Central and Eastern Europe, http://www.enercee.ne

Table 23 Electricity Feed-in Tariffs for Biogas,Sludge and Landfill Gas in Czech Republic

Electricity Technology Source	Euro Cents/kWh as of 1.1.2009	Green Bonus Euro Cents /kWh as of 1.1.2009
From CHP from Biogas, only for new units after 1.1.2008	9.9-17.3 depending on biomass source	4,0-11.3 depending on biomass source
From Landfill or Sludge Gases for plants after 1.1.2006	9.3	3.4

A feed-in system for RES-E and cogeneration, established in 2000, was extended by the New RES Act of 2005 and offers a choice between a feed-in tariff (a guaranteed price) or a "green bonus" (an amount paid on top of the market price).
Exchange rate 1 CZK = 0.0387 EUR

Sources: EREF (European Renewable Energy Federation), Prices for Renewable Energies in Europe: Report 2009, Edited by Dr. Doerte Fouquet. , Austrian Energy Agency, Energy in Central and Eastern Europe, http://www.enercee.ne

Table 24 Electricity Feed-in Tariffs for Biogas,Sludge and Landfill Gas in Hungary

Electricity Technology Source	Tariff under 2006 Obligatory Purchase with Capacity>100kW. Euro Cents/kWh		
	Peak	**Valley**	**Deep Valley**
From RES and energy from waste <2MW	12.76	11.42	4.66
2-5MW	10.17	9.14	3.73
Up to 5 MW, comprising used equipment	7.94	5.08	5.08
>5MW	7.94	5.08	5.08
CHP with District Heat Production<6MW	13.00	7.00	3.00
Waste	11.97	8.25	4.30

Sources: EREF (European Renewable Energy Federation), Prices for Renewable Energies in Europe: Report 2009, Edited by Dr. Doerte Fouquet. , Austrian Energy Agency, Energy in Central and Eastern Europe, http://www.enercee.ne

Table 25 Electricity Feed-in Tariffs for Biogas,Sludge and Landfill Gas in Latvia

Electricity Technology Source	**Euro Cents/kWh**
Biomass: <4 MW	from 18.34 to 23.52
>4 MW	from 10.38 to 17.84
Biogas***:*** <2 MW	from 18.99 to 23.36
>2 MW	from 12.97 to 16.34
CHP power plants using RES or peat 0,08 MW- 4 MW,	from 18.75 to 12.05

Regulation No. 198 ensures the mandatory procurement of power generated from renewable energy resources (wind, small hydro, biomass, biogas) with an agreed long-term purchase price based on a feed-in tariff system with the quantity and price determined through public tender. There is also guaranteed payment for installed capacity (for biomass and biogas power plants above 1 MW.
Exchange rate: 1 LVL = 1.43 EUR

Sources: EREF (European Renewable Energy Federation), Prices for Renewable Energies in Europe: Report 2009, Edited by Dr. Doerte Fouquet. , Austrian Energy Agency, Energy in Central and Eastern Europe, http://www.enercee.ne

Table 26 Electricity Feed-in Tariffs for Biogas,Sludge and Landfill Gas in Lithuania

Electricity Technology Source	**Euro Cents/kWh**
Biomass	6.95 since 1 January 2008

Sources: EREF (European Renewable Energy Federation), Prices for Renewable Energies in Europe: Report 2009, Edited by Dr. Doerte Fouquet. , Austrian Energy Agency, Energy in Central and Eastern Europe, http://www.enercee.ne

Table 27 Electricity Feed-in Tariffs for Biogas,Sludge and Landfill Gas in Poland

Electricity Technology Source	Euro Cents/kWh
Price scheme: • The guarantee price of electricity produced from renewable energy sources in 2009 is Euro 3.50/kWh; • The substitution fee in 2009 is Euro 5.90/kWh; • The green certificate price (June 2009) is ca. Euro 5.70 euro/kWh. In 2008 the average price of a green certificate was Euro 5.4/kWh and the substitution fee was Euro5.65/kWh. **Support scheme**: Quota obligation (certificates of origin/green certificates); the income from electricity produced from renewables consists of both electricity price and the green certificates price. - The electricity shall be purchased at a guaranteed price. The payment corresponds to the mean electricity price of the previous year, which is calculated by the regulatory authority (URE). - All energy companies that sell electricity to final consumers that are connected to the Polish grid are obliged to fulfill a specified quota of green certificates. In order to provide evidence for the fulfillment of the quota, companies shall present certificates of origin/ green certificates. Upon request of the regulatory authority, green certificates are issued to those plant operators that generate electricity from renewable energy sources. Certificates of origin are transferable and may be acquired by either by generating electricity from renewable energy or purchasing certificates from other producers. The institution, which is responsible for organizing trading in property rights arising from the certificates of origin is the Polish Power Exchange. - As an alternative, the companies may pay a substitution fee. - If a company fails to present certificates of origin or does not pay the fee, the regulatory authority of URE charges a penalty.	

Exchange Rate: 1Euro=4.4PLN

Sources: EREF (European Renewable Energy Federation), Prices for Renewable Energies in Europe: Report 2009, Edited by Dr. Doerte Fouquet., Austrian Energy Agency, Energy in Central and Eastern Europe, *http://www.enercee.ne*

Table 28 Electricity Feed-in Tariffs for Biogas,Sludge and Landfill Gas in Romania

Electricity Technology Source	Euro Cents/kWh
Support scheme Quota obligation system (tradable Certificates of Origin additional to the electricity market price) **Current applicable law** A quota system with tradable green certificates (TGC) for new RES-E has been in place since 2004. **Particularities** The mandatory quota increase from 0.7% in 2005 to 8.3% in 2010. TGCs are issued to electricity production from wind, solar, biomass or hydro power generated in plants with less than 10 MW capacities. Average electricity market price for June 2009: Euro 3.7/kWh	
Electricity from Biomass or Biogas	5.5

Sources: EREF (European Renewable Energy Federation), Prices for Renewable Energies in Europe: Report 2009, Edited by Dr. Doerte Fouquet. , Austrian Energy Agency, Energy in Central and Eastern Europe, http://www.enercee.ne

Table 29 Electricity Feed-in Tariffs for Biogas,Sludge and Landfill Gas in Slovakia

Electricity Technology Source	Euro Cents/kWh
Biomass from plantations dedicated to energy production	10.4
Waste biomass, plant commissioned after 1 January 2005	9.77
Co-firing of biomass or waste with fossil fuels plant commissioned after 1 January 2005	8.74
Biogas from Sewage and landfill	8.68
Biogas from anaerobic digestion, up to 1 MW	14.22
Biogas from anaerobic digestion, above 1 MW	12.87

Sources: EREF (European Renewable Energy Federation), Prices for Renewable Energies in Europe: Report 2009, Edited by Dr. Doerte Fouquet. , Austrian Energy Agency, Energy in Central and Eastern Europe, http://www.enercee.ne

Table 30 Electricity Feed-in Tariffs for Biogas,Sludge and Landfill Gas in Slovenia

Electricity Technology Source	Euro Cents/kWh
Biogas obtained from biomass < 50 kW:	16.01(= 11.88 as fixed part + 4.13 as variable part)
< 1 MW:	15.58 (= 11.186 as fixed part + 4.4 as variable part)
up to 5 MW:	14.078 (= 96,18 as fixed part + 4.42 as variable part)
Biogas obtained from biodegradable waste < 50 kW:	13.92
up to 5 MW:	12.92
Plants using landfill gas < 50 kW:	9.93
< 1 MW:	6.75
up to 5 MW:	6.17
Gas derived from sludge from wastewater treatment plants < 50 kW:	8.58
< 1 MW:	7.44
up to 5 MW:	6.61
Plants using biodegradable waste < 50 kW:	n.a.
< 1 MW:	7.74
up to 5 MW:	7.43

Note: The program guarantees a purchase price (fixed tariff) for projects up to 5 MW. For projects greater than 5 MW a premium or bonus system is used. Total payments are intended to equal the Reference Cost of Electricity from renewable technologies but the tariff is not fixed. The revised policy : Increases the length of contracts to 15 years; the project size cap to 125 MW and the transparency and predictability of the tariffs. A review of technology costs is stipulate every five years. Slovenia has introduced a sophisticated tariff concept which differentiates tariffs by technologies and four size categories.

Sources: EREF (European Renewable Energy Federation), Prices for Renewable Energies in Europe: Report 2009, Edited by Dr. Doerte Fouquet., Austrian Energy Agency, Energy in Central and Eastern Europe, http://www.enercee.ne