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Esa Sipilä, Jürgen Vehlow, Pasi Vainikka,
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Market potential of high efficiency CHP and waste based ethanol in European pulp and paper industry

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VTT, Bergsmansvägen 3, PB 1000, 02044 VTT
tel. växel 020 722 111, fax 020 722 4374

VTT Technical Research Centre of Finland, Vuorimiehentie 3, P.O. Box 1000, FI-02044 VTT, Finland
phone internat. +358 20 722 111, fax +358 20 722 4374

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Executive Summary

Fossil fuel prices have increased significantly during the last two years in Europe. This has had a great impact on energy intense European pulp and paper industry, especially in Central and Western Europe where the main energy source has been natural gas and fuel oil. The recent development in pulp and paper industry energy investments in Europe has been towards more advanced multi-fuel combined heat and power (CHP) production, where the modern fluidised bed (FB) combustion technology with high steam values and efficiencies has a significant role. There are already examples from Germany that the new recycled paper based paper mills use modern fluidised bed CHP power plants to produce needed heat and power with waste fuels and side streams from production.

The objective of this study is to analyse the market potential of new high efficiency CHP concept developed by VTT in German and European pulp and paper industry. The basic idea behind the new CHP concept is to co-combust SRF and other waste fuels together with paper mill sludge and coal to reach high steam values and high efficiencies. The analysis methods of this market study were divided into three main levels; European level, country level and state level. The aim was to find out if there are drivers that would support the fact that high efficiency CHP production from waste fuels is a potential option in Europe by year 2020. As a result of the country level analysis for Germany, a market potential estimate for high efficiency CHP was produced at state level. The state level analysis of selected states was made to test the correctness of the country level results and to give feedback for the iteration round for the country level analysis. The state level analysis was performed together with Forschungszentrum Karlsruhe (FZK), Germany, to get the best available local knowledge of the current situation and the future prospects.

Vigorous cost cutting programs implemented during the last 10–15 years have improved the efficiency of pulp and paper operations in the key production regions. At the same time, paper prices have declined 3–6 %/a in real terms leading to weakening profitability. Even recent improvements in capacity utilization have not resulted in significant price increases. Instead, the benefits of lower production costs have been passed on to customers. It appears that the pulp and paper industry lacks true price leadership which would be effective in reaching consensus on pricing without collusion in violation of antitrust laws. This means that one of the best ways to increase the profitability of the European pulp and paper industry is to find new ways and concepts to change the current cost structure of paper making. Introduction of new energy production from waste fuels provide one option for a solution to these problems. Waste offers also a good chance for the industry to cut energy cost and collect new revenues from waste management operations and sales of recyclable products that can be produced at the paper mill when good quality fuel is produced for the paper mill's needs.

Fluidised bed combustion has been the main technology in European pulp and paper industry especially with solid fuels due to its fuel flexibility while grate technology is dominant technology in waste incineration. For this reason, fluidised bed boilers are also be compared to grate boilers even if the pulp and paper industry prefers fluidised bed technology due to its suitability to combust the mill sludges. The main result of the feasibility evaluation is that both technologies give a good feasibility for the paper mills in Germany. However, the difference between the two technologies cannot be estimated reliably with the data available for the analysis. The internal rate of return (IRR) of the CFB alternative was 26 % and 25 % for the grate alternative; both cases showing thus very high financial feasibility compared to typical levels achieved in the pulp and paper industry. Thus other issues such as security of fuel supply, value for fuel flexibility, quality of waste available and partial load capability may become the decisive factors for the preferred technology choice. As a conclusion, it can be stated that according to the analysis made, the good financial feasibility of waste-to-energy unit investments in German paper industry is a significant driver to increase the utilisation of waste fuels in order to reduce the energy costs in paper production.

European and country level legislations are driving the waste sector towards higher efficiencies and recycling. They both support FB-CHP combustion because the fuel preparation allows recycling before combustion and increasing electrical efficiencies. Also the overall efficiency is very high at paper mill where the heat energy is used for paper production. Latest Directive also introduced the so called “double count” for biofuels for transport that are produced from residues and waste. This increases the viability of new energy concepts from waste e.g. ethanol production from waste and waste fibres. Germany has been the fore runner in regulations and efficiency targets that support this new technology. Also the increased natural gas and fuel oil prices have made the situation for German paper mills very hard, calling for new energy solutions. That is where the needs from waste management and paper industry meet in a profitable way.

The situation in the German SRF market gives room for speculation that at least for the next 5–10 years there is a surplus of waste derived fuel which will find no customer. This is to be expected especially for high calorific waste fractions from the industry and trade sector. It has to be investigated in detail whether there are bigger streams of fibre containing waste fractions and if it makes sense to separate the fibre from the available waste. Based on the analysis made, the business potential of high efficiency CHP is 25–36 units in Germany by 2020 and resulting in additional waste treatment capacity of 4–6 million tons annually. The potential is the highest in gas boiler replacement were the potential is 7–11 units. The potential is the lowest in new MSW boilers and in gas turbine replacement investments. The potential can be divided according to replacement class, sector and state.

The state level analysis showed that the estimated potential in Baden-Württemberg was 7 boiler units with total capacity of 1.1 million tons of SRF. Out of these, 6 are in the pulp and paper industry and 1 in public MSW treatment. Based on the local information, in the long term there is a lack of incineration capacity of around 0.3–0.5 million tons – this waste volume could be utilised by the pulp and paper industry. It is likely, that the local opposition of new incineration units and the economical difficulties of SRF producers can have a negative impact on the possibilities to utilise the potential in near future. These factors affect the main analysis result so that it is estimated that perhaps only half of the main potential could be utilised in new high efficiency CHP plants by 2020.

Energy recovery from waste can be performed in different ways. Residual MSW can be directly incinerated in a waste incineration plant and the released energy can be used in form of process steam, power or district heat. These plants are, even if operated in CHP mode, typically no high efficiency facilities. However, there are attempts to increase the overall efficiency of such plants. The potentially available fuel is for the time being all that waste which is not recycled and either incinerated or going to landfills. This would result in a potential of roughly 150 000 000 t of waste in EU with a net calorific value in the order of 10 MJ/kg. However, the recycling rate will increase from the actual 40 % to expected 50–55 % which leaves an amount of residual MSW for energy recovery of some 115–125 000 000 t. In a number of countries there is tendency to extend the production of SRF. Mechanical treatment (MT), mechanical-biological treatment (MBT), or mechanical-biological stabilisation (MBS) are used for SRF product. From German experience it can be estimated that approx. 20–30 % of the incoming MSW end up as low polluted and high calorific SRF, about the same amount can be classified as lower quality SRF.

Pulp and paper industry has a large number of solid fuel boilers in Europe that reach the end of their technical age by 2020 and need to be replaced. In these harsh times for pulp and paper industry the replacement of old boilers is the main potential for new CHP boilers because the number of new pulp and paper mills is very limited in the near future. There are 37 solid fuel boilers larger than 30 MWth in European pulp and paper industry that have an age between 15–25 years and 89 boilers over 25 years. The market potential in this study includes an assumption that 25 % of the 15–25 years old and 50 % of the over 25 years old boilers can be replaced with new advanced high efficiency CHP boiler that uses SRF as a main fuel. These assumptions results in an estimate that there are 54 potential boilers that could be replaced by high efficiency CHP unit and the average size of these units is 64 MWth.

The results show that the European pulp and paper industry could be a major user of SRF by 2020 with treatment capacity of 8–13 million tonnes. This would require 54–82 new CHP investments by 2020 replacing old solid fuel boilers. The results have a lower and higher values depending is the detailed potential described in chapter 8 for Germany used or not. The highest potential in this analysis was found in Germany, Finland and Sweden where there is a high number of solid fuel boilers. The lowest potential or no potential was found in countries like Italy, the Netherlands and UK where the energy production at the pulp and paper mills has traditionally been based on natural gas and fuel oil because the main raw material is recycled paper. The financial value of the replacement investments has an investment potential of 4.7 to 7.5 billion euros by 2020.

Finnish companies UPM-Kymmene and Lassila & Tikanoja have developed together with VTT and Pöyry a new innovative FibreEtOH-concept to produce ethanol from commercial and industrial waste. The concept includes integrated production of ethanol together with biogas, heat and electricity production. The projected production costs compared to other 2nd generation ethanol concepts that use lignocellulosic raw materials are very low. In this study it was assumed that this concept could provide new business opportunities for the European pulp and paper industry together with high efficiency CHP boilers. The FireEtOH-concept includes also a high efficiency CHP boiler for waste fuels integrated to the ethanol production. The effect of additional ethanol production to the waste CHP was studied with same assumptions than the main market potential for Europe by 2020.

The business potential of integrated FibreEtOH-concepts to new high efficiency CHP boilers in Europe is 780 000–1 300 000 m^3 of ethanol per year which equals to a turnover of 400–650 million euros per year using a moderate ethanol price of 0.5 EUR/litre. If the value of the biogas is included the turnover increases to 700–1 100 million euros per year. This is already a significant addition to the pulp and paper industry’s revenues. The investment potential for the ethanol production units on top of the CHP boilers is 2.5–4 billion euros by 2020.

Preface

This study was carried out as a joint effort between two major research projects: “Development and Demonstration of Advanced SRF Co-firing Concept for High Efficiency Fluidised Bed CHP Boilers”, a technical development project funded by Tekes (Finnish Funding Agency for Technology and Innovation), VTT and industrial stakeholders, and the Network of Excellence “Overcoming Barriers to Bioenergy” (Bioenergy NoE) funded by European Commission DG Research (SES6-CT-2003-502788) and co-ordinated by VTT. In a Jointly Execute Research project within the network the market and business potentials of new advanced waste based bioenergy technologies were evaluated in 2008. The project was lead by Mr. Esa Sipilä from Pöyry Forest Industry Consulting Oy, Finland, and the supervisor was Mr. Jaakko Jokinen from the same company. The project was carried out in close co-operation with VTT, Finland and Forschungszentrum Karlsruhe (FZK), Germany. VTT was represented by Prof. Kai Sipilä, Mr. Pasi Vainikka and Mr. Carl Wilén. The German data and market knowledge was produced by Dr. Jürgen Vehlow from FZK.

Espoo, August 2009

Authors

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1. Introduction

1.1 European pulp and paper industry energy palette

Fossil fuel prices have increased significantly during the last two years in Europe. This has had a great impact on energy intense European pulp and paper industry, especially in Central and Western Europe where the main energy source has been natural gas and fuel oil. The recent development in pulp and paper industry energy investments in Europe has been towards more advanced multi-fuel combined heat and power (CHP) production, where the modern fluidised bed (FB) combustion technology with high steam values and efficiencies has a significant role. There are already examples from Germany that the new recycled paper based paper mills use modern fluidised bed CHP power plants to produce needed heat and power with waste fuels and side streams from production.

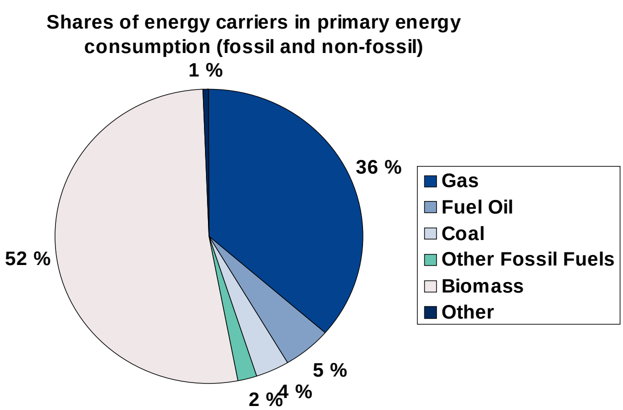

Figure 1. Primary energy sources of European pulp and paper industry in 2006 (Source CEPI key statistics 2007).

Primary energy consumption in European pulp and paper industry was 1 322 000 TJ in 2006 from which biomass represented 52 %. Most of the biomass that is used for energy production in pulp and paper industry is based on production residues such as bark, black liquor and forest residues. It means that most of the bioenergy is produced and used at pulp mills and integrated paper mills that use pulpwood as their main raw material. Paper production in Central Europe does not use much pulpwood to produce their paper products; instead recycled paper is the main raw material. At the paper mills where recycled paper is the main raw material there are none or very limited amount of by-products that can be used for energy production and that is why most of the fossil fuels consumed in pulp and paper production are used in Central and Western Europe.

1.2 The concept of high efficiency fluidised bed co-incineration

The new EU waste framework directive (European Parliament 2008), CO_2 emission trading and various combinations of national taxation, incentives and obligations drive towards enlarged utilisation of biomass and anthropogenic waste fuels in heat and power generation. Simultaneously, electric efficiency of the conversion systems is becoming increasingly important competitive factor due to rising prices of electricity. Regarding co-firing the maximisation of waste and biomass proportions as well as diminishing their impact on the conversion unit's performance are the current main research areas.

Fluidised bed boilers are known for their fuel flexibility, i.e. capability to co-fire different types of fuels. In the "high efficiency co-incineration concept" Circulating Fluidised Bed (CFB) is used. Some basic characteristics of CFB are essential to know in order to understand the principles of the high efficiency concept.

Circulating Fluidised Bed Combustor (CFBC) is characterised by fast bed consisting of ash and/or sand moving and circulating in the combustor. This is a regime lying between turbulent fluidization and pneumatic transport. In a typical fast fluidized bed, one observes a nonuniform suspension of slender particle agglomerates or clusters moving up and down in a dilute, upwardly flowing gas–solid continuum. High slip velocity between the gas and solids, formation and disintegration of particle agglomerates and excellent mixing are major characteristics of this regime. (Basu 2006.)

The particles entrained with the combustion gases from the furnace are separated with typically a cyclone type gas-solids separator and are retuned at the bottom of the furnace. Another solids circulation is found within the furnace cavity where solids flow downwards in the annular region, i.e. the membrane/refractory wall of the furnace, see Figure 2. CFB combustion is characterised by

- gas-solids density profile in the furnace
- high heat transfer
- excellent mixing
- long residence time for combustion (depending upon particle size).

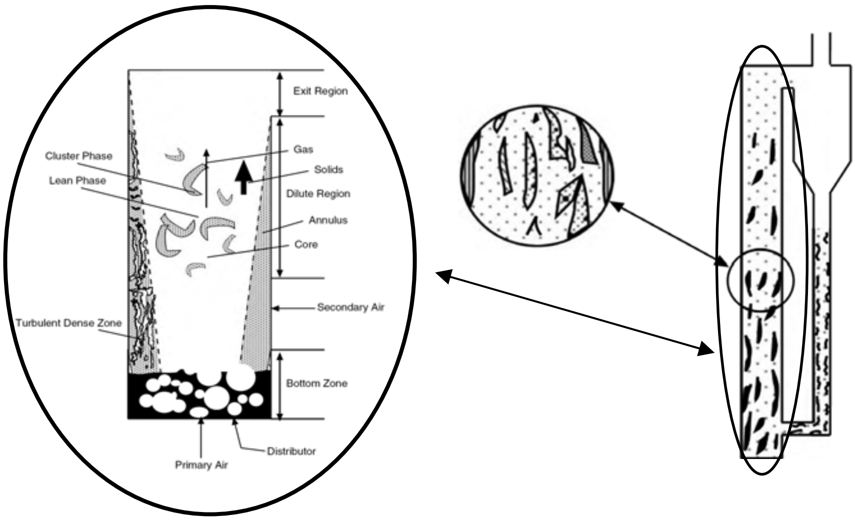

Figure 2. Circulating fluidised bed is comprised of solid agglomerates moving up and down in a very dilute dispersion of solids. Internal circulation is formed by solids flow downwards in the annular region of the furnace and the external circulation by the solids escaping the furnace, separated by cyclone separator and returned back in the lower part of the furnace. (Basu 2006.)

After reaching stable operation the solids inventory in a CFB firing coal consists eventually of coal ash, and of course unburned fuel, but this is only some 0.5–5.0 wt-% of the total solids inventory (Basu 2006). If solid sorbents are used, they also form a part of the circulation. Thus, it is characteristic for a CFB that coal is combusted in a fluidised suspension of its ash.

It is widely known that high alkali halogen concentrations in the combustion gases and consequent halogen deposition, ash melting and corrosion are the main limiting factors in increasing the steam values – and further the electric efficiency – of waste and biomass fired combustion systems. Biomass and waste fuels are typically high in alkali metals and halogens, unlike coal or Scandinavian peat. Not only coal being low in volatile alkali and halogens, it has been shown in numerous publications (Zheng et al. 2008, Ferrer et al. 2005, Aho & Ferrer 2005, Tran et al. 2005) that coal minerals, especially kaolinite, can absorb and chemically react with gaseous alkali chlorides.

The main innovation in the high efficiency FBC co-incineration is to co-incinerate small amount of coal – with appropriate mineralogical composition – with SRF in order to let waste and biomass originated alkali halogens to be adsorbed and further decomposed by coal ash. Eventually, this means that SRF is combusted in a suspension of coal ash, which is capable of adsorbing SRF originated vaporised ash forming compounds within the residence time and operating temperature typical to a CFBC.

For demonstrating this an experimental campaign was carried out at a CFB pilot scale test rig with the objective to demonstrate the difference in the effectiveness of four different types of coals in decomposing waste and biomass originated corrosive alkali halogen aerosols, and in particular, to elucidate the mechanisms influencing the fate of waste and biomass originated corrosive alkali halogen vapours.

A specific technique for monitoring the concentration of corrosive aerosols in the furnace was applied. This includes extracting the sample from the furnace by a means of a quenching probe, further dilution of the sample gas outside the furnace and collection of aerosols in a low pressure impactor (LPI) (Valmari et al. 1998, Pyykönen et al. 2007, Sippula et al. 2008, Christensen & Livbjerg 1995, Christensen et al. 1998, Hindiyarti et al. 2008).

In figure 3 are shown so called mass size distributions from three experiments measured with LPI from a CFB pilot scale test rig combustion gases after the cyclone separator. Gas temperature at the sampling location was 780°C. On the left is mass size distribution from SRF combustion. Together with the SRF 50 % on energy basis spruce bark was combusted in order to maximise alkali halogen concentration in the furnace. There is a clear accumulation of alkali halogens on the particle size fraction around dp=0.1µm. In Figure 3 the bar chart in the middle is showing a corresponding distribution from coal combustion. As expected no vapours are present in the gases. On the far right is shown a result from co-firing 15% on energy basis a specific type of coal with the reference SRF-Bark mix. The fine mode is completely absent in the measurement.

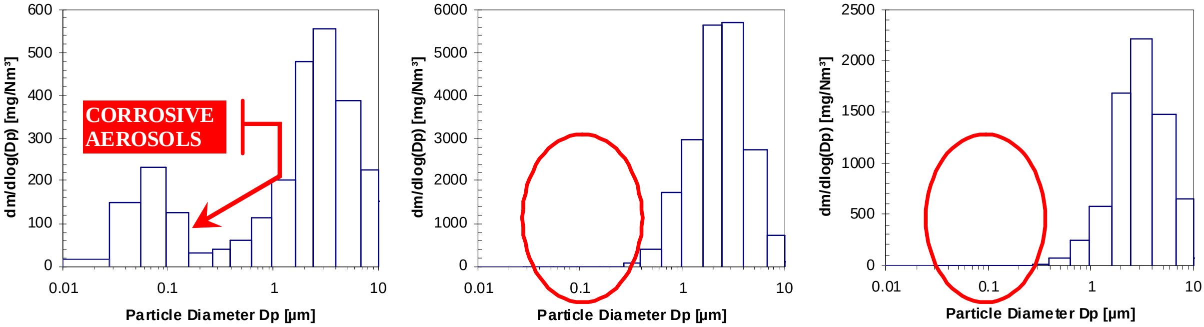

Figure 3. Mass size distributions of SRF-Bark (left), coal (middle) and co-incineration of SRF-Bark and coal (right).

It was demonstrated in the experiments that the minimum required proportion of coal for reaching the conditions with complete absence of corrosive aerosols varied from 15 to 70 % on energy basis depending upon the mineralogical composition the coal.

2. Scope and methods

The objective of this study is to analyse the market potential of new high efficiency CHP concept developed by VTT in German and European pulp and paper industry. German potential in public MSW incineration and SRF combustion was also analysed in this study. The basic idea behind the new CHP concept is to co-combust SRF and other waste fuels together with paper mill sludge and coal to reach high steam values and high efficiencies.

The analysis method of this study was divided into three main levels; European level, country level and state level. The basic idea is to asses the drivers that would support the fact that high efficiency CHP production from waste fuels would be a potential option in Europe by year 2020. The methods and the analysed issues are presented in the Figure 4.

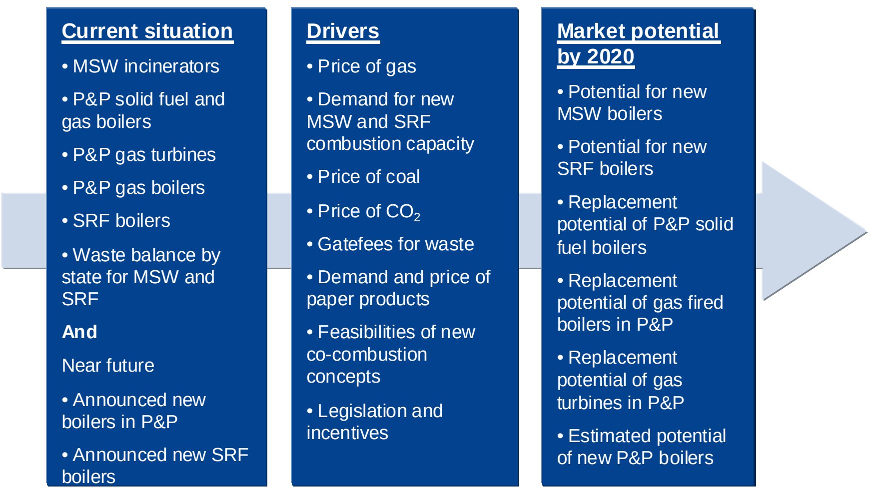

Figure 4. Methods of the market potential analysis.

This analysis method was used in all three levels to generate an iterative analysis that starts from the waste generation statistics as well as current incineration and combustion statistics for waste fuels. Statistics were used as an input in parallel analysis on the country and state level for Germany. As a result of the country level analysis, a market potential estimate for high efficiency CHP was produced at state level. The state level analysis of selected states was made to test the correctness of the country level results and to give feedback for the iteration round for the country level analysis. The state level analysis was performed together with Forschungszentrum Karlsruhe (FZK), Germany, to get the best available local knowledge of the current situation and the future prospects.

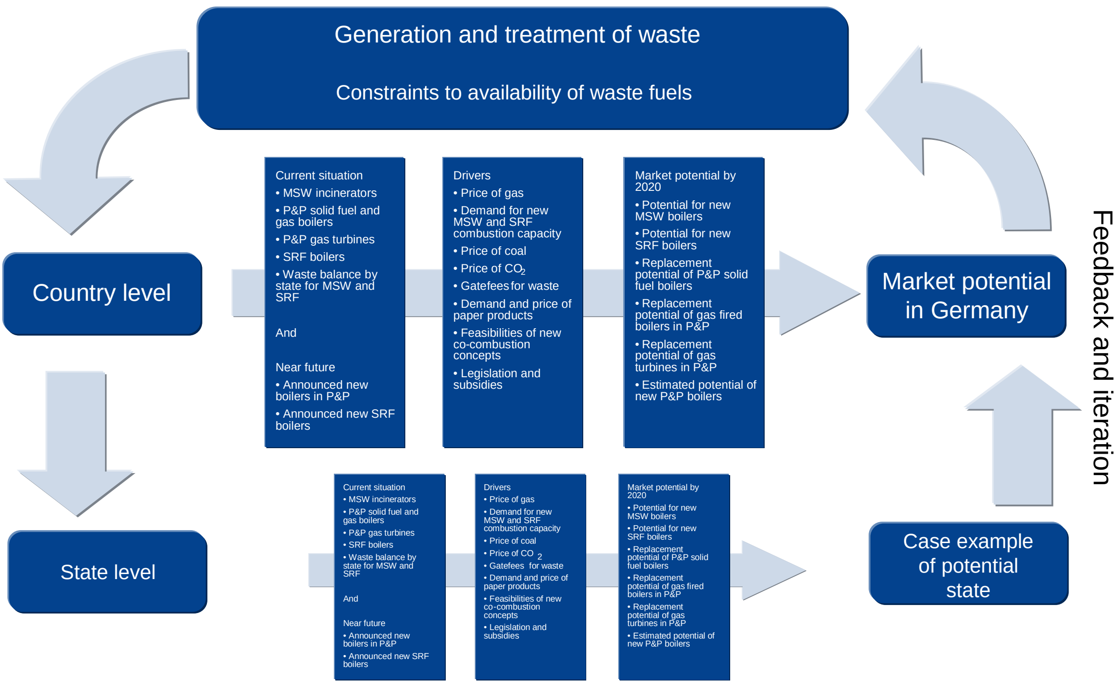

Figure 5. Iterative country and state level analysis as main methods for the study.

3. Renewable energy targets and waste regulations

3.1 Price development of fossil fuels and waste

Fossil fuel prices have increased significantly in Europe during the period of 2005–2007 (Figure 6). Especially prices of fuel oil and natural gas have increased due to the global price increase of crude oil. This has changed the competitiveness of different energy production alternatives and as a result, the situation has become more favourable for solid biofuels and waste and also coal.

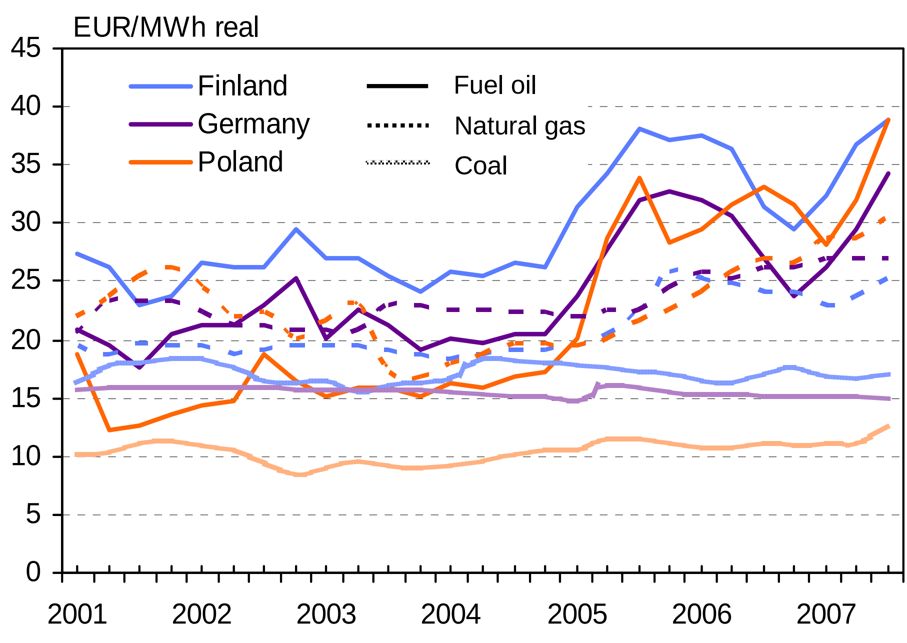

Figure 6. Fossil fuel price development in European pulp and paper industry.

On top of fossil fuel price rise, the emission trading scheme (ETS) has also increased the production costs of fossil fuel based heat and power. The CO_2 emission allowance price has been very volatile during the first season of the EU-ETS; the price has varied from 0 to 30 EUR/t CO_2 (Figure 7). Allowance price increase of 10 EUR/t CO_2 has an impact of 2.8 EUR/MWh for fuel oil, 2.0 EUR/MWh for natural gas and 3.4 EUR/MWh for coal. Using current future prices for CO_2, allowances, the cost increase for these fossil fuels would be 5.5–9 EUR/MWh for the years 2008–2012. High CO_2 allowance prices have positive impact on the feasibility of new multifuel power plant investments especially in the case where the power plant could utilise solid biofuels and waste that are significantly cheaper than fossil fuels.

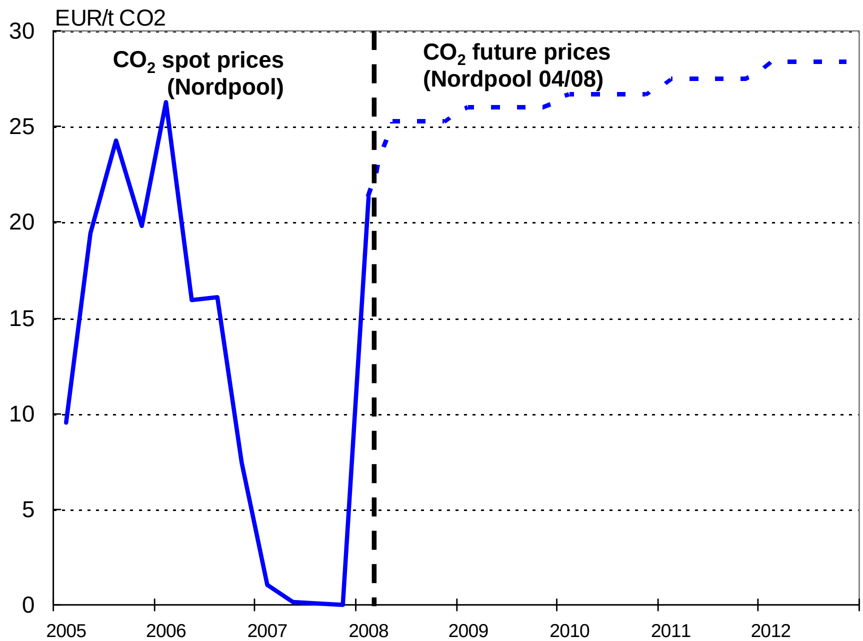

Figure 7. Historical price development and future prices of CO_2 emissions.

The recent rising price trend of fossil fuels and CO_2 allowances has had an impact also on the price of wood fuels (hog fuels) in Europe. Based on the Pöyry's price databanks, the industrial price of hog fuel has increased only slightly during the last few years to a level of 10–15 EUR/MWh, but the news from Germany and Austria indicate that the spot market price level for forest residues has varied between 20–30 EUR/MWh. In addition especially in Central Europe, the availability of other solid biofuels is very limited. That is why the option to co-combust waste fuels and SRF in pulp and paper industry's power plants has become more attractive. There are already examples of this in Germany where SCA in Witzenhausen and LEIPA in Schwedt have made investments in new fluidised bed power plants that use also large amounts of waste fuel to produce cost-efficient heat and power to be used at the paper mill.

3.2 Regulations and incentives

3.2.1 The renewable energy sector in the EU

In the year 2000 the European Commission issued a paper for the European Council outlining the framework and the targets of future EU energy politics, the so-called Green Paper on Security of Energy Supply. This paper contained a target for the share of renewable energy sources (RES) of 12 % of primary energy. One year later the European Commission and the European Council passed the so-called RES-E (renewable sources for electricity) Directive which set a target or 20 % to be reached in 2010 in the electricity market.

Whereas these papers addressed the total renewable energy market comprising the hydro, wind, solar, and geothermal sector a specific paper on bioenergy was issued in 2005, the Biomass Action Plan. It contained the following specific biomass targets for 2010:

- a share in total primary energy of 149 Mtoe (6 250 PJ)
- a share in the heat market of 75 Mtoe (3 150 PJ)
- a share in the power market of 55 Mtoe (2 300 PJ)
- a share in the transport market of 19 Mtoe (800 PJ).

This action plan was partially revised in early 2007 when the European Commission issued the Renewable Energy Roadmap, a communication paper to the European Parliament and the European Council, which describes medium term policies in the energy sector and sets the following targets for 2020:

- 20 % of renewable energy in the in primary energy supply
- 10 % biofuels in the transportation sector.

These EU activities are complimented by to some extend even more challenging goals on national level. The Swedish government, e.g., announced a strategy to become independent from oil imports in 2020.

The most recent European Directive to support advanced utilisation of biomass and waste in energy production is the Directive on the promotion of the use of energy from renewable sources that was accepted in the European Parliament in December 2008. The Directive is based on the Renewable Energy Roadmap and it endorses a mandatory target of a 20 % share of renewable energies in overall Community energy consumption by 2020 and a mandatory 10 % minimum target to be achieved by all Member States for the share of biofuels in transport petrol and diesel consumption by 2020, to be introduced in a cost-effective way. The Directive also gives a chance for new 2nd generation biofuels to have a double share in renewable energy calculations if the biofuel is produced from residues and waste.

3.2.2 Renewable energy targets in Germany

The German government aims for

- an RES share of primary energy consumption of 10 % in 2020 and of 50 % in 2050
- an RES share of power consumption of 12.5 % in 2010 and of 20 % in 2020
- a share of 5.75 % of biofuels of total fuel consumption in 2010.

For reaching these targets support instruments have been installed. The most successful one in the power market is the Renewable Energy Resource Act (EEG) released in 2000 and amended in 2004. According to this act, operators of electricity grids have to buy electricity from solar hydro, and wind power, geothermal energy, and biomass and to pay certain minimum rates for it. The political support for renewable energy was so successful that Germany surpassed already in 2007 the goal of 12.5 % for 2010 by reaching 14 %.

An important role for the EEG plays the Ordinance on Generation of Electricity from Biomass of 2001 which defines the different biomass resources receiving these special tariffs which are listed in Table 1. The remuneration is granted for 20 years to provide planning security for the investors. A degression of the basic remuneration of 1.5 % per annum is foreseen for new installations.

Table 1. Tariffs for electricity from biomass in €-cent/kWh.

Capacity	Basic tariff	Fuel bonus		Cogeneration bonus	Technology bonus
		Biogas	Solid biomass		
< 150 kW	11.5	6	6	2	2
150–500 kW	9.9	6	6	2	2
500 kW–5 MW	8.9	4	2.5	2	2
5–20 MW	8.4	0	0	2	0

The EEG supports especially small biomass power plants and has induced a high increase in biogas production.

The RES-heat market profits mainly from the Program to Promote Renewable Energies, the Market Incentive Program (MAP). Although this program addresses the electricity and biogas market as well, it supports first of all small scale heating systems. In 2004 some 22.3 % of the budget was allocated for bioenergy: 20 mio € for heating systems < 100 kW, 8.2 mio € for cogeneration systems > 100 kW and 10 mio € for biogas plants.

3.2.3 Regulations in the EU waste sector

Today the waste management sector in the EU is almost totally regulated by EU Directives which are issued by the European Council and the European Parliament and have to be or are adopted already by all member states. This practice started in the seventies of the last century already and resulted in a harmonisation of national regulations in terms of management strategies, technological measures, and environmental standards. The Framework Directive 75/442/EEC on Waste Disposal was enacted in 1975. It gave general advises on waste management and disposal. Under the umbrella of this Framework Directive a number of directives have been released which regulate the disposal and/or recycling of specific waste streams, among others sewage sludge, packaging waste, ELV (end of life vehicles), WEEE (waste from electrical and electronic equipment), PCBs and PCTs, batteries and accumulators.

A directive of fundamental importance for the disposal of MSW is the Landfill Directive 1999/31/EC. The Landfill Directive is intended to prevent or reduce the adverse effects of direct disposal of untreated waste on human health and on the environment, in particular on surface water, groundwater, soil, and air. It stipulates a system of operating permits for landfill sites. The most important part is Article 5 which requires a reduction of biodegradable waste going to landfills. The reduction targets to be met in comparison to the amount of organic waste disposed of in 1995 are

- 25 % in 2006
- 50 % in 2009
- 75 % in 2016.

The Landfill Directive specifies only general criteria and principles to be obeyed for the acceptance of waste or residues on a landfill but it does not contain specific parameters and their limit values. These are laid down in the Council Decision 2003/33/EC. Measures to achieve the directive's targets are in particular recycling, composting, biogas production or materials and energy recovery. Consequently the directive does not only promote recycling and composting but even more waste incineration which is for the time being the only proven and efficient technology to destroy organic matter.

The gross annual generation of MSW reached in the EU in 2006 approximately 493 000 000 t. The person specific generation ranged from approximately 260 kg in Poland to slightly more than 800 kg in Ireland with the new member states at the lower end. The average figure for the EU 27 is 517 kg per person and year. Table 2 lists for selected countries person specific waste generation figures and gives information about the percentage of recycling, incineration, and landfilling. The recycling data contain material recycling and composting.

Table 2. Generation of MSW in kg/cap/y and recycled (REC), incinerated (INC) and landfilled (LF) fraction in % for selected countries in 2006 (European Commission 2008).

Country	MSW	REC	INC	LF
Austria	617	61	29	10
Belgium	475	62	33	5
Bulgaria	446	20	0	80
Cyprus	745	12	0	88
Czech Republic	296	11	10	79
Denmark	737	40	55	5
Estonia	466	40	< 1	60
Finland	488	59	9	32
France	553	32	33	35
Germany	566	68	32	<1
Greece	443	13	0	87
Hungary	468	12	8	80
Ireland	804	41	0	59
Italy	548	36	12	52

Country	MSW	REC	INC	LF
Latvia	411	28	< 1	71
Lithuania	390	9	0	91
Luxembourg	702	43	38	19
Malta	652	14	0	86
Netherland	625	64	34	2
Poland	259	8	< 1	91
Portugal	435	15	22	63
Romania	385	15	0	85
Slovakia	301	10	12	78
Slovenia	432	16	< 1	84
Spain	583	43	7	50
Sweden	497	48	47	5
United Kingdom	588	31	9	60
EU 27	517	40	19	41

A visualisation ranked in terms of amount of waste directly disposed of on landfills is depicted in Figure 8. The graph shows on top some old member states of the EU which started integrated waste management strategies in the early 1990's already. At the end mainly new member states are found which had till recently no controlled waste management at all. However, there is also a decent number of old member states which are still landfilling more than 50 % of their MSW.

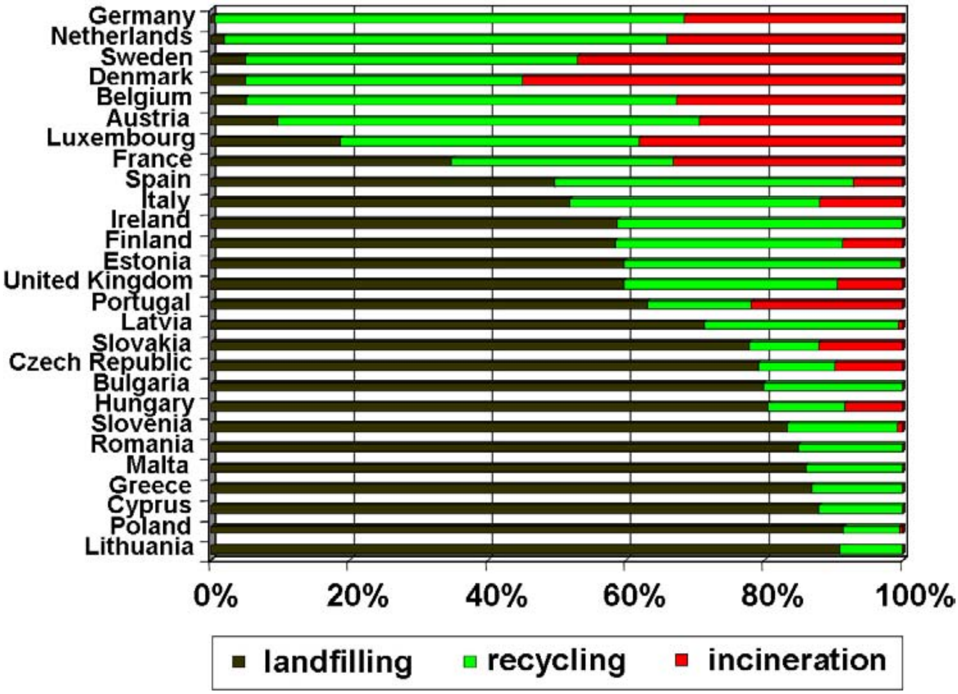

Figure 8. Waste management practice in EU 27 in 2006.

The graph documents the fact that countries with high recycling rates have also implemented high shares in incineration capacity for their residual waste, that fraction left over after all recycling activities. Since the EU Landfill Directive has to be adopted by national law in all member states the situation shown in Figure 8 will rapidly change. It can be expected that recycling rates of 60–70 % achieved in some countries are close to the practical limit of material recycling. That would mean that approximately 30–40 % of the generated MSW would be available for incineration. This is an amount of almost 200 000 000 t of energy inventory of which is on an average approximately 50 % of biogenic origin.

3.2.4 Disposal versus recovery in EU

The Waste Framework Directive has after many years of discussion recently been replaced by the Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste. The major change compared to former regulations is a new definition of the terms “disposal” and “recovery”. This distinction was only vaguely defined in former directives and led to finely to two decisions of the European Court in February 2003 (cases C-228/00 and C-458/00) which again left questions for their application in practice.

Annex I lists 15 disposal operations and Annex II defines 13 recovery operations. The most important one is “R1 Use principally as a fuel or other means to generate energy”. In a footnote it defines very specific conditions for the acceptance of energy recovery from municipal solid waste.

The footnote contains the so-called R1 Formula for the calculation of the energy efficiency of a combustion plant which is in principal no physical efficiency but a classification number:

$$\text{Energy efficiency} = (Ep - (Ef + Ei))/(0.97 \times (Ew + Ef))$$

Ep is the annual energy produced by the plant as heat or electricity where the heat produced for commercial use is multiplied by 1.1 and the produced electricity is multiplied by 2.6. Ew is the annual energy contained in the treated waste calculated using the net calorific value of the waste and Ef is the annual energy input from auxiliary fuels and Ei is the annual energy imported excluding Ew and Ef. 0.97 is a factor accounting for energy losses due to bottom ash and radiation.

Incineration facilities are accepted as recovery facilities if the calculated energy efficiency is equal of above:

- 0,60 for installations in operation and permitted in accordance with applicable Community legislation before 1 January 2009
- 0,65 for installations permitted after 31 December 2008.

The Directive 2008/98/EC has to be adopted by national law before December 10, 2010 and it has to be waited and seen whether these new regulations will bring more clarity for the practice.

Waste incineration had – and in some countries still has – a bad reputation in terms of its presumed ecological impact. Hence this disposal route has already in the 1980’s and 1990’s been regulated in various countries. A continuous strengthening of standards, mainly those on air emission, resulted in the Directive 2000/76/EC of the European Parliament and of the Council on the incineration of waste, the so-called Waste Incineration Directive which was published by 28. December 2000. This directive sets standards for the operation of MSW and hazardous waste incineration plants in terms of temperature, residence time, energy recovery, and air emission values. It contains also specific provisions for the co-combustion of waste in cement kilns and power plants. On top of that concentration limits for liquid effluents from wet flue gas cleaning are contained. Also rather general statements concerning residues from waste incineration or co-combustion are included: these should be minimised and as far as possible utilised.

It can be expected that in the course of harmonisation of air emission standards for all combustion facilities the limits of the Waste Incineration Directive will in due time be valid for all power plants in the EU.

3.2.5 Regulations on waste management in Germany

Already in the early 1990's the German government started activities to develop an integrated waste management strategy. The principles are the same as those of the EU Waste Framework Directive on Waste Disposal 75/442/EEC. The most important acts, ordinances, guidelines and memoranda will be described in short terms. In this context only regulations affecting the management of non-hazardous waste will be considered.

Waste Disposal Act and Waste Avoidance and Management Act

The first Waste Disposal Act was enacted in 1972, three years before the EU Waste Framework Directive. It replaced approximately 50 000 dump sites by 300 controlled landfills. This was accomplished within few years; however, lacking logistics and shortage in capacity caused local crises and public opposition. To cope with the permanently rising waste generation the Waste Avoidance and Management Act was adopted in 1986. It set the principle of giving avoidance and recycling preference over disposal.

Air Emission Regulations

Along with the re-organisation of landfills the number and capacity of waste incineration plants was extended. This technology was soon blamed for unacceptable air emissions, especially after dioxins had been detected in the fly ashes of Dutch waste incinerators. Declining public acceptance in the early 1980's was the driver for the release of the Technical Guideline Clean Air (TA Luft 86) in 1986. Its limits were only 5 years later strengthened by the 17. Federal Immission Control Ordinance (17. BImSchV). This ordinance is one of the sources of the later EU Waste Incineration Directive 2000/76/EC discussed above already and is after a number of minor changes still in power today.

The 17. BImSchV regulates the entire waste incineration process and sets limits to air emissions and ash utilisation.

It has to be mentioned that these stringent safety standards helped to reduce the public opposition against thermal waste treatment to a great extent.

Packaging Ordinance

Approximately 50 % of the volume of waste from households is packaging material which was the reason to regulate the disposal of this waste stream in the Packaging Ordinance by shifting the responsibility for its adequate management to the manufacturers and retailers. As a consequence of this ordinance the Dual System Germany (DSD) was established which collects packaging material free of charge for the citizen and organises the recycling of special fractions like glass, paper, or plastics. The system is financed by the 'Green Dot' licence fee which the manufacturer – but in fact the customer – pays. Meanwhile the DSD lost its exclusivity and a number of dual systems are in operation.

Technical Ordinance on Waste from Human Settlements (TASi)

For mixed residential waste the government issued the Technical Ordinance on Waste from Human Settlements (TASi) in 1993. The core target of the ordinance was the prevention of direct disposal of reactive waste. Its main objectives are the restriction of direct disposal of biodegradable waste on landfills, the priority for material recovery including composting and anaerobic digestion, and finally thermal treatment of residual waste with energy recovery and – as far as possible – residue utilisation prior to final disposal.

The principles and requirements laid down already in the TASi have later been used as basis of the EU Landfill Directive. In that way this ordinance – although not really effective in Germany – resembled at least an important input for the waste management strategies in the EU.

Closed Substance Cycle Act (KrW-/AbfG)

In the early 1990's the German government had in mind to fight the still increasing waste generation by introducing a landfill tax. This attempt failed due to heavy resistance, especially from various industry sectors which had to deal with high amounts of production residues. Another reason was the unclear constitutional situation since a high fraction of the tax should not serve common interests in the waste disposal area but was foreseen for other purposes. At the same time Germany was sued by the European Court of Justice for not having fully adopted the Waste Framework Directive. Hence in 1994 the Act for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal (KrW-/AbfG) was issued as a legal act which adopted the waste classification of the EU Waste Framework Directive and was in line with the fundamentals of the former TASi.

For waste incinerators the KrW-/AbfG set criteria to distinguish between disposal and energy recovery. The latter operation mode is accepted if

- the lower heating value of the material has to exceed 11 MJ/kg
- the combustion efficiency of the combustion plant must exceed 75 %
- the energy released by the process has to be used as heat or power
- the residues meet the landfill acceptance criteria of the TASi without further treatment.

The KrW-/AbfG stated also that energy recovery will in principal not be accepted for municipal solid waste, regardless of the compliance with the above cited acceptance parameters. For municipal solid waste the main purpose of incineration has to be taken into account and that is according to most regulators the inertisation prior to landfilling, hence a disposal operation. Especially this part will be changed in near future when Germany has to adopt the new Directive 2008/98/EC.

Ordinance on Landfills and Long-Term Storage (DepV)

The EU Landfill Directive was adopted by German law in July 2001 with the Ordinance on Landfills and Long-Term Storage Facilities and Amending the Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and Biological Waste-Treatment Facilities (DepV). This ordinance converted finally the principles of the TASi into a legally binding regulation. The direct disposal of untreated reactive waste on landfills was now definitely prohibited after 1. June 2005. After this date all standards for design, operation and aftercare of all landfill classes for municipal waste, commercial waste and waste requiring special surveillance (hazardous waste) came in force as they had been laid down already in the TASi. All initially granted exemptions expired.

Act on Commercial, Construction and Demolition Wastes

In 2002 the German government released new rules for the disposal of commercial as well as construction and demolition waste with the Ordinance on the Management of Municipal Wastes of Commercial Origin and Certain Construction and Demolition Wastes. The disposal of these waste streams has to be taken care of by their producers. The new ordinance defines pre-treatment and recovery requirements.

3.2.6 Energy recovery from waste in Finland

The waste management in Finland has been heavily relying on landfills still in the 1990's. However, landfilling will be limited in future due to legislative decisions and new solutions for material and energy recovery of waste are considered.

The total amount of municipal solid waste (MSW) in Finland (2005) is estimated to be approximately 2.5 million t/a, of which about 780 000 t/a are recycled and recovered as material. About 180 000 t/a is recovered as energy, and 1.5 million t/a is still deposited on landfills. The current recovery rate for MSW is some about 40 %. In order to meet the recovery targets set in the Finnish national waste plan for 2016, additional 1 million t/a waste should be recovered as energy.

An increasing amount of waste is burnt in Finland in co-combustion with wood, peat and coal. Co-fired waste, Solid Recovered Fuel, is usually a processed fuel from source separated household waste or packaging waste from stores and industry. The quality of SRF is based on good source separation of wastes and recovered fuel production technology. There are about 20 co-firing plants in Finland nowadays. The amount of waste co-fired ranges typically between 5 and 30 % of fuel energy input. About 150 000 t/a of dry SRF is co-fired in industrial and municipal boilers. For countries like Finland with low population density but a well established power and heat market "clean" SRF is a promising option to dispose most of the waste of in a way which complies with the EU directives.

For the new investments, the references are typical mixed-waste incineration plants in Europe, most of them generating only electricity and most units in

Scandinavia predominately district heat. In Finland, most of the solid fuel boilers generate combined heat and power (CHP) for municipalities or industry, and there are more than 150 biomass-fired boilers where also high-grade SRF could be co-fired. The power price in the Scandinavian grid is low, typically 3–4 cent/kWh, and economically condensed-mode separate power production from waste fuels is not attractive. Most of heat loads in cities have already been built, and it is difficult to sell additional SRF-based energy to the market other than for co-firing in CHP boilers.

Two new mixed-waste incineration plants have been commissioned in Finland during 2007–2008. In addition to the old MSW incinerator in Turku (50 000 t/a), these plants have a total capacity of 235 000 t/a and are producing district heat, steam and electricity. A waste gasification plant has been co-firing a pulverised coal CHP plant in Lahti since 1998, replacing about 15 % of the fossil energy. A large number of new plants (about 20) are in the phase of environmental permitting, all being delayed by complaints filed by NGOs. The general estimate is that less than 10 waste incineration plants will be built in Finland in the near future. The most notable project will be the mixed-waste incinerator to be built in the Metropolitan area, having a capacity of 300 000 t/a and planned to be operational in 2015. This plant will probably influence the waste management strategies and practises in the area significantly.

The following issues should be considered to influence the waste management solutions in Finland:

- high efficient combined heat and power production extensively low electricity price
- strong seasonal fluctuation in heat and power demand
- rather small waste volumes and long transport distances compared to Central Europe
- a well developed source separation system implemented in major part of the country
- material recycling favoured before energy use.

A possible solution model could be:

- Good quality SRF could be locally produced and used in co-combustion (or gasification) in existing fluidised bed CHP-plants. The problem of surplus heat to a saturated district heating net could be avoided and high efficient power production utilised.

- Low quality and inhomogeneous waste fractions (in case of limited source separation) could be combusted in medium size grate boilers located so that the energy can be utilised. This would be the option if SRF of good quality cannot be produced with reasonable energy input from mixed waste.

3.3 Conclusions

European and country level legislations are driving the waste sector towards higher efficiencies and recycling. They both support FB-CHP combustion because the fuel preparation allows recycling before combustion and increasing electrical efficiencies. Also the overall efficiency is very high at paper mill where the heat energy is used for paper production. Latest Directive also introduced the so called “double count” for biofuels for transport that are produced from residues and waste. This increases the viability of new energy concepts from waste e.g. ethanol production from waste and waste fibres.

Germany has been the fore runner in regulations and efficiency targets that support this new technology. Also the increased natural gas and fuel oil prices have in Germany have made the situation very hard for German paper mills that now need new energy solutions. That is where the needs from waste management and paper industry meet in profitable way.

4. Supply, demand and price development of paper and paperboard

4.1 Paper industry structure in Western Europe

The total production capacity of paper mills in Western Europe amounts to 105 million tons/a, accounting roughly for one quarter of the global paper industry capacity. Other key supply regions in the world are Asia (170 million tons/a), North America (103 million tons/a), Latin America (22 million tons/a) and Eastern Europe (19 million tons/a).

The largest paper producing countries in Western Europe are Germany (23 % of total capacity in Western Europe) and Finland (14 %) followed by Sweden (12 %), Italy (12 %) and France (10 %).

Since the early 1980's, the structure of Western European paper industry has changed dramatically, bringing an increase in the concentration of power amongst fewer companies. The share of the leading ten companies of the region's total paper manufacturing capacity has grown from about 18 % in 1980 to 51 % in 2008. The corresponding shares of the leading twenty companies were 28 % in 1980 and 65 % in 2008, respectively Regional mergers and acquisitions have led to a situation where over 30 % of the region's paper and paperboard capacity is now in the hands of Finnish paper industry companies (32 million tons/a, 12 companies), Table 3.

Table 3. Largest paper producing countries in Western Europe 2008 classified by P&P company ownership.

Home country of P&P companies	Number of companies	Cumulative capacity Mill. t/a	Share %
Finland	12	31.99	30.5
Italy	149	11.99	11.4
Sweden	14	11.87	11.4
Germany	100	10.16	9.7
France	39	6.26	6.0
Ireland	1	5.80	5.5
Spain	63	5.01	4.8
South Africa	2	4.42	4.2
Norway	6	4.19	4.0
USA	11	3.12	3.0
Austria	12	2063	2.5
UK	18	1.88	1.8
Others	66	5.59	5.3
TOTAL	**493**	**104.91**	**100.0**

The top ten paper companies in Western Europe account for over 51% of the region's paper and paperboard capacity. The combined share of the leading 20 firms is 65%.

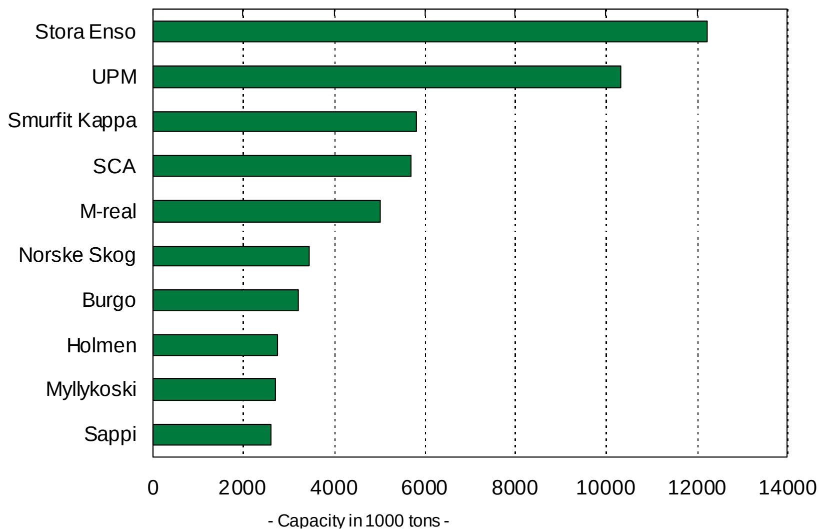

Figure 9. Leading paper companies in Western Europe 2008/II.

Table 4 shows the capacity distribution of paper mills in Western Europe by mill size class.

Table 4. Capacity distribution of paper mills in Western Europe 2008/II.

Capacity class 1000 t/a	**Total W. Europe**		**Nordic countries**		**Germany**	
	Number	Capacity Mill. t/a	Number	Capacity Mill. t/a	Number	Capacity Mill. t/a
> 500	42	31.5	23	18.2	8	6.2
100–500	228	54.2	40	10.0	55	14.6
51–100	146	10.4	14	1.0	26	1.9
26–50	144	5.3	10	0.4	26	1.0
0–25	336	3.5	10	0.2	78	0.8
TOTAL	**896**	**104.9**	**97**	**29.8**	**193**	**24.4**

4.2 Outlook for paper and paperboard demand

The demand for paper and paperboard in Western Europe is expected to grow from the current 84 million tons to 87 million tons by 2015, corresponding to an average growth rate of 0.4 %/a (Figure 10).

The growth of the Western European paper and paperboard market is slowing. The main reasons for the stagnant or even declining demand profile are:

- Competition between paper-based and electronic/on-line media has led to fairly modest growth rates or even declining demand in some graphic paper end uses. Various electronic applications are competing for consumers' attention and time; on-line providers are actively promoting the new advertising media and advertisers are gradually adopting an on-line strategy in their media mix. However, despite losing part of its market share, print on paper will remain a powerful advertising medium in the future.
- Globalization of manufacturing industries; consumer goods industries have invested in manufacturing capacity in emerging markets to gain advantage of lower manufacturing costs, or to get better access to rapidly growing markets. Consequently, packaging companies have redi-

rected their box plant investments from industrialized countries to emerging regions, resulting in a demand shift from high cost to low cost regions.

Paper and paperboard demand in Western Europe is expected to grow by 0.4%/a through 2015. Tissue paper, containerboards, cartonboards and coated woodfrees will remain on growth track, while others will remain stagnant or decline.

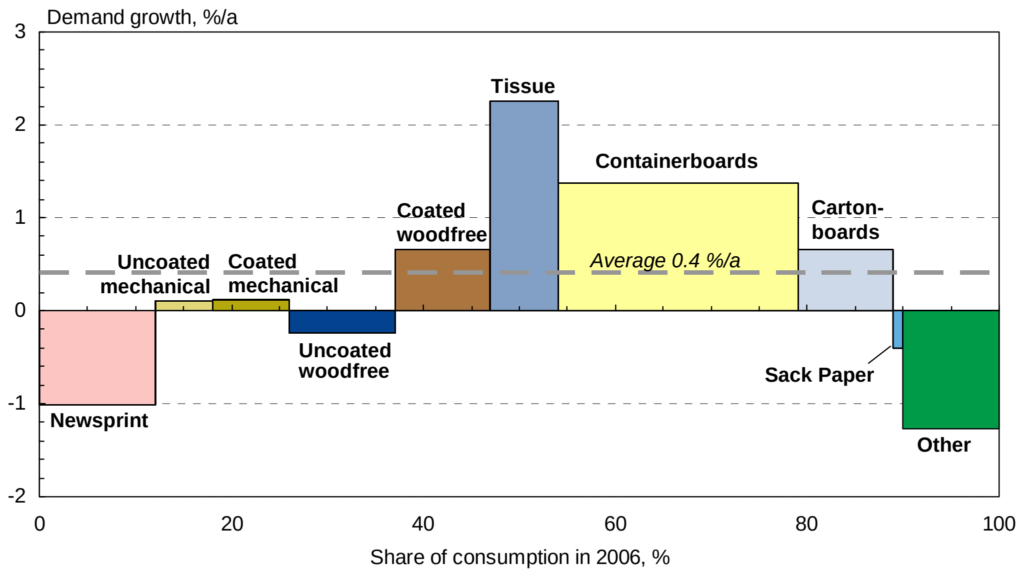

Figure 10. Long term paper demand growth by product area through 2015.

The demand for newsprint in Western Europe is expected to decline by 1 %/a through 2015. This is mainly due to the generally declining newspaper readership amongst young people, and consequent decline in daily newspaper circulations. The distribution of free newspapers has somewhat slowed the decline in newspaper readership, and kept newsprint consumption up at the current 10 million ton level over the last ten years.

The demand for uncoated mechanical papers – typically used in diverse magazine, directory, book printing and advertising applications – will remain stable in the medium term (5 million tons/a in 2006). The gently sloping SC paper consumption for catalogues, magazines and commercial printing will help the uncoated mechanical paper product area maintain its current volumes while on-line penetration in directory applications will have an adverse effect on demand. The main drivers underlying coated mechanical paper demand (7 million tons/a) include paper-based advertising and development of special interest magazines, which are expected to keep the coated mechanical paper demand up in the foreseeable future.

Uncoated woodfree paper, including cut size/copy papers, business forms etc. has reached its peak in terms of demand (9 million tons/a). The demand for uncoated woodfrees will grow in direct mail applications while electronic invoicing, on-line bill paying, e-mail and other electronic devices are displacing uncoated woodfree papers in business forms. The growth of coated woodfree paper demand (currently 8 million tons/a) will be supported by the increasing use of four-color direct mail, special catalogues and up-market magazines.

The consumption of tissue paper (6 million tons/a) is expected to grow relatively rapidly with the increasing standards of living, life style changes, growth of travel/hotel businesses, and the growing number of elderly people.

The demand for containerboards (21 million tons/a in 2006) and cartonboards (9 million tons/a) will depend on a diverse set of factors. The packaging board demand in Western Europe has suffered from the shift of demand from the west to the east, as well as the trend toward reduced packaging. The general light-weighting tendency has reduced the overall volumes of packaging in many end uses. However, changes in retail trade, increasing use of corrugated board in consumer packages and display applications, increasing demand for high quality cartonboards for convenience food applications etc. will continue to support the growth of fibre-based packaging in Western Europe.

4.3 Outlook for paper and paperboard production and net trade

The production of paper and paperboard in Western Europe is expected to grow from 98 million tons in 2007 to 103 million tons in 2015. The following points may be worth noting:

- Newsprint capacity has declined mainly in Finland (–470 000 tons in 2008) and Norway (–130 000 tons in 2008), and increased a bit in Switzerland (75 000 tons in 2008). Announced investments in the UK suggest that Britain’s newsprint capacity will increase by 400 000–600 000 tons by the end of the current decade.
- Uncoated woodfree paper capacity is expected to dwindle in the UK (–230 000 tons in 2009), and eventually in other Central/Northern Euro-

pean countries, too in response to the declining demand trend in the region. The largest ongoing paper industry investments include Portucel-Soporcel's 400 000 ton/a uncoated woodfree paper machine, which is scheduled to come on stream in 2009.

- New containerboard capacity will be built in Germany (confirmed start-ups > 800 000 tons/a as from 2008), the UK (270 000 tons/a), Italy (280 000 tons/a), Portugal (85 000 tons/a) and Belgium (80 000 tons/a).

Paper and paperboard net exports from Western Europe are expected to grow from 13.6 million tons in 2007 to 15.8 million tons by 2015. One of the fundamental assumptions behind this projection is the strengthening of the US dollar in the long term. The dollar is expected to remain relatively weak for the short to medium term, but strengthen from the current level and reach the average long term parity level of USD 1.15 per Euro by 2012.

The recent weakness of the dollar has aggravated the Western European paper industry's operating conditions in many ways. First, exports to the US market have lost their competitiveness vis-à-vis US suppliers. In consequence, Western European mills have redirected their deliveries more onto the regional markets. Second, supply pressures from Asia to Western European markets have grown. Third, attempts to increase Euro-based prices in the phase of cyclical peak have become extremely difficult.

4.4 Price development

In the long term, the real prices of market pulps, paper and paperboard have been declining, Figure 11. Historically, the main drivers of declining price trends have been

- good availability of main production inputs such as wood, virgin fibre pulps, recovered paper and energy
- technological development, including advances in material saving technologies and production efficiency
- economies of scale such as higher machine speeds, growing mill capacities, lower investment costs per ton of capacity and lower manufacturing costs/ton of product.

Paper prices delivered in Germany, pulp prices CIF

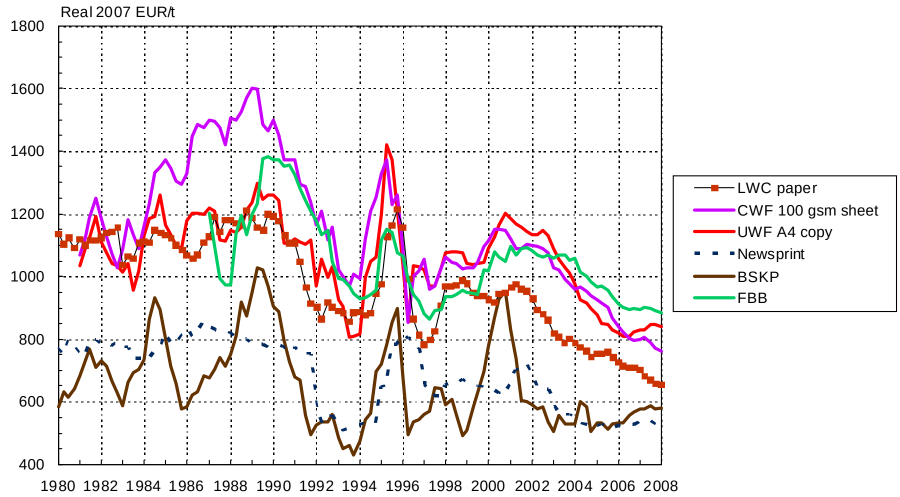

Figure 11. Real price development 1980–2008/I.

Vigorous cost cutting programs implemented during the last 10–15 years have improved the efficiency of pulp and paper operations in the key production regions. At the same time, paper prices have declined 3–6 %/a in real terms leading to weakening profitability. Even recent improvements in capacity utilization have not resulted in significant price increases. Instead, the benefits of lower production costs have been passed on to customers. It appears that the pulp and paper industry lacks true price leadership which would be effective in reaching consensus on pricing without collusion in violation of antitrust laws.

Exchange rate movements tend to change the cost position of companies selling onto the international markets, and thus disturb the industry equilibrium and prices. Recently, the industry's attempts to reach some sort of price discipline have been hampered by the exceptionally weak dollar. Weak USD has put Western European papermakers in a very difficult competitive position, squeezed by weakening demand from North America and consequent delivery pressures from both Western European and Asian rivals.

5. Feasibility of high efficiency CHP in pulp and paper industry

Feasibility of advanced fluidised bed power plant investment in German pulp and paper industry is evaluated as a desktop calculation exercise. To evaluate the feasibility, there are two main criteria that are the most relevant; feasibility of a power plant as such and in a situation where it is compared to feasibility of a typical grate fired waste incinerator. Fluidised bed technology has been the main technology in European pulp and paper industry especially with solid fuels while grate technology is dominant technology in waste incineration. For this reason, fluidised bed boilers should also be compared to grate boilers even if the pulp and paper industry prefers fluidised bed technology due to it's suitability to combust the mill sludges.

The feasibility evaluation is based on data from Metso Power's concept for fluidised bed power plant that also includes the mechanical treatment of the waste to SRF. Data concerning the grate fired power plant has been taken from a publication (de Vries et al. 2000) and it has been supported with expert estimates. The design parameters for the power plants were: steam consumption of 55 MW at 4 bar at the paper mill and annual operation time of 7 500 hours. The investment cost for these 80 MWfuel power plants were 115 MEUR for the Circulating Fluidised Bed boiler (CFB) including the investment for the mechanical waste treatment and 113 MEUR for the grate boiler. The energy price assumptions and other cost factors used in the calculation are presented in the table below (Table 5). Live steam values of the two plants differ so that for the CFB boiler, values of 470 oC and 70 bar and 400 oC and 40 bar for the grate boiler were being used. These steam values result in different electricity efficiencies which are 19 % for the CFB and 14 % for the grate in the back-pressure turbines.

Table 5. Price and cost assumptions for the calculation.

Name	Price	Unit	Source
Electricity price	62	EUR/MWh	Germany Power Futures price year 2012 [EEX.com (4.12.2008)]
Steam price	29	EUR/MWh	German Natural Gas Futures price 2012 / 90 % [EEX.com (4.12.2008)]
MSW gatefee	130	EUR/t	FZK
Ash handling price	130	EUR/t	Estimate

The feasibility evaluation is based on cash flow analysis using real constant prices. The calculated values for the feasibility evaluation were internal rate of return (IRR) and net present value (NPV). The results are calculated before taxes, without residual values and capital expenditure for re-investment.

The feasibility evaluation can be tested in a dynamic feasibility model where it is possible to vary all the main price variables to see the feasibility variation of the two technologies. A still image of the dynamic model is presented in Figure 12.

The main result of the feasibility evaluation is that both technologies give a good feasibility for the paper mills in Germany. However, the difference between the two technologies cannot be estimated reliably with the data available for the analysis. The IRR of the CFB alternative was 26 % and 25 % for the grate alternative; both cases showing thus very high financial feasibilities compared to typical levels achieved in the pulp and paper industry. The main uncertainty factor in the analysis is the investment costs of these two technologies. Another factor that has a major impact in the feasibility of the CFB alternative is the yield and investment cost of mechanical waste treatment process. The quality of the waste plays a significant role in the mechanical waste treatment process and it is commonly known that good quality commercial and industrial waste (CIW) is more suitable for the CFB technology than residential municipal solid waste (MSW). As a conclusion, it can be stated that according to the analysis made, the good financial feasibility of waste-to-energy unit investments in German paper industry is a significant driver to increase the utilisation of waste fuels to reduce the energy costs in paper production.

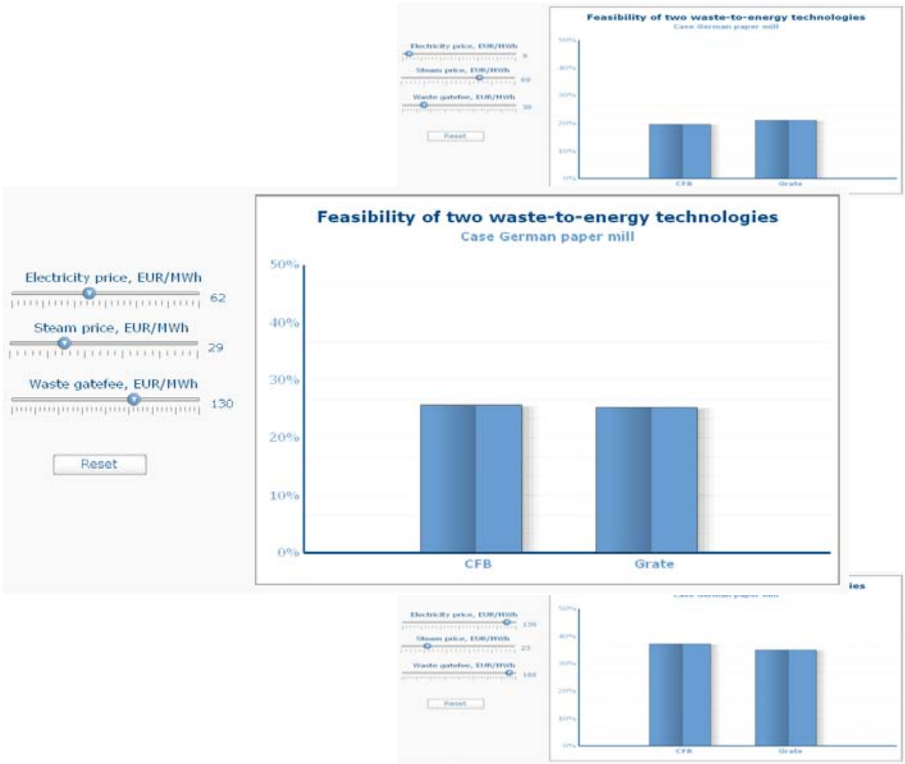

Figure 12. Dynamic model of the feasibility evaluation.

6. Waste generation in Germany

Waste incineration is a common practice in Germany with over 70 operational incinerators that burn mainly municipal solid waste (MSW). Waste incineration has been traditionally a way of stabilising the generated waste, but the current trend is towards more efficient energy recovery/utilisation of the waste. Grate boiler technology is the dominant technology in Germany for waste incineration but during the past decade, also few fluidised bed boilers have been built for solid recovered fuels (SRF). The most common practice to use SRF in Germany is in cement kilns where roughly two thirds of the SRF is being used.

6.1 Municipal solid waste

German waste generation was analysed based on the official statistics from Statistics Offices of Länder and the Federal Statistical Office (Statistisches Bundesamt 2007, Statistisches Bundesamt 2008). The amount of municipal solid waste generated in Germany is presented by state in the following table (Table 6).

Treatment of the MSW is also presented by state in Table 7. Balance of MSW generation and treatment is calculated from the statistics excluding the waste that is potentially recycled. From the results it is clear that there is lack of treatment capacity for MSW. At the country level, the treatment capacity deficit is only 454 000 tons, but in some states like Baden-Württemberg and Bayern, there is a significant under capacity. This doesn't mean that there is a need for new treatment capacity to handle the whole amount, because the waste is already partly treated in the neighbouring states where there is overcapacity. As a conclusion, it is clear that there is not a significant potential to build high efficiency CHP power plants to handle MSW in Germany. Maximum capacity for new treatment plants is around 450 000 t annually assuming MSW volumes stay at present levels.

Table 6. MSW generation in Germany by state in 2006, 1 000 t.

1000 t / State	municipal and bulky waste	separately collected: organic wastes	separately collected: potentially recyclable waste	Total
Baden-Württemberg	1 584	1 232	1 752	**4 568**
Bayern	2 066	1 630	1 977	**5 673**
Berlin	944	119	414	**1 477**
Brandenburg	569	57	357	**983**
Bremen	166	57	86	**309**
Hamburg	613	36	168	**816**
Hessen	1 288	722	863	**2 874**
Mecklenburg-Vorpommern	392	74	248	**714**
Niedersachsen	1 589	1 146	1 235	**3 970**
Nordrhein-Westfalen	4 091	1 864	2 497	**8 453**
Rheinland-Pfalz	801	536	677	**2 013**
Saarland	258	135	133	**526**
Sachsen	662	208	557	**1 428**
Sachsen-Anhalt	536	202	325	**1 063**
Schleswig-Holstein	655	280	428	**1 362**
Thüringen	473	146	321	**941**
Germany total	**16 687**	**8 444**	**12 037**	**37 168**

Table 7. Treament and balanceof MSW in Germany by state in 2006 (*Balance = Total waste – Potentially recyclable waste – Total treatment).

1000 t / State	Waste incineration	Mechanical-Biological Treatment	Total treatment	Balance for non-recycled waste*
Baden-Württemberg	1350	639	**1 989**	**827**
Bayern	2876	16	**2 892**	**804**
Berlin	520	320	**840**	**223**
Brandenburg	80	939	**1 019**	**-393**
Bremen	783	75	**858**	**-635**
Hamburg	800		**800**	**-152**
Hessen	1112	419	**1 531**	**480**
Mecklenburg-Vorpommern	216	520	**736**	**-270**
Niedersachsen	1375	1123	**2 498**	**236**
Nordrhein-Westfalen	5215	925	**6 140**	**-184**
Rheinland-Pfalz	606	522	**1 128**	**208**
Saarland	360		**360**	**33**
Sachsen	225	785	**1 010**	**-139**
Sachsen-Anhalt	1475	65	**1 540**	**-802**
Schleswig-Holstein	626	320	**946**	**-12**
Thüringen	160	230	**390**	**229**
Germany total	**17779**	**6898**	**24 677**	**454**

The geographic distribution of waste incinerators and mechanical-biological treatment plants is presented in Figure 13.

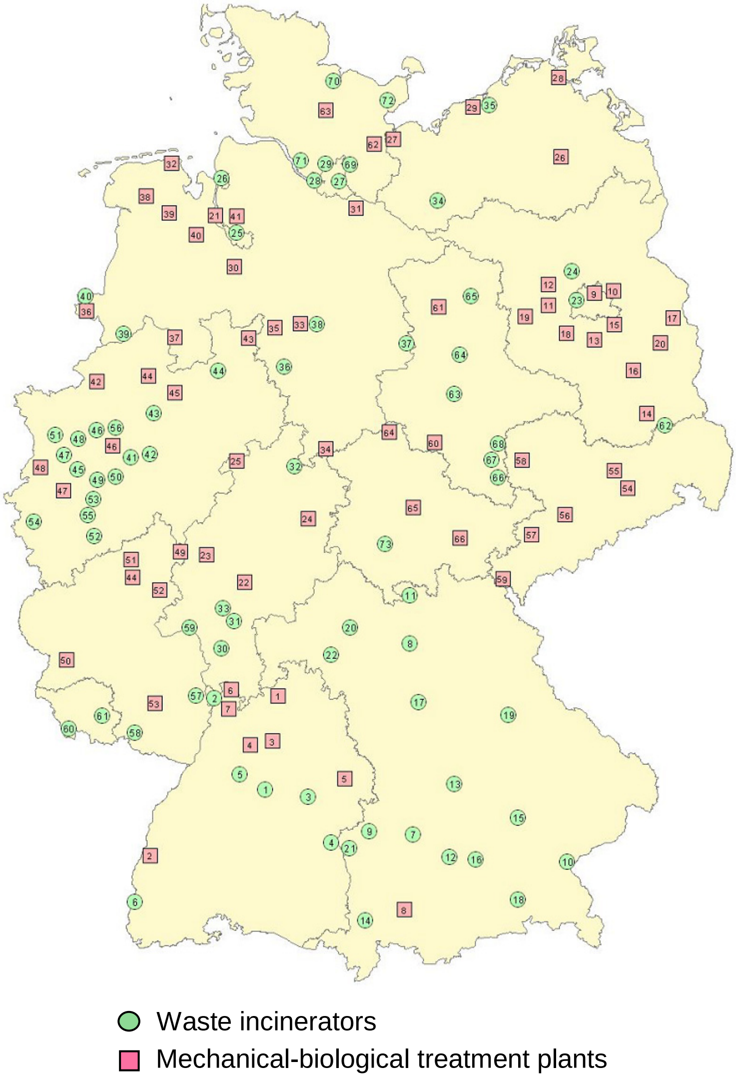

Figure 13. Geographical distribution of MSW incinerators and mechanical-biological treatment plants in Germany (Source: Umweltbundesamt 2008).

6.2 Solid recovered fuel

6.2.1 Amount, sources and quality

Currently there are 52 mechanical or mechanical-biological treatment plants in operation – these plants produce approximately 2.5 million tons of SRF annually. Additional 4.2 million tons of SRF is derived from treated commercial and light industrial waste which is not handled by the public waste management system (Schu 2007). However, the total amount of high calorific waste from the industry and commercial sector is expected to reach > 9 million tons.

SRF is typically a mix of paper, wood, and plastics. Its heating value varies between 11 and 18 MJ/kg. The lower limit is set to comply with the German legislative regulation for energetic utilisation of waste derived fuels.

The utilisation of SRF is depending on the one hand on its market price and on the other hand on its quality. The latter one is mainly depending on its inventory of unwanted ingredients like halogens and heavy metals. The most critical component in that respect is chlorine (Cl). Municipal solid waste has a Cl concentration of 0.5–1 wt-%, whereas the respective figure for SRF is typically in the order of 1 or even > 2 wt-%.

6.2.2 Co-combustion and SRF power plants

SRF is in most cases used together with other fuels. Main users of SRF for co-combustion are power plants, cement and lime kilns, paper and steel industry. An overview of the co-combustion practice in 2006 is compiled in Table 8.

Table 8. Co-combustion in various industry furnaces in 2006. Table 8. Co-combustion in various industry furnaces in 2006.

	SRF throughput in mill. T
Power plants	0.5
Cement kilns	2.0
Paper industry	1.4
Steel industry	0.1
Lime kilns	0.2
Total	**4.2**

The future of co-combustion is not clear due to the difficulties in quality control and the for that reason unstable market of SRF. An example illustrating this situation is the co-combustion in power plants. The high Cl content limits the utilisation of SRF due to the risk of Cl induced boiler corrosion. In 2006 co-combustion was practised in 8 hard coal and also in 8 lignite fired power plants. In 2007 only 6 hard coal and 2 lignite boilers continued co-combustion (Thiel 2007).

Table 9. Dedicated SRF plants in Germany (CFB: circulating fluidised bed).

Location	**Tech-nology**	**Capacity in t/a**	
		In oper.	**Planned**
Amsdorf	grate	60 000	
Andernach/ Rasselstein			100 000
Aßlar	grate	15 000	
Bremen-Blumenthal	grate	60 000	
Degussa			
Erfurt-Ost	grate		64 000
Frankfurt			500 000
Großräschen/ Freienhufen	grate		200 000
Hagenow			80 000
Hamburg (NA) (cancelled)	CFB		750 000
Heringen	grate		270 000
Hürth	grate		240 000
Meuselwitz-Licka	grate	50 000	
Minden Industriehafen	grate	35 000	
Neumünster	CFB	150 000	
Premnitz	CFB	100 000	
Premnitz	grate/ CFB		130 000
Rheinberg	grate		300 000
Rostock	grate		136 000
Rüdersdorf	grate		200 000
Rudolstadt-Schwarza	grate		14 000
Schwedt	CFB		200 000
Sottrum			150 000
Stavenhagen	grate		90 000
Witzenhausen			250 000
Sum		**470 000**	**3 674 000**

Cement kilns, too, cannot cope with high halogen levels in their fuel. They have a typical acceptance standard of < 1 wt-% Cl which may also limit the utilisation of SRF in this industry sector. The total capacity for co-combustion in the cement industry in Germany is assumed to be in the order of 2 million tons which means this potential sink for SRF is already more or less exhausted.

As an alternative, there are a number of dedicated combustion plants for heat and/or power in operation and a much higher number of such plants are being planned. An overview of the situation in 2006 is shown in Table 9. These plants are either using grate or circulating fluidised bed technology and are equipped with a flue-gas cleaning system which allows the compliance with the 17. BImSchV, the German regulation for air emissions from waste incineration plants.

In 2006, there were 7 SRF power plants in operation with a total capacity of 470 000 tons. The current situation is unclear. How many of the planned plants will be realised depends on the price development of SRF in view of a long-term stable market and on the guarantee which the suppliers can give concerning the SRF quality. The actual 2006 prices or other payments, which the producer has to pay to his customers if he takes the SRF, are listed in following table (Table 10).

Table 10. SRF extra payments for various utilisation scenarios.

	Payment in €/t
SRF power plant (CFB)	50–75
SRF power plant (grate)	60–100
Cement kiln	25–40
Hard coal fired power plant	35–60
Lignite fired power plant	35–60

It can also be assumed that some projects have a low likelihood of being materialised and are only published by companies to have a better position in the negotiations with the respective power supplier. An example of this is the Hamburg project issued by a big copper refinery and cancelled after a satisfying contract with the local energy supplier was reached. Hence it is probable that a great number of the listed projects will not be realised during the next years.

6.2.3 Conclusions

The situation in the German SRF market gives room for speculation that at least for the next 5–10 years there is a surplus of waste derived fuel which will find no customer. This is especially to be expected for high calorific waste fractions from the industry and trade sector.

7. Pulp and paper industry power boilers in Germany

There are 196 pulp and paper mills in Germany, with the total paper capacity of 24 million tons and pulp capacity of 8.5 million tons, which is mainly de-inked pulp (DIP) from recycled paper (5.1 million tons). The recent trend in new greenfield and rebuild projects has been the utilisation of waste fuels in CHP production. There are at least two big ongoing projects for large CHP power plants (>120 MWth) that will use waste derived fuels as the main fuel.

Pulp and paper production in Germany is centralised mainly to four states, namely Baden-Württemberg, Bayern, Niedersachsen and Nordhein-Westfalen. The production in these 4 states represents ¾ of the total pulp and paper production in Germany. Based on the pulp and paper capacities shown below (Figure 14), also Brandenburg is an interesting state because it produces annually 875 000 tonnes of de-inked pulp.

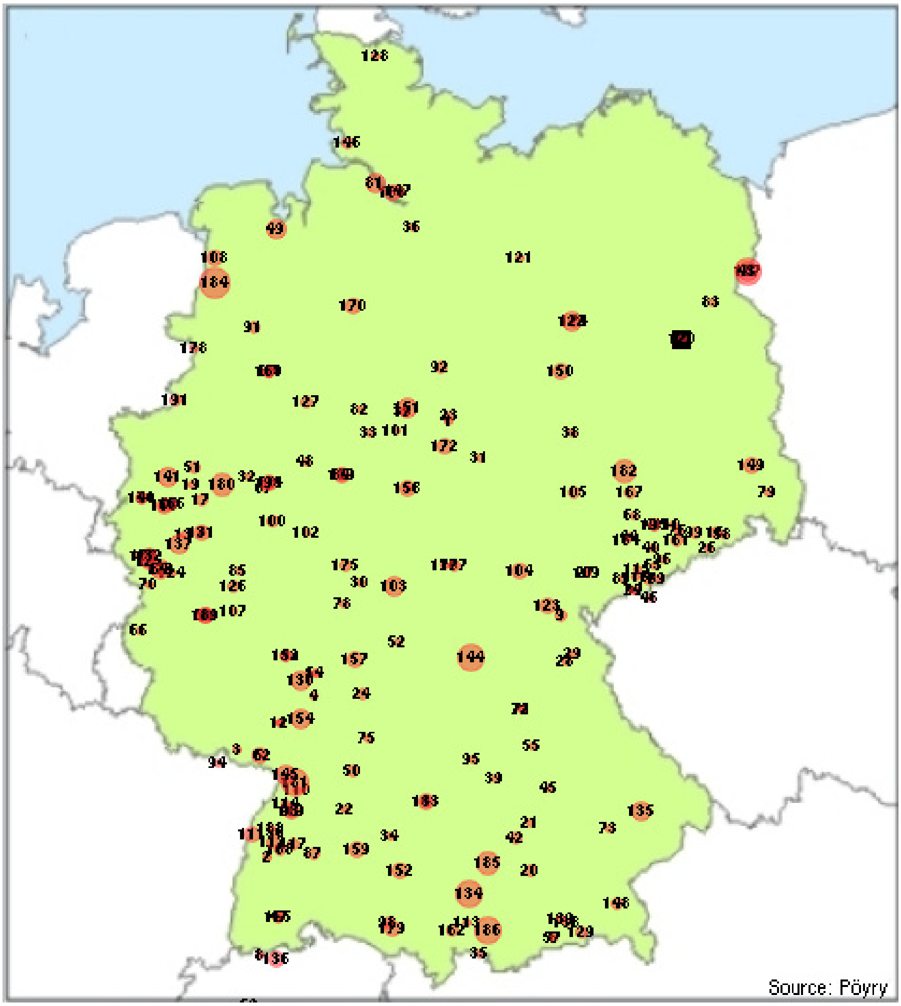

Figure 14. Pulp and paper mills in Germany – Geographical distribution (bullet size shows the capacity of the mill).

Table 11. Pulp and paper production capacities in Germany (situation in April 2008).

State	Total Paper Cap. (1000 t/a)	Total Pulp Cap. (1000 t/a)	Mech. pulp cap. (1000 t/a)	Chem. pulp cap. (1000 t/a)	DIP cap.(1000 t/a)
Baden-Württemberg	**4564**	1500	605	355	**540**
Bayern	**4774**	2760	645	170	**1945**
Berlin	25	0	0	0	0
Brandenburg	1570	875	0	0	**875**
Bremen					
Hamburg					
Hessen	968	0	0	0	0
Mecklenburg-Vorpommern	10	0	0	0	0
Niedersachsen	**4379**	115	0	115	0
Nordrhein-Westfalen	**4590**	1500	440	310	**750**
Rheinland-Pfalz	1039	219	20	4	195
Saarland					
Sachsen	1079	576	15	1	560
Sachsen-Anhalt	120	600	0	600	0
Schleswig-Holstein	585	270	0	0	270
Thüringen	567	40	0	0	40
Germany total	**24270**	**8455**	**1725**	**1555**	**5175**

Based on the Pöyry databanks, there are 25 solid fuel boilers in German pulp and paper industry (Table 12). Most of the boilers are over 20 years old (13 boilers) and thus majority of them will reach replacement age before the year 2020. Main states where the pulp and paper industry solid fuel boilers are located are Baden-Württemberg, Bayern and Nordhein-Westfalen. The average size of the boilers is rather small – only 42 MW. The small size compared to equivalent boilers in e.g. the Scandinavian mills is due to the historical use of natural gas as a main fuel and lower supply of forest and mill residues. Pulp and paper production in Scandinavia is mainly based on virgin fibre meaning there is a significant amount of surplus woody biomass. Pulp and paper production is in Germany mainly based on recycled fibre and imported market pulp, so there is not a large amount of woody biomass available for energy production. This is reflected in the fact that there were 23 gas boilers in 2005 that have capacity of over 40 MWth (Table 13). These boilers face cost pressures from the increasing natural gas prices and for this reason, the option to replace them with modern high efficiency solid fuel boilers is a viable option.

Table 12. Solid fuel boilers in German pulp and paper industry.

State	Solid fuel boilers			
	Thermal capacity , MW	Age		
		Over 20 years	10-20 years	Under 10 years
Baden-Württemberg	**383**	**5**	1	1
Bayern	**215**	**3**	1	1
Berlin	0			
Brandenburg	48	0	1	0
Bremen	0			
Hamburg	0			
Hessen	0			
Mecklenburg-Vorpommern	0			
Niedersachsen	71	0	1	0
Nordrhein-Westfalen	**114**	**3**	2	1
Rheinland-Pfalz	61	2	1	0
Saarland	0			
Sachsen	33	0	1	0
Sachsen-Anhalt	86	0	0	1
Schleswig-Holstein	0			
Thüringen	0			
Germany total	**1 011**	**13**	8	4

Table 13. Gas boilers larger than 40 MWth in Geman pulp and paper industry in 2005.

State	MW	Number of units
Baden-Württemberg	325	4
Bayern	503	5
Hessen	100	2
Mecklenburg-Vorpommern	190	3
Niedersachsen	318	5
Nordrhein-Westfalen	97	2
Rheinland-Pfalz	54	1
Sachsen	75	1
Germany Total	**1663**	**23**

8. Market potential of high efficiency CHP in Germany

Business potential of high efficiency CHP is calculated based on the amounts of generated waste, applied waste treatment methods and existing boilers in the German pulp and paper industry. In the country level analysis, certain replacement factors and lack of treatment capacity is also used as influencing parameters. The business potential is assumed to use only waste fuels or SRF as the main fuel so the co-combustion factor of 10–30 % of coal or other secondary fuel has to be excluded from the treatment capacities. The summary of the results and the calculation factors used are presented below (Table 14). The detailed analysis by state in Germany is presented in Tables 15–17.

Table 14. Summary of business potential of high efficiency CHP in Germany.

Type	Based on	Number of units	Thermal capacity, MW	Capacity of waste, t/a
New MSW boilers	Shortage of capacity at national level 450 000 t	2	208	450 000
New SRF boilers	50% of estimated new capacity	9	935	1 737 000
Replacement potential of P&P solid fuel boilers	50% of over 20 year old and 25% of 10-20 year old boilers	9	368	841 143
Replacement potential of gas fired boilers in P&P	50% of over 40 MW gas boilers	11	831	1 899 429
Replacement potential of gas turbines in P&P	50% of over 10 MW_e gas turbines	5	338	772 571
Total		**36**	**2 680**	**5 700 143**

These results can be summed up in a graph were the uncertainty of the investment potential increases when moving from the left to right. The potential is also presented using lower potentiality factors to show the "pipe" inside which the potential is assumed to vary. This graph is presented below (Figure 15).

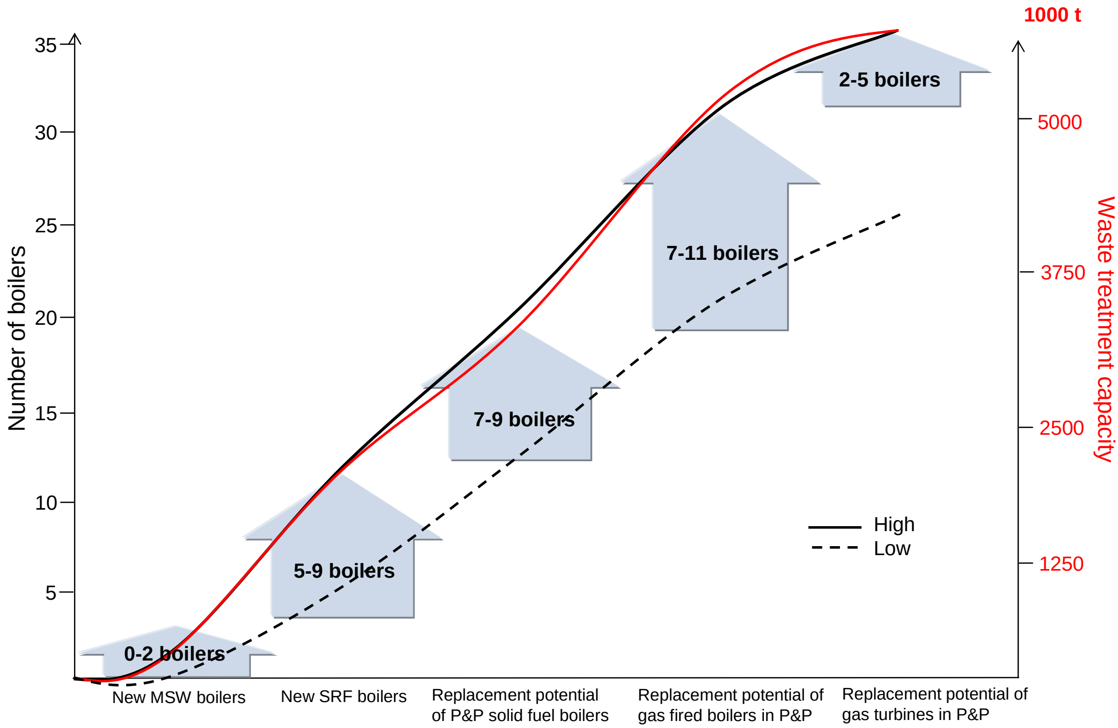

Figure 15. Business potential breakdown by type.

Based on the analysis made, the business potential of high efficiency CHP is 25–36 units in Germany by 2020 and resulting in additional waste treatment capa-city of 4–6 million tons annually. The potential is the highest in gas boiler replacement, 7–11 units. The potential is lowest in new MSW boilers and in gas turbine replacement investments. The potential can be divided according to replacement class, sector and state. The results are presented in the following tables.

Table 15. Business potential of high efficiency CHP in Geman public waste management sector.

State	Public and private waste sector					
	MSW			SRF		
	Number of units	Capacity, MW	Capacity, tonnes	Number of units	Capacity, MW	Capacity, tonnes
Baden-Württemberg	1	104	225000			
Bayern	1	104	225000			
Berlin						
Brandenburg				1	143	265000
Bremen						
Hamburg				1	202	375000
Hessen				2	275	510000
Mecklenburg-Vorpommern				1	82	153000
Niedersachsen				1	40	75000
Nordrhein-Westfalen				1	145	270000
Rheinland-Pfalz				1	27	50000
Saarland						
Sachsen						
Sachsen-Anhalt						
Schleswig-Holstein						
Thüringen				1	21	39000
Germany total	**2**	**208**	**450000**	**9**	**935**	**1 737 000**

Table 16. Business potential of high efficiency CHP in pulp and paper sector in Germany.

State	Pulp & Paper industry								
	Solid fuel boilers			Gas boilers			Gas turbines		
	Number of units	Capacity, MW	Capacity, tonnes	Number of units	Capacity, MW	Capacity, tonnes	Number of units	Capacity, MW	Capacity, tonnes
Baden-Württemberg	3	163	371 429	2	163	371 429	1	39	89 143
Bayern	2	93	213 333	2	252	574 857	1	101	230 857
Berlin									
Brandenburg		12	27 619						
Bremen									
Hamburg									
Hessen				1	50	114 286			
Mecklenburg-Vorpommern				1	95	217 143			
Niedersachsen		18	40 476	2	159	363 429			
Nordrhein-Westfalen	2	48	108 571	1	49	110 857	1	124	283 429
Rheinland-Pfalz	1	27	60 952	1	27	61 714	1	21	48 000
Saarland									
Sachsen		8	19 048	1	38	85 714	1	52	118 857
Sachsen-Anhalt									
Schleswig-Holstein									
Thüringen									
Germany total	**8**	**368**	**841 429**	**11**	**831**	**1 899 429**	**5**	**337**	**770 286**

The business potential varies greatly between states: Five states have no potential while in 5 states the potential is over 4 units. The geographical division of the business potential can be seen in Table 17 and is visualised by a dynamic model presented in Figure 16.

Table 17. Summary of business potential in Germany by state.

State	Total potential		
	Number of units	**Capacity, MW**	**Capacity, tonnes**
Baden-Württemberg	7	468	1 057 000
Bayern	6	550	1 244 048
Berlin	0	0	0
Brandenburg	1	155	292 619
Bremen	0	0	0
Hamburg	1	202	375 000
Hessen	3	325	624 286
Mecklenburg-Vorpommern	2	177	370 143
Niedersachsen	3	217	478 905
Nordrhein-Westfalen	5	365	772 857
Rheinland-Pfalz	4	102	220 667
Saarland	0	0	0
Sachsen	2	98	223 619
Sachsen-Anhalt	0	0	0
Schleswig-Holstein	0	0	0
Thüringen	1	21	39 000
Germany total	**36**	**2 679**	**5 698 000**

In this study also a dynamic presentation of the results by state was made to visualise the business potential (Figure 17). The colours indicate the amount of units potential for high efficiency CHP by state in a way that green means high potential and red no potential. The Figure also shows the state potential with a figure by boiler capacity, Waste demand (waste capacity) and current waste (MSW) balance.

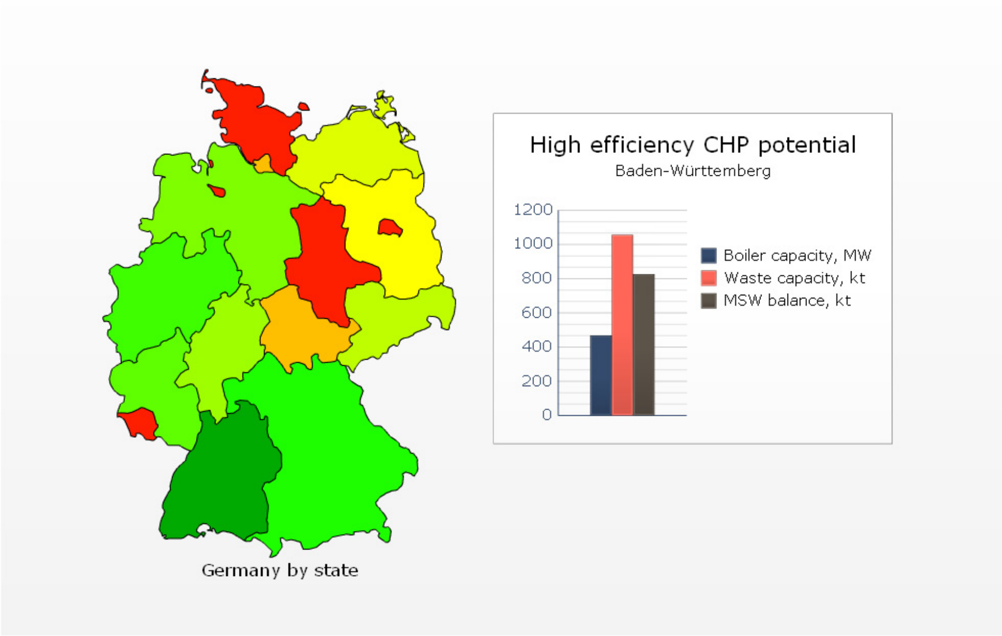

Figure 16. Dynamic presentation of high efficiency CHP in Germany by state.

9. Business potential by state – Case Baden-Württemberg

9.1 Structural data

Baden-Wuerttemberg (BW) is the South-Western federal state characterised by highly industrialised regions with world-leading key industries (e.g. car manufacturers and related companies, electronics and IT) and a number of outstanding public and private research institutes. On the other hand there are also large forested/agricultural areas. The population in 2006 was approximately 10.8 million of which some 4.6 million lived in bigger cities and densely populated counties. These are marked as brown or dark yellow in the map in Figure 17.

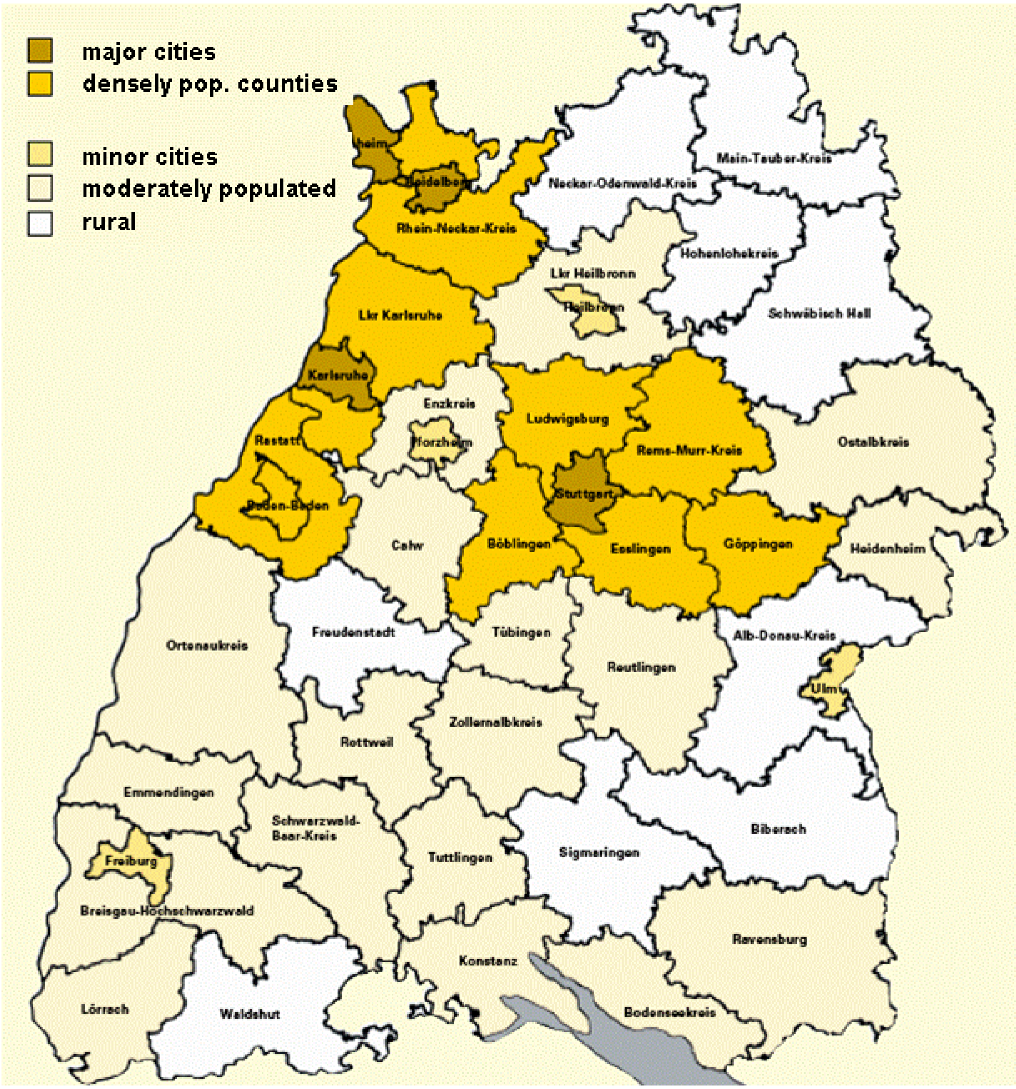

Figure 17. Population distribution in BW.

9.2 Waste generation

The long-term development in waste generation and shares of different waste components is depicted for household and commercial waste in Figure 18 (Umweltministerium Baden-Württemberg 2007).

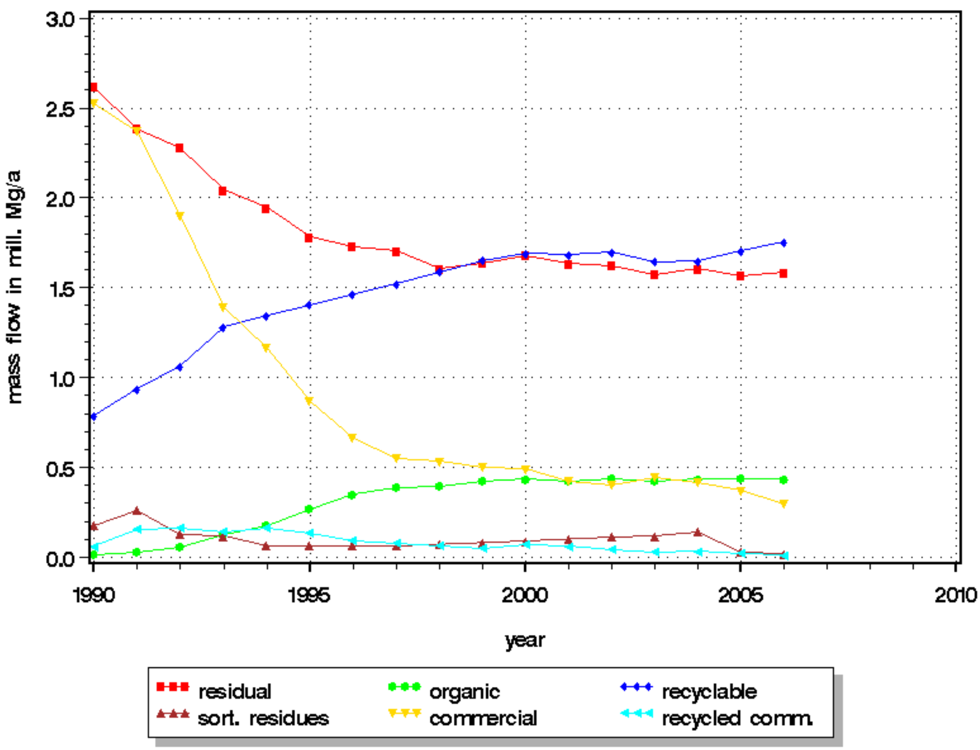

Figure 18. Generation of various fractions of household and commercial waste in Baden-Württemberg.

From the chart, it can be seen that the separate collection of recyclable, organic, and residual household waste improved significantly during the 1990's and that the volumes of these fractions has stayed almost constant since 2000. The data for the years 2000 to 2006 are compiled in Table 18.

Table 18. Generation of separately collected household waste fractions, sorting residues, commercial waste, and recycled fractions in 2006 (data in 1 000 tons; CDW: construction and demolition waste).

Year	2000	2001	2002	2003	2004	2005	2006
Residual household waste & bulky waste	1 678	1 633	1 625	1 575	1 606	1 568	1 584
Organic household waste	434	422	437	422	435	436	434
Recyclable household waste	1 689	1 682	1 696	1 643	1 648	1 705	1 753
Sorting residues	90	101	112	118	140	29	18
Commercial waste & CDW	492	423	401	447	418	372	298
Recycled commercial waste	70	61	43	29	33	24	11

Annually collected residual waste per capita was in 2006 approximately 147 kg/a, which is one of the lowest figures in Germany. The respective amount of organic waste was approximately 40 kg. The share of paper in the 163 kg of recyclable household waste collected per capita annually was 53 %.

The surprising fact that can be seen in the table above is the rapidly decreasing generation of commercial waste between 1990 and 1997 and the very low amount of recycled commercial waste. The most likely explanation to this development is landfilling of this waste type, which is not automatically handed over to the public waste management system, on cheap landfills in the new eastern federal states after the re-unification of Germany.

The decrease in commercial waste volumes in 2005 and 2006 is explained by the landfill ban issued for the untreated waste in 2005 by the BW Minister of Environment. The commercial waste has since the adoption of the ban been taken care of by the private sector.

9.3 Production of SRF

BW operated in 2006 three MBT and three MT (mechanical treatment) plants with a total capacity of 640 000 tons. These plants produced 51 000 tons of SRF. Another 43 000 tons came from sorting plants located in 9 counties. Marketing of SRF was extremely difficult. Meanwhile two big MBT plants with a capacity of 240 000 tons have been shut down for operational and commercial problems. Whether the MBT capacity of these plants will be replaced, has not yet been decided.

9.4 Waste management

9.4.1 Management routes

The waste management routes in BW are seen in Table 19. According to the statistics, the share of household (including bulky waste) and commercial waste (including CDW) is in the order of 75 %. Mechanical-biological treatment is not a viable option to handle these types of wastes.

Table 19. Management routes of various waste fractions in 1 000 tons.

	Total	Recycling	Biological treatment	Other utilisation	MBT	Thermal treatment	Disposal
Residual household waste	1340.2	1.5	-	0.2	272.3	1075.2	-
Bulky waste	234.8	106.2	-	1.0	12.1	116.4	-
Yard and garden waste	798.7	2.7	734.0	0.4	-	61.6	-
Organic household waste	433.7	0.6	430.4	-	-	2.7	-
Recyclables	1785.1	1687.9	-	-	-	97.2	-
Commercial waste	259.4	25.9	-	-	20.3	205.7	7.4
CDW	38.6	3.6	-	-	0.2	12.2	22.6

9.4.2 Waste Incineration

BW operated six waste incineration plants in 2006 with a total capacity of 1.05 million tons. The plants and their 2006 capacities are listed in Table 20.

Table 20. Waste incineration plants in BW in 2006 (capacity in 1 000 t).

	Capacity
Eschbach	150
Böblingen	140
Göppingen	140
Mannheim	317
Stuttgart	195
Ulm	112
Total	1 054

Furthermore, there were contracts with waste incinerators operating in other federal states and in Zurich, Switzerland. The total combustion capacity was according to the reported information almost 2 million tons. Meanwhile the Mannheim plant capacity has been raised by 70 000 tons/a and the capacity of the Stuttgart plant by 170 000 tons/a. However, there is still a lack of capacity for treatment of residual waste and even more so for treatment of SRF. Plans for new waste incineration plants, dedicated SRF and mixed waste/SRF combustion plants were not realised, partly due to public opposition. The long design and building times of these type of plants are the main reasons that there will still be a 300 000–500 000 ton deficit in combustion capacity which has to be compensated somehow, e.g. by external contracts.

9.5 Conclusions from the state level analysis

Potential in Baden-Württemberg was 7 units with total capacity of 1.1 million tons of SRF, see Table 16. Out of these, 6 are in the pulp and paper industry and 1 in public MSW treatment. Based on the local information, in the long term there is a lack of incineration capacity of around 0.3–0.5 million tons – this waste volume could be utilised by the pulp and paper industry. It is likely, that the local opposition of new incineration units and the economical difficulties of SRF producers can have a negative impact on the possibilities to utilise the potential in near future. These factors affect the main analysis result so that it is estimated that perhaps only half of the main potential could be utilised in new high efficiency CHP plants by 2020.

10. European potential of high efficiency CHP in pulp and paper industry

10.1 Availability of waste based fuels in the EU

According to Eurostat statistics the total amount on MSW in the EU 27 accounted in 2006 to approx. 255 000 000 t. 19 % or 48 000 000 t were incinerated and 41 % or 105 000 000 t were directly landfilled. The potentially available fuel is for the time being all waste which is not recycled and either incinerated or going to landfills. This would result in a potential of roughly 150 000 000 t of waste with a net calorific value in the order of 10 MJ/kg. However, the recycling rate will increase from the actual 40 % to expected 50–55 % which leaves an amount of residual MSW for energy recovery of some 115–125 000 000 t.

Residual MSW can be burnt in a waste incineration plant and the released energy can be used in form of process steam, as power, of for district heating. These plants are typically grate fired incinerators with relatively low power efficiencies. However, there are attempts to increase the overall efficiency of such plants.

Fuel for high efficiency CHP plants will be solid recovered fuels (SRF). The problems associated with production and utilisation of SRF has already been discussed earlier (see chapter 6.2).

In a number of countries there is tendency to extend the production of SRF. Mechanical treatment (MT), mechanical-biological treatment (MBT), or mechanical-biological stabilisation (MBS) are used for SRF product. From German experience it can be estimated that approximately 20–30 % of the incoming MSW end up as low polluted and high calorific SRF, about the same amount can be classified as lower quality SRF.

Waste wood from construction and demolition waste and especially waste from commerce and industry are preferred sources for SRF production. For the latter there are only fragmented data to be found since these types of waste is typically not under the regime of the public waste management authorities and does not show up in official statistics.

The production of SRF in the EU in 2005 is shown in Figure 19. The data are adopted from ERFO, the European Recovered Fuel Organisation.

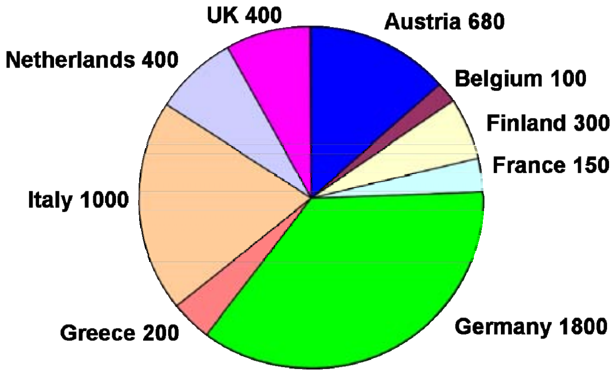

Figure 19. Production of SRF in the EU in 2005 in 1 000 t.

It can be expected that the production of SRF can be significantly increased if other fractions like waste wood are included – and if a stable market can be established. There is e.g. an annual amount of approx. 10 000 t of waste wood in the UK which is almost totally landfilled.

The main customers for SRF are shown in Figure 20 based again on data published by ERFO. The data are rather fragmented and it is evident that the figures of produced SRF (see Figure 20, approximately 5 000 000 t) and of consumed material (4 400 000 t) do not fit. This is caused by the above mentioned problems with quality and economy in the SRF market.

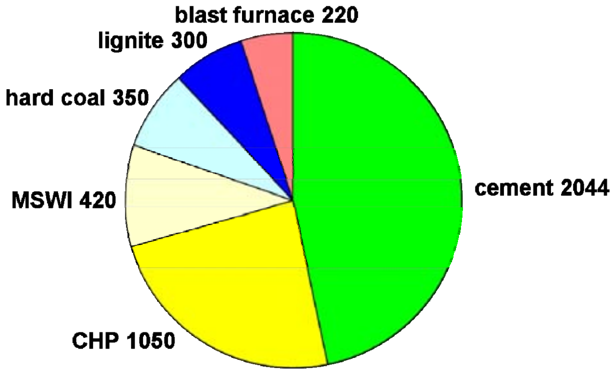

Figure 20. SRF consumption in the EU in 2005 in 1 000 t.

The main consumer is the cement industry which can cope with approximately 1 % of chlorine in the material and has not too big problems with alkali and heavy metals except chromium and mercury. Coal fired power plants are more reluctant due to the risk of boiler corrosion caused by high chlorine inventory and ash quality changes in case of too high heavy metal content. Nevertheless, there will be a future for SRF as long as it is produced from well defined waste fractions. Further technology development might be helpful if the economy is acceptable.

10.2 Replacement potential of high efficiency CHP in European pulp and paper industry

Pulp and paper industry has a large number of solid fuel boilers in Europe that reach their technical age by 2020 and need to be replaced. In these harsh times for pulp and paper industry the replacement of old boilers is the main potential for new CHP boilers because number of new pulp and paper mill investments is very limited in the near future.

There are 37 solid fuel boilers that are larger than 30 MWth in European pulp and paper industry that have age between 15–25 years and 89 boilers over 25 years. The market potential in this study has an assumption that 25 % of the 15–25 years old and 50 % of over 25 years old boiler have a potential to be replaced with new advanced high efficiency CHP boiler that uses SRF as a main fuel. These assumptions have a result that there are 54 potential boilers that could be replaced by high efficiency CHP unit and the average size of these units is 64 MWth, Table 21.

Table 21. Replacement potential of solid fuel boilers in European pulp and paperindustry by 2020 (only boilers larger than 30 MW).

Country	**Number of plants**	**Total capacity, MW**	**Average capacity, MW**	**SRF demand, 1 000 t/a**
Austria	2	140	70	319
Belgium	1	53	71	121
Bosnia-Herzegovina	1	21	42	48
Czech Republic	4	75	18	172
Finland	10	1 001	105	2 287
France	4	154	44	353
Germany	*8*	*384*	*51*	879
Hungary	1	21	42	48
Italy	0	0	0	0
Netherlands	0	0	0	0
Norway	1	48	38	110
Poland	2	125	63	286
Portugal	2	114	76	259
Romania	2	58	39	133
Serbia	0	0	0	0
Slovakia	2	68	39	154
Slovenia	1	27	53	61
Spain	2	111	49	253
Sweden	13	962	74	2 199
Switzerland	1	31	63	71
United Kingdom	1	29	39	67
Total Europe	**54**	**3 421**	**64**	**7 820**
Germany detailed analysis	***36***	***2 679***	***75***	***6 124***

The results show that the pulp and paper industry could be a major user of SRF by 2020 with treatment capacity of 8–13 million tonnes. This would require 54–82 new CHP investments by 2020 replacing old solid fuel boilers. The results have lower and higher values depending whether the detailed potential described in chapter 8 for Germany is used or not. The highest potential in this analysis was found in Germany, Finland and Sweden where there is a high number of solid fuel boilers. The lowest potential or no potential was found in countries like Italy, the Netherlands and UK where the energy production at the pulp and paper mills has traditionally been based on natural gas and fuel oil because the main raw material is recycled paper. The replacement potential in terms of investment is in the order of 4.7 to 7.5 billion euros by 2020 when reference investment cost of 100 million euros for 80 MW unit is used together with estimation formula of relative size of investment is in power to 0.6. [Formula = (size of boiler/80 MW)^0.6*100 MEUR.]

11. Market potential of waste based ethanol production in European pulp and paper industry

Finnish companies UPM-Kymmene and Lassila & Tikanoja have developed together with VTT and Pöyry a new innovative FibreEtOH-concept to produce ethanol from commercial and industrial waste. It is integrated production of ethanol together with biogas, heat and electricity production that has very low production costs compared to other 2nd generation ethanol concepts that use lignocellulosic raw materials. In this market potential study it was assumed that this concept could provide new business opportunities for European pulp and paper industry together with high efficiency CHP boilers. The FireEtOH-concept has also a high efficiency CHP boiler for waste fuels integrated to the ethanol production and the effect of additional ethanol production to the waste CHP in terms of increased waste demand and revenues was studied with same assumptions than the main market potential for Europe by 2020.

The market potential analysis for integrated ethanol production was based on the European high efficiency CHP potential analysis where the replacement potential of solid fuel boilers in European pulp and paper production were analysed. The integration of ethanol production increases the waste demand by 44 % compared to just CHP production when the heat load is kept constant. The FibreEtOH-concept is presented in Figure 21.

The basic design data for the FibreEtOH-concept used in this study were

- waste demand (CIW) 250 000 t/a
- ethanol production 20 000 m3/a
- biogas production 15 MW.

With these assumptions a business potential analysis was made to find out what is the potential role of waste based ethanol in European pulp and paper industry. The results are in Table 22.

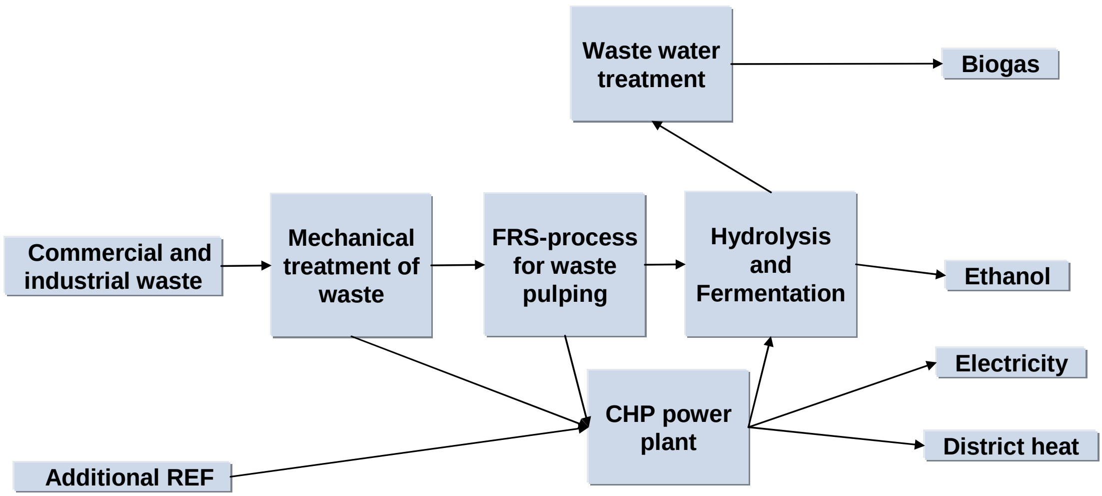

Figure 21. FibreEtOH concept principles.

Table 22. Business potential of FibreEtOH-concept in European pulp and paper industry by 2020.

Country	**Number of plants**	**Ethanol potential, 1 000 m3/a**	**Biogas potential, GWh**	**CIW demand with ethanol, 1 000 t/a**
Austria	2	32	192	460
Belgium	1	12	73	175
Bosnia-Herzegovina	1	5	29	69
Czech Republic	4	17	103	248
Finland	10	229	1 372	3 294
France	4	35	212	508
Germany	*8*	88	527	1265
Hungary	1	5	29	69
Italy	0	0	0	0
Netherlands	0	0	0	0
Norway	1	11	66	158
Poland	2	29	171	411
Portugal	2	26	156	374
Romania	2	13	80	192
Serbia	0	0	0	0
Slovakia	2	15	93	222
Slovenia	1	6	37	88
Spain	2	25	152	365
Sweden	13	220	1 319	3 166
Switzerland	1	7	43	103
United Kingdom	1	7	40	96
Total Europe	**54**	**782**	**4 692**	**11 261**
Germany detailed analysis	***36***	***612***	***3 675***	***8 819***

The business potential of integrated FibreEtOH-concepts to new high efficiency CHP boilers is 780 000–1 300 000 m^3 of ethanol per year which equals to turnover of 400–650 million euros per year using a moderate ethanol price of 0.5 EUR/litre. If the biogas value is included the turnover increases to 700–1 100 million euros per year. This is already a significant addition to the pulp and paper industry’s revenues. The investment potential for the ethanol production units on top of the CHP boilers is 2.5–4 billion euros by 2020.

12. Summary and conclusions

The pulp and paper industry provides an excellent platform for advanced waste treatment opportunities due to its high heat demand and need for alternative fuel sources for CHP production. Based on this market potential analysis, some 54–82 new CHP investments are needed by 2020 to replace old solid fuel boilers in European pulp and paper industry. These new units would require 8–13 million tons of waste derived fuels. The value of the required investments amounts to 4.7 to 7.5 billion euros by 2020. Because of the latest European directives and national action plans, it seems that there will be an intensive competition on the wood based solid fuels such as forest residues. This can support the growing use of SRF in pulp and paper industry's new boiler investments due to increasing price pressures for wood fuels. Additional paper fibre can be used for material recovery and especially in packaging products.

Based on this study also waste based ethanol production in integrated units in pulp and paper industry seems to have a significant market potential. With 54–82 units mentioned above, the integrated ethanol production could be as high as 780 000–1 130 000 m^3 annually. Ethanol production increases the demand for SRF by 44% which results in SRF demand of 12–19 million tons annually. The value of the investments in integrated ethanol production units is 2.5–4 billion euros on top of the CHP unit investments.

This study also shows that there are also a lot of local aspects (e.g. local waste availability, mill specific integration issues, etc.) that have an effect on the market potential. This study already has different accuracies for European, German and Baden-Württemberg state level analysis but the main message that the pulp and paper industry offers a significant investment potential for waste based CHP and ethanol plants, can be concluded in all levels.

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Author(s)
Esa Sipilä, Jürgen Vehlow, Pasi Vainikka, Carl Wilen & Kai Sipilä

Title

Market potential of high efficiency CHP and waste based ethanol in European pulp and paper industry

Abstract

The objective of this study is to analyse the market potential of new high efficiency CHP concept developed by VTT in German and European pulp and paper industry. The basic idea behind the new CHP concept is to co-combust SRF and other waste fuels together with paper mill sludge and coal to reach high steam values and high efficiencies.

Because of the latest European directives and national action plans, it seems that there will be an intensive competition on the wood based solid fuels such as forest residues. This can support the growing use of SRF in pulp and paper industry's new boiler investments due to increasing price pressures for wood fuels.

Based on this market potential analysis, some 54–82 new CHP investments are needed by 2020 to replace old solid fuel boilers in European pulp and paper industry. These new units would require 8–13 million tons of waste derived fuels.

Based on this study also waste based ethanol production in integrated units in pulp and paper industry seems to have a significant market potential.

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• • • VTT RESEARCH NOTES 2500 MARKET POTENTIAL OF HIGH EFFICIENCY CHP AND WASTE BASED ETHANOL...

Bioenergy NoE

The study carried out within the Bioenergy Network of Excellence analyses the market potential of high effiency co-combustion of waste derived fuels in the European pulp and paper industry.

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