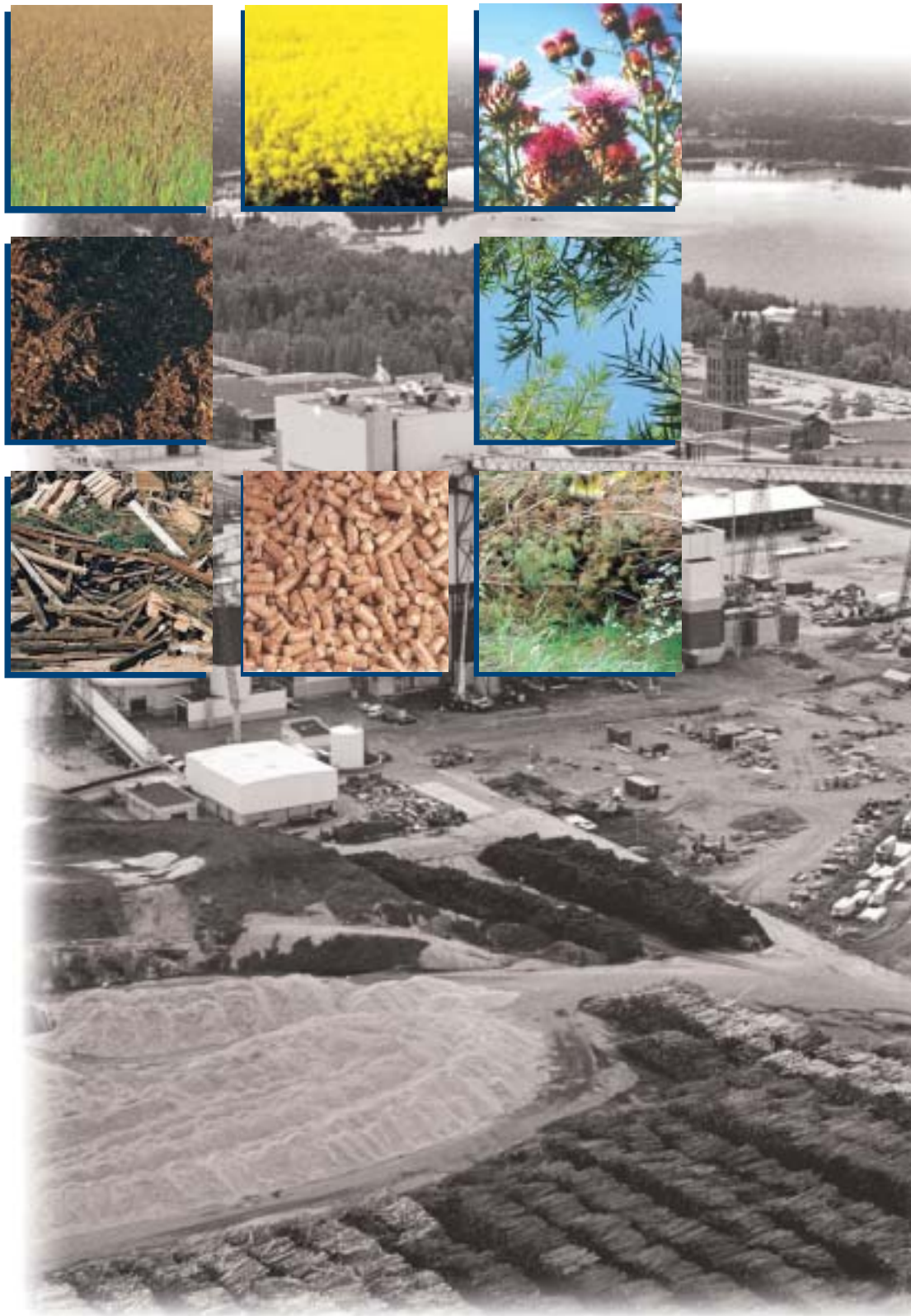


# BIOMASS CO-FIRING

- AN EFFICIENT WAY TO REDUCE GREENHOUSE GAS EMISSIONS



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## CO-FIRING PROMOTES THE USE OF BIOMASS

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The main reasons for the growing international interest in utilising renewable fuels are the objectives of promoting the use of renewable fuels in line with the statements in the European Commission's White Paper and of meeting emission limits and targets set by the EU directives. Emission allowance trading may also pose new challenges to power producers in the future. It can already be stated with great confidence that power producers will have to cope with an increasing number of EU-level regulations concerning emission levels in general, and especially greenhouse gas emissions. Usually these regulatory actions aim at favouring the use of biomass.

On one hand co-firing, which is defined as simultaneous combustion of different fuels in the same boiler, provides one alternative to achieve emission reductions. This is not only accomplished by replacing fossil fuel with biomass, but also as a result of the interaction of fuel reactants of different origin, e.g. biomass and coal. On the other hand, utilisation of solid biofuels and wastes sets new demands for boiler process control and boiler design, as well as for combustion technologies, fuel blend control and fuel handling systems.



*Spanish thistle artichoke plantation in central Greece. CRES.*

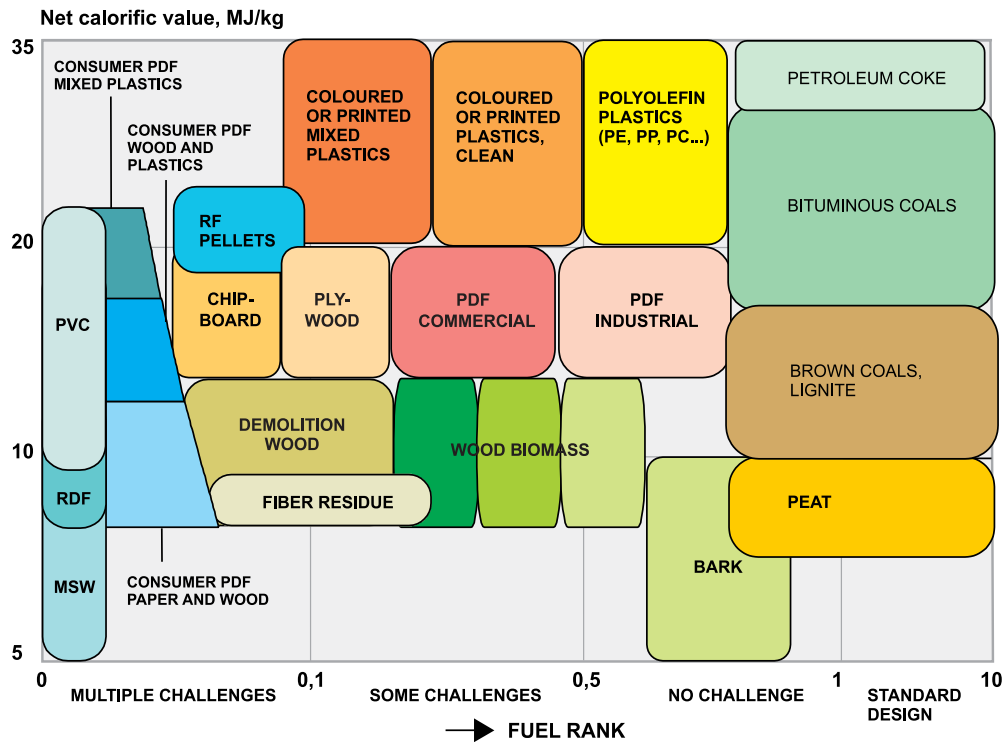


*Rape seed do not only contribute to enhance the environmental situation, but also benefit the sectors of agriculture and energy. Ademe*

# IMPORTANT TO STUDY BIOMASS FUEL CHARACTERISTICS

The characteristics of biomass are very different from those of coal. The content of volatile matter in wood-based biomass is generally close to 80%, whereas in coal it is around 30%. Wood char is highly reactive, which results in complete combustion of wood fuels in fluidised bed combustion. Nitrogen and sulphur contents of wood are low. This

implies that blending wood biomass with coal lowers emissions simply because of dilution. Further, one important difference between coal and biomass is the net calorific value. Biomass fuels often have high moisture content which results in relatively low net calorific value.



Influence of fuel characterisation to boiler design. Courtesy of Foster Wheeler and VTT Processes.

| TYPICAL PROPERTIES OF SOLID FUELS |          |           |                   |           |  |           |           |                                      |                |
|-----------------------------------|----------|-----------|-------------------|-----------|--|-----------|-----------|--------------------------------------|----------------|
| Property                          | Coal     | Peat      | Wood without bark | Bark      | Forest residues (coniferous tree with needles) | Willow    | Straw     | Reed canary grass (spring harvested) | Olive residues |
| Ash content (d)                   | 8.5-10.9 | 4-7       | 0.4-0.5           | 2-3       | 1-3  | 1.1-4.0   | 5         | 6.2-7.5                              | 2-7            |
| Moisture content, w-%             | 6-10     | 40-55     | 5-60              | 45-65     | 50-60  | 50-60     | 17-25     | 15-20                                | 60-70          |
| Net calorific value, MJ/kg        | 26-28.3  | 20.9-21.3 | 18.5-20           | 18.5-23   | 18.5-20  | 18.4-19.2 | 17.4      | 17.1-17.5                            | 17.5-19        |
| C, % (d)                          | 76-87    | 52-56     | 48-52             | 48-52     | 48-52  | 47-51     | 45-47     | 45.5-46.1                            | 48-50          |
| H, % (d)                          | 3.5-5    | 5-6.5     | 6.2-6.4           | 5.7-6.8   | 6-6.2  | 5.8-6.7   | 5.8-6.0   | 5.7-5.8                              | 5.5-6.5        |
| N, % (d)                          | 0.8-1.5  | 1-3       | 0.1-0.5           | 0.3-0.8   | 0.3-0.5  | 0.2-0.8   | 0.4-0.6   | 0.65-1.04                            | 0.5-1.5        |
| O, % (d)                          | 2.8-11.3 | 30-40     | 38-42             | 24.3-40.2 | 40-44  | 40-46     | 40-46     | 44                                   | 34             |
| S, % (d)                          | 0.5-3.1  | <0.05-0.3 | <0.05             | <0.05     | <0.05  | 0.02-0.10 | 0.05-0.2  | 0.08-0.13                            | 0.07-0.17      |
| Cl, % (d)                         | <0.1     | 0.02-0.06 | 0.01-0.03         | 0.01-0.03 | 0.01-0.04                                      | 0.01-0.05 | 0.14-0.97 | 0.09                                 | 0.1*           |
| K, % (d)                          | 0.003    | 0.8-5.8   | 0.02-0.05         | 0.1-0.4   | 0.1-0.4  | 0.2-0.5   | 0.69-1.3  | 0.3-0.5                              | 30*            |
| Ca, % (d)                         | 4-12     | 0.05-0.1  | 0.1-1.5           | 0.02-0.08 | 0.2-0.9  | 0.2-0.7   | 0.1-0.6   | 9                                    |                |

d=dry basis  
\*= in ash

CEN-335 – Solid biofuels, Fuel specifications and classes. March 2003.

## VARIETY OF WOOD FUELS AVAILABLE FOR CO-COMBUSTION

Wood fuel resources available for co-combustion are diverse: sawdust, cutter chips, demolition wood, recycled wood, bark, logging residue chips, or even more refined biofuels, such as pellets. Fluidised bed and grate boilers can use any type of wood fuels, whereas pulverised fuel boilers are more selective.

Co-firing of wood and coal has been demonstrated in several pulverised fuel plants in Europe and the United States. The results have been promising - boiler efficiencies have not suffered considerably. However, the maximum share of wood in the fuel blend has been small, only about 5-10%.

The properties of wood biomass set demanding requirements for power plant operation. These properties include total ash content, ash melting behaviour and the chemical composition of ash. Alkaline metals that are usually responsible for fouling of heat transfer surfaces are abundant in wood fuel ashes and will be easily released in the gas phase during combustion. In biomass fuels, these inorganic compounds are in the form of salts or bound in the organic matter, but in peat, for example, inorganic matter is bound mostly in silicates, which are more stable at elevated temperature. The elemental composition of ash (alkali metals, phosphorous, chlorine, silicon and calcium), as well as the chemical concentration of the compounds affect ash melting behaviour.

During combustion the behaviour of biomass fuel is influenced by the presence of other fuels. Even a small concentration of chlorine in the fuel can result in the formation of harmful alkaline and chlorine compounds on boiler heat transfer surfaces. This can be prevented by co-firing fuels such as containing sulphur and aluminium silicate peat or coal with chlorine bearing fuels.

Residues from the wood processing industry form one specific group of risky wood fuels. By-products, such as plywood and particle board cuttings are attractive fuels for energy producers: the fuel price may be even negative, as this material should otherwise be taken to a landfill site. But glue, coating and shielding materials may cause bed agglomeration, slagging, fouling and unexpectedly high flue gas emissions.

*Wood fuel resources from top: wood pellets, sawdust, willow and logging residues.*  
*Vapo Oy, Agrobränsle and TTS-Institute.*



# COFIRING OF WOODY BIOMASS IN A GIANT-SCALE BIOFUELLED PLANT

The Alholmens Kraft CHP plant in Pietarsaari with 20,000 inhabitants on the western coast of Finland is a unique illustration of the possibilities of biofuel-based energy production. The plant produces steam for the adjacent paper mill and for a utility generating electricity and heat. A UPM-Kymmene Pulp and Paper Mill nearby supplies the power plant with wood and bark residues. The mill produces almost 600,000 tons of pulp, 159,000 tons of paper and 95,000 tons of packaging materials.

The innovative forest fuel procurement system is based on bundling logging residues from regeneration areas. Since the plant is of giant scale, special attention has been paid to the logistics of fuel procurement. The goal is to use at least 200,000 solid m<sup>3</sup> (1,440 TJ) of logging residues annually. These are hauled to the plant as loose material or, more frequently, in bundles, and then crushed at the plant.

The fuel range of the plant is extremely diverse. The design of the plant allows great fuel flexibility – a fact that makes it feasible almost anywhere in the world. The heavy fuel oil and coal are only reserve fuels for exceptional cases, like problems with fuel handling.

The Alholmens Kraft plant is the largest biofuelled power plant in the world.

## Technical data

|                               |                      |
|-------------------------------|----------------------|
| Owner                         | Alholmens Kraft Ltd  |
| Commissioned                  | 2001                 |
| Investment cost               | EUR 170 million      |
| Electricity output            | 240 MW <sub>e</sub>  |
| Process steam output          | 100 MW <sub>th</sub> |
| District heat output          | 60 MW <sub>th</sub>  |
| Annual electricity production | 1,300 GWh            |
| Annual heat production        | 2,520 TJ             |

## Fuel data

|                                     |           |
|-------------------------------------|-----------|
| Annual fuel consumption             | 12,600 TJ |
| - Industrial wood and bark residues | 35%       |
| - Forest residues                   | 10%       |
| - Peat                              | 45%       |
| - Heavy fuel oil or coal            | 10%       |

## Boiler data

|                 |                                      |
|-----------------|--------------------------------------|
| Boiler supplier | Kvaerner Power Oy                    |
| Boiler type     | Circulating fluidised bed combustion |
| Boiler output   | 550 MW <sub>th</sub>                 |
| Steam           | 194 kg/s, 165 bar, 545°C             |



*The Alholmens Kraft CHP plant is a good example of how biofuels can also be burnt in larger applications.*



*CFB boiler is design for flexible utilisation of biomass or coal. Kvaerner Power Oy.*



*Alholmens Kraft CHP plant aims to use also agrobiomass in the future, mainly reed canary grass. Vapo Oy.*

*Forest fuel supply is based on bundling of logging residues. The bundles are delivered by classic timber lorries to the plant and crushed on site at CHP plant. Timberjack.*



Source: Growing Power, Tekes, 2002.

## GREAT POTENTIAL IN OLIVE OIL PRODUCTION RESIDUES

Olive oil production residues constitute a substantial source of pollution in some Mediterranean areas. Eighty percent of the world's olive oil is produced and consumed in Mediterranean countries. Only 21% of the weight of an olive is actually oil, the rest is water, olive skin, flesh and stone.

Consequently, the amount of olive oil production residue is huge and storing is not a realistic option. Up till now the waste has been disposed of in landfills, used as fertiliser or animal feed or in some cases combusted. Olive oil mills are gradually abandoning the traditional processes and the new three or two-phase production systems generate new types of residue.

In Spain so called 'alpeorujo' from a two-phase process represents about 90% of this type of olive oil production waste. Alpeorujo is made up of solid residues from olive oil extraction (stones, skin and flesh), water, oil (2-4%) and ashes (2%). Because of the high moisture content, 50-60%, and high alkaline content of 'alpeorujo', it is quite a problematic fuel. High alkaline metal content often means low ash melting temperature. In fluidised bed combustion this means an increased risk of bed agglomeration and deposit formation on heat transfer surfaces.

Co-combustion of olive oil processing residue with coal has been studied in several research institutes in Europe. Depending the type of residue, the maximum share of the residue in the fuel blend can range between 25 and 50% of the weight. For example, co-combustion tests using 'alpeorujo' with lignite and anthracite coals in a fluidised bed reactor showed promising results. By fuel blending, bed ash impurities are in better control and the risk of agglomeration and defluidisation is lower. The share of olive processing residue in the tests was low, only 10-25w-%. Higher proportions of 'alpeorujo' resulted in combustion problems.

A power plant producing 10 MW of electricity would need about 100, 000 tons of 'alpeorujo' annually. This means about 4.2 million olive trees and an area of 28,000 hec-

tares. If half of the fuel were replaced with coal, residue transportation distances and consequently also the costs would be lower. This is also important for the power plant in terms of fuel availability, as it is easier to cope with short interruptions in biofuel deliveries. The feasibility of combustion of coal and 'alpeorujo' also depends on the price and transportation distance of coal. Power plants should be located close to the olive oil production areas as the long-distance transportation of 'alpeorujo' is not feasible due to its low energy density.

## STRAW - CHALLENGING FUEL FOR CO-FIRING

Straw is a somewhat challenging fuel for co-combustion, as it has low bulk density and high chlorine and potassium content. Straw-fired boilers have had major operational problems because of rapid deposit accumulation and corrosion rates. Nevertheless, straw has been widely used for energy production in some countries for many years. An advanced logistic system and proper combustion technology are unquestionably fundamental requirements when straw combustion is considered.

There are several examples on straw firing in a stoker, or pulverised or fluidised bed boilers. The lowest levels of slagging, fouling and corrosion have been achieved with pulverised combustion. Reports of pulverised fuel installations suggest that no major fouling or corrosion has been detected, whereas experiences with fluidised bed boilers are more complex. Some studies indicate that with steam temperatures above 565°C, the lifetime of superheaters is unacceptably low, although problems start to occur even at lower temperatures.

In Denmark, Tech-wise has conducted a number of biomass co-firing experiments and demonstrations, for example at the Studstrup power station. In Studstrup, straw was co-fired up to 20% of the energy basis. Corrosion increased slightly, but the result would have been approximately the same if medium-corrosive coal had been used. Slagging increased when the proportion of straw was increased.



*Olive tree plantation in Spain.*



*Straw is co-fired with coal in Denmark. DTI.*

# FUEL FLEXIBLE AVEDØRE PLANT WITH ULTRA SUPERCRITICAL BOILER

Avedøre power station is located in Copenhagen in Denmark. It is one of the world's most energy-efficient combined heat and power plants. Avedøre power station produces electricity to the Nordic power grid and district heat to the Copenhagen metropolitan area. The heat produced in Avedøre accounts for the needs of 280,000 single-family houses.

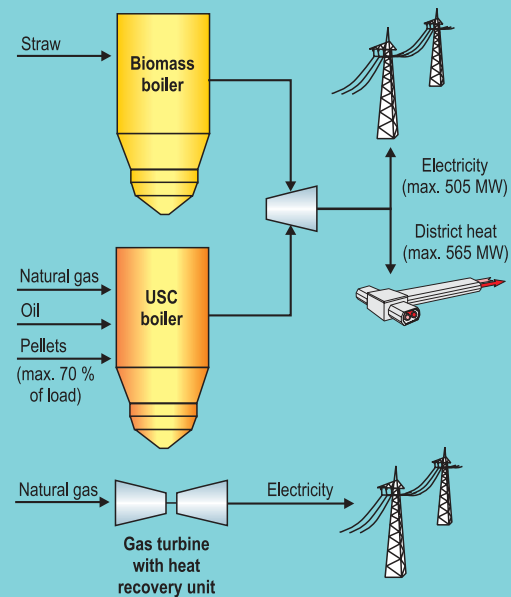
Coal and oil-fired Avedøre unit 1 started operation in 1990 and multifuelled Avedøre unit 2 in 2001. Avedøre 2 is divided into three modules: an ultra supercritical boiler plant, a gas turbine plant and a biomass plant. Avedøre 2 uses a new multifuel concept and embodies a range of cutting-edge technologies, including an ultra supercritical boiler, the world's most advanced steam turbines, the largest straw-fired biomass boiler yet build and areoderivative gas turbines for feedwater preheating. The ultrasupercritical boiler was originally prepared to burn natural gas and heavy fuel oil. The boiler was retrofitted in 2002 to fire 300,000 tonnes of wood pellets annually as an additional fuel.

Special attention was paid into adapting the power plant to the surrounding landscape. Its innovative architecture has been awarded with several international prizes. Avedøre 2 can utilise as much as up to 94% of the energy in the fuel. The commissioning of Avedøre 2 and the closing of a number of older coal-fired facilities in eastern Denmark lead to a reduction of about 10% in CO<sub>2</sub> emissions.

The world's largest straw-fired boiler can burn 150,000 tonnes of straw annually (25 tonnes per hour) which constitutes about 10% of Avedøre 2's fuel consumption. Some 50 truck loads of straw a day are transported to Avedøre Power Station from farms situated in eastern Denmark. The ash from the straw is returned to the fields due to its fertiliser value.



Avedøre plant in Copenhagen. Energi E2.



The principal scheme of Avedøre 2 plant.

## Technical data

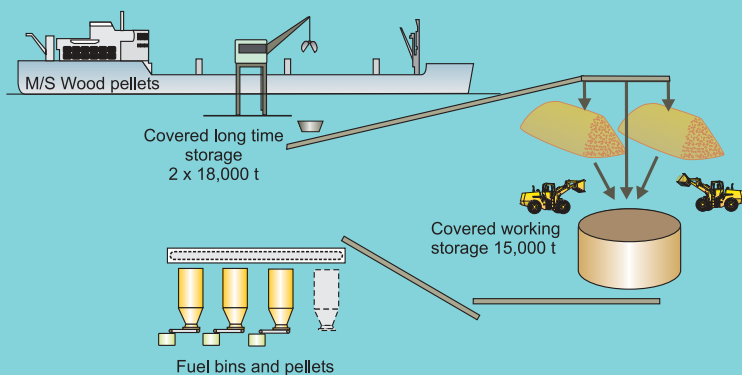
|                            |  |
|----------------------------|--|
| Owner                      | i/s Avedøreværket 2 (Energi E2)  |
| Commissioned               | 2001   |
| Capacity at full load, net | 435 MW <sub>e</sub> without gas turbines<br>585 MW <sub>e</sub> with gas turbines or<br>365 MW <sub>e</sub> and 475 MW <sub>th</sub> heat<br>without gas turbines<br>505 MW electricity and<br>565 MW <sub>th</sub> heat with gas turbines |

## Fuel data

|                              |  |
|------------------------------|--|
| - Ultra supercritical boiler | Natural gas, fuel oil, pulverised wood pellets |
| - Biomass plant              | Straw  |
| - Gas turbines               | Natural gas                                    |

## Boiler data

|                         |  |
|-------------------------|--|
| USB boiler supplier     | BWE/FLS miljø A/S  |
| Boiler type             | Benson type single pass boiler   |
| Biomass boiler supplier | Ansaldo Vølund/<br>Babcock Borsig Power                                    |
| Boiler type             | Vibrating grate boiler   |
| Steam turbine           | The two boilers and two gas turbines share one common steam turbine plant. |
| Steam                   | 336 kg/s, 585°C<br>300 bar USC boiler,<br>310 bar biomass boiler           |



Handling of wood pellets at of Avedøre 2 plant. In order to keep the wood pellets dry and to minimise dust, all handling is performed in closed systems. Existing coal conveyors are covered and dust is removed at strategic places by a vacuum cleaning system.



## WASTE TO ENERGY - BLENDING WASTE WITH SOLID BIOFUELS

As the energy density in untreated waste is low, transporting waste fuels over long distances is not feasible. This is the main reason why biofuel-based power plants are typically quite small compared to coal-fired plants.

The European Union has only recently adopted legislation that promotes the use of waste in energy production. European Union directives on waste combustion have been recently revised. Either the Large Combustion Plant (LCP) directive or the Waste Incineration Directive (WID) is applied, depending on the fuel. The Waste Incineration Directive is applied when the plant incinerates or co-incinerates wastes. WID sets strict limits to flue gas emissions, which requires stability of combustion. In the directive on the promotion of electricity produced from renewable energy sources (the RES-E directive), a biodegradable fraction of industrial and municipal waste is classified as biomass.

Technically, small amounts of wastes may be co-fired with the main fuels in conventional fluidised bed boilers and grate boilers, the fuel input being only a few percent. There are some experiences of co-firing recycled fuels in pulverised fuel boilers in Germany and the Netherlands. Dry pelletised fuel was fed together with coal into coal mills where it was comminuted before combustion as pulverised fuel.

High-quality recycled fuel can be used in existing grate boilers and fluidised bed boilers mixed with the main fuel. This requires stability of combustion and therefore stability of the fuel feeding. The fuel gas cleaning systems should be prepared to retain emissions different from those originating from the main fuel.

The possibilities of recycled fuel use with the main fuel should be considered in new plants. One of the design parameters for boiler dimensioning is the quality of waste material.

Fluidised bed boilers are more suitable for direct co-firing of waste because of their ability to tolerate variations in fuel quality and moisture. However, the use of recycled fuels often has a negative effect on power plant availability. High steam temperature increases the risk of hot corrosion. Because of this, the chlorine concentration of recycled fuel should be less than 0.5w-% or even 0.1w-%, depending on the share of the recycled fuel and other fuels.

Indirect combustion is an option if solid waste fuel is co-fired in a pulverised fuel boiler, natural gas boiler or gas turbine. The waste is gasified and cleaned before it is fed



*A circulating fluidised bed boiler (91.2 MW) of Birka Energi, an energy utility in Högdalen, Sweden, burns recovered fuels with forest residues, sawdust, bark and wood pellets. Foster Wheeler.*



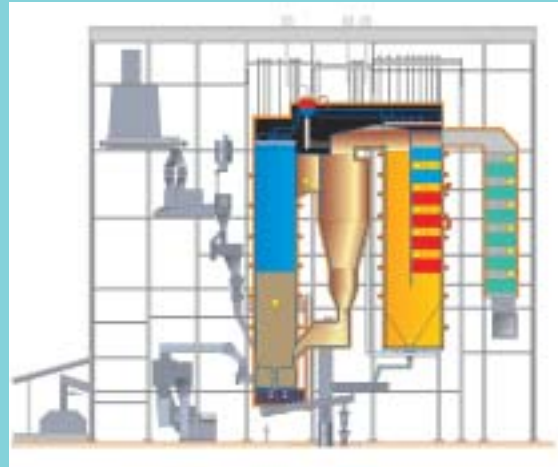
*Wood waste can be produced to recovered fuel, which has required properties. VTT Processes*

into the furnace. Also in case of solid fuel fluidised bed combustion, this is a practical solution, as undisturbed boiler operation is easier to achieve this way.

One of the advantages of gasification is effective emission control. No dioxin is formed when the atmosphere of gasifiers is reduced. Heavy metals and up to 90-99% of the chlorine is removed before gas combustion. No doubt one of the characteristics appreciated by the plant owners is that the waste ash is not mixed with coal ash.

# THE NORRKÖPING 75 MW CHP PLANT - A DESIGN FOR BURNING A VARIETY OF WASTE

The Händelö combined heat and power (CHP) plant in Norrköping, a town of 122,000 inhabitants in southern Sweden, is a new design of the waste-to-energy concept. Since 1993, Norrköping municipality has investigated on biomass and waste combustion. Currently the plant has four boilers: two CFB boilers for combustion of biomass and waste materials and one vibrating grate for demolition wood and one travelling grate originally designed for coal. The newest CFB boiler was installed in 2002 and it is specially designed for the combustion of MSW, industrial waste, sewage sludge, rubber and demolition wood. In addition to flexible combustion technology, a specific fuel handling (e.g. removal of aluminium) and flue gas cleaning system has been designed. The capacity of the boiler is optimised with respect to the amount of waste available in the Norrköping region. The boiler is similar to the two boilers in SOGAMA. The SOGAMA plant is located near the town of Cerceda in Galicia, northwestern Spain. The plant generates electricity from 400,000 tonnes of RDF annually.



*The Händelö CFB boiler is designed for fuel flexibility and low emissions. Kvaerner Power Oy*



## Technical data

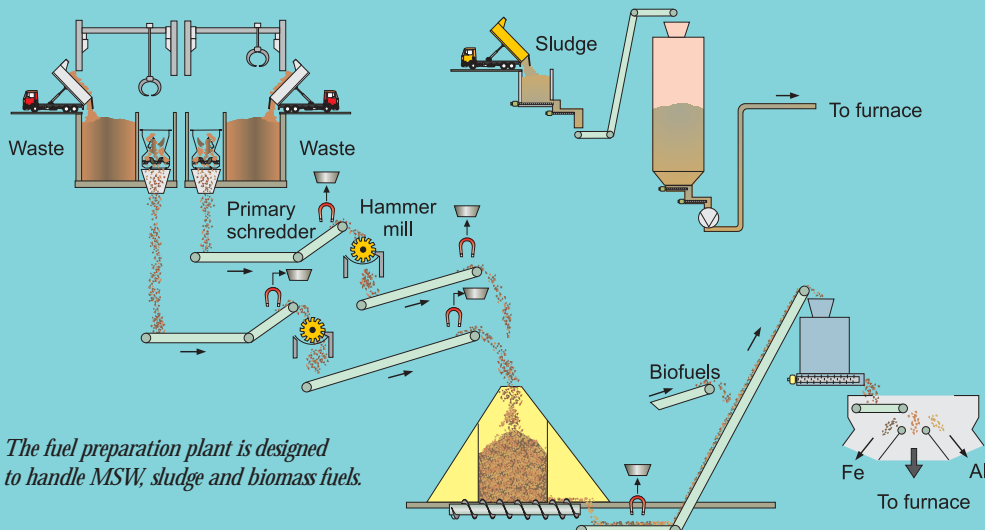
|  |                      |
|--|----------------------|
| Owner  | Sydkraft Östvärme AB |
| Commissioned   | 2002                 |
| Electricity output                                     | 11 MW <sub>e</sub>   |
| Thermal heat output as district heat and process steam | 64 MW <sub>th</sub>  |
| Annual electricity production                          | 88 GWh               |
| Annual heat production                                 | 1,840 TJ             |

## Fuel data

|  |                                    |
|--|------------------------------------|
| Annual fuel consumption                          | 200,000 tonnes of waste (2,400 TJ) |
| Net calorific value and moisture content of fuel | 10–16 MJ/kg (15–40% moisture)      |
| - Combined household waste                       | 30–50%                             |
| - Classified industrial waste                    | 50–70%                             |
| - Sewage sludge                                  | max. 20%                           |

## Boiler data

|                    |  |
|--------------------|--|
| Boiler supplier    | Kvaerner Power Oy  |
| Boiler type        | Circulating fluidised bed combustion SNCR system using ammonia for NO <sub>x</sub> reduction |
| Boiler output      | 75 MW <sub>th</sub>  |
| Steam              | 27.2 kg/s, 6.5MPa, 470°C   |
| Flue gas treatment | Ahlstrom Power AB, NID system  |



*The fuel preparation plant is designed to handle MSW, sludge and biomass fuels.*

## FUEL HANDLING AND PRE-TREATMENT AT THE PLANT

Each combustion method needs specific handling and feeding operations and therefore it is impossible to give detailed overall design basics for handling and feeding operations. However, there are some common features specific to biofuel properties.

The handling and flow properties of biofuels are usually poor because of particle size variation and high fibre and oversized particle content. Additionally, the bulk is adherent, corrosive and even abrasive. The weak flow properties imply high internal and external friction. Of course, there are exceptions like pelletised fuels made from dry raw material.

Basically the handling and conveying system should be designed according to the fuel properties. Because of the obscure dimensioning parameters and the fact that several fuel types have to be fed into the boiler either through the same or separate lines depending on the case, the investments become rather expensive and the systems complicated.

### FUEL RECEIVING SERVES AS A BLENDING UNIT

Solid biofuels are delivered normally by trucks or truck containers. In most cases the fuel supplier is responsible for delivery and unloading. High shear strength and low energy density of biofuels have led to the design of receiving pits and pre-screens that are as open as possible, enabling sufficient unloading for the boiler capacity. Usually different fuel fractions will be blended during transportation and in the receiving station. There are very few separate units for mixing. In large plants, fuels are blended sufficiently also in handling and conveying, especially in the loading and unloading of silos.

Manual fuel sampling is common if many fuel types are used and if there are several suppliers but also automatic sampling has been developed.

### SCREENING GUARANTIES BETTER FUEL QUALITY

The high shear strength and fibre content emphasise the design of screening. One of the best screening devices is a disc screen where the critical factors are the feeding, screen aperture dimensions, disc-shape and rotation velocity when optimising the proportion of acceptable fuel from over-sized reject material. The normal metal separation based on ferromagnetic character is sufficient if the proportion of demolition wood is not extensive. In some cases where the fuel flow has increased, the capacity of magnetic separation has been adjusted accordingly.



*Bark, sawdust and the mixture of bark, sawdust and logging residue chips in the fuel yard of a large-scale power plant.  
VTT Processes*



*Logging residue chips on the disc screen of a power plant.  
Roxon.*



*Screening of fuel before combustion.  
Roxon.*

## CONVEYING AND STORING CAPACITIES ARE INCREASING

The transport capacity of conveyors and reclaimers is very important when fuel quality reduces. The handling of more fibrous materials has affected the design of crossing points, chutes and openings and especially silos and stores. The principal design methods are not as valid as practical experience and feedback from plant operators. The store sizes (of intermediate storages) have grown larger due to lower calorific values. At the moment the largest round-bottom intermediate store equipped with a slewing screw reclaimer is 5,000 m<sup>3</sup>. The volume of a single A-shape store can exceed 10,000 m<sup>3</sup>. Present stores are often provided with flow distributors, which prevent segregation and direct flow.



*The round-bottom intermediate storage (1500 m<sup>3</sup>) of a biofuel power plant. Roxon.*

## BOILER MEASUREMENTS CONTROL FUEL FEEDING INTO THE BOILER

The most reliable boiler hopper or silo has been proved to be a cylindrical silo equipped with an unloading screw turning on the bottom. This structure ensures also the most accurate and adjustable discharge of fuel. Fuel will be unloaded mostly on chain conveyors on both sides of the boiler. The mass flow rate is measured from conveyors but the primary information for fuel feeding control comes from steam pressure and combustion chamber measurements, which provide faster response for adjustments. Most electric motors have variable speed control (VSC). This is done with frequency converters, which can be controlled externally or locally for example by rotation speed, level, space, position, and torque using modern control methods.

## CONTROL, FIRE AND OCCUPATIONAL SAFETY IS BASED ON A MODERN DISTRIBUTED CONTROL SYSTEM

Control, fire and occupational safety are based on a modern distributed control system. A lot of research has been done to study fuel safety properties. Experience has shown that the most critical parts of the process are the receiving, screening, crushing and feeding line near the boiler. The use of modern monitoring (also cameras utilising broader wavelengths), detection and preventive technology has been significantly increased.



*The main fuels of the Kokkola power plant in Finland are wood-derived fuels and peat, which can be stored in the fuel yard. In the basic planning, special attention was paid to a flexible selection of fuels on an extensive range of partial loading without the risk of corrosion. The Kokkola power plant is producing 20 MW<sub>e</sub> of electricity and the output of the BFB-boiler is 70 MW<sub>th</sub>. Pohjolan Voima Oy.*

# CHOICE BETWEEN DIRECT, INDIRECT OR PARALLEL CO-COMBUSTION

There are basically three options for co-combustion: direct, indirect and parallel co-combustion. Direct co-combustion is combustion of biomass together with fossil fuel in a single combustion chamber. Indirect co-combustion means combustion of fossil fuel with previously gasified biofuel, and parallel combustion requires at least two boilers as biomass is burned in one and fossil fuel in another.

## FLUIDISED BED COMBUSTION GIVES FLEXIBILITY

Fluidised bed technology is the most flexible for burning different types of fuel. With careful planning and testing, boilers designed for multifuel use may accept new fuels without any problems. Fluidised bed boilers designed for coal combustion can also be converted for biomass/coal co-combustion with a relatively small investment.

A fluidised bed is a bed of solid particles suspended or fluidised by forcing air through the bed. When the air velocity is increased above the minimum fluidisation velocity, air flows through the bed as bubbles. This type of bed is called bubbling fluidised bed (BFB). When the air velocity is increased, the particles are carried higher up in the reactor. With a circulating fluidised bed (CFB) it is no longer possible to distinguish between the bed and freeboard area. A large fraction of the particles rise up from the bed and are circulated with the help of a cyclone back to the bed. The circulating bed material can be used for temperature control in the boiler. Fluidisation velocity of a bubbling fluidised bed boiler is typically between 1 and 3.5 m/s, whereas in a circulating fluidised bed boiler it is 3-6 m/s.

Fluidised bed boilers can be designed to combust almost any solid, semi-solid, or liquid fuel as long as the calorific value is sufficient to heat the fuel, drive off the moisture and preheat the combustion air. They achieve high fuel-to-steam efficiency, typically over 90%, even with challenging, low-grade fuels. Because of the high amount of hot circulating bed material, it is possible to burn moist, heterogeneous fuels with low calorific value. With high moisture content fuels, a support fuel can be used. More than 90% of the bed is sand or ash and the rest is fuel. This balances changes in fuel quality and moisture and prevents combustion disturbances and undesired variation of bed temperature. In some cases, special bed materials can be used in order to avoid bed agglomeration.

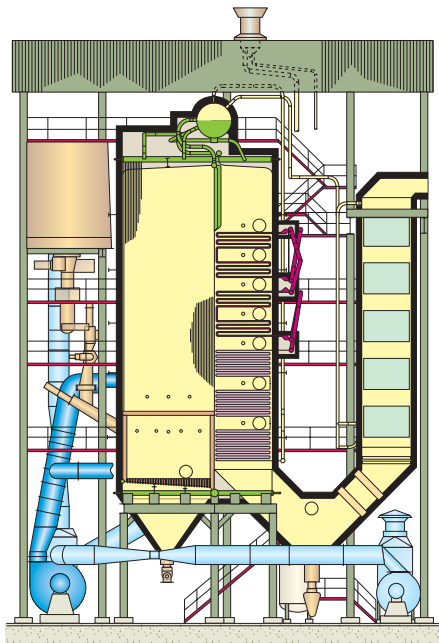


*Quartz-free sand enables efficient combustion of alkali-rich fuels such as plywood residue. Kvaerner Power Oy.*

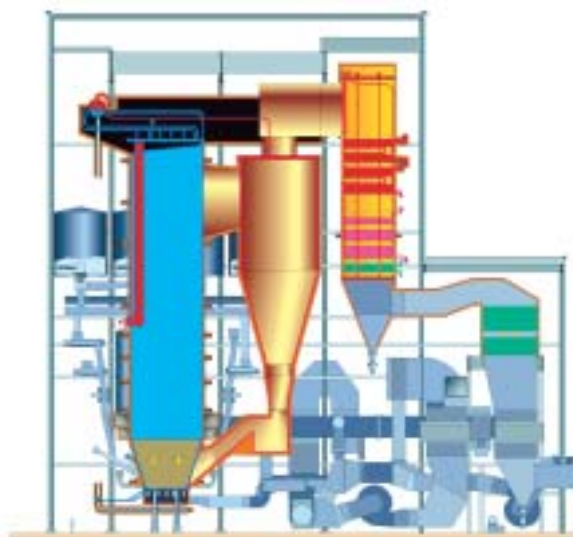
Coal contains large portion of fixed carbon which burns in the bed and the freeboard or riser temperature is clearly lower than the bed temperature. With a higher amount of wood, the freeboard temperature increases. Wood contains large amounts of volatile matter which burns mostly in the freeboard area, thus causing the temperature to rise.

The choice between BFB and CFB technology has been largely linked to the choice of fuels. As a simpler and cheaper technology, BFB has been favoured in plants fuelled exclusively with biomass or similar low-grade fuels containing highly volatile substances. The new enhanced CFB designs can be a competitive alternative even in smaller biomass-fired plants.

At the moment, fluidised bed combustors are the best combustion systems thanks to their ability to burn a wide assortment of fuels and still keep emissions low. The temperature in a fluidised bed is lower than in pulverised fuel combustion, and efficient combustion is achieved by a relatively long residence time in the bed. Because of the relatively low combustion temperature in a circulating fluidised bed (typically 850°C), thermal NO<sub>x</sub> formation is not a problem.



*Bubbling fluidised bed combustion.  
Foster Wheeler.*



*Circulating fluidised bed combustion.  
Kvaerner Power.*

## PULVERISED COMBUSTION FOR CO-FIRING IN EXISTING COAL-FIRED BOILERS

The main motive to use biofuels in coal-fired pulverised fuel boilers is the need to reduce emissions and to exploit available local biomass resources. Using biomass in existing pulverised fuel boilers can be more profitable than building a new biomass plant using 100% biomass. On the other hand, the amount of available biomass may be a restricting factor. The American experiences on biomass and coal co-combustion are mostly based on pulverised fuel combustion in coal-fired boilers.

Different options in using solid biomass in a pulverised fuel boiler are described in the "Handbook of biomass combustion and co-firing" as follows.

There are basically four options for direct combustion in a pulverised fuel boiler.

- When the proportion of biofuel is rather low, it can be fed together with coal to coal mills and then be burned together with coal through coal burners. In principle, this is the simplest option and involves the smallest investments. On the other hand, this technology also carries the highest risk of malfunction of fuel feeding systems.
- The second option involves separate handling, metering and comminution of the biofuel and injection into the pulverised fuel upstream of the burners or at the burners. This option requires the installation of a number of biofuel transport pipes across the boiler front, which may already be congested. It may also prove to be more difficult to control and to maintain the burner operating characteristics over the normal boiler load curve.
- The third option involves the separate handling and comminution of the biofuel with combustion through a number of dedicated burners. This approach represents the highest capital cost option, but involves the least risk to normal boiler operation.
- The final option involves the use of biofuel as a reburn fuel for NO<sub>x</sub> emissions control, i.e. the combustion of biofuel is a specially-de-



signed reburn system located in the upper furnace. This system is still in the development stage, although some small-scale tests have been carried out.

The problem with all these is that the loss in power output is almost inevitable and that the proportion of biofuel in fuel blend is limited. However, new solutions are being developed.

## GRATE COMBUSTION TRADITIONAL SOLUTION FOR SOLID FUELS

Grate boilers have been traditionally used for solid fuel combustion. The size range is broad; grate boiler technology is available from 15 kW up to 150 MW. Grate boilers are suitable for many types of fuels: coal, wood fuels, waste fuels, peat and even straw. Even fairly moist fuels can be used if this is taken into account in boiler design.

In comparison to fluidised bed combustion, boiler efficiency of a grate boiler is lower and flue gas emissions higher. It is also more sensitive to changes in fuel quality and moisture, and automation of grate combustion is difficult. However, the structure is simpler so the investment, operation and maintenance costs in most cases are lower.

It is not common to apply grate combustion in multifuel combustion. There are experiences on co-firing of recycled fuels, packaging derived fuels, refuse derived fuels, recovered fuels and plastics with wood fuels or other by-products of forest industry.

Co-firing of recycled fuels in small power plants is relatively safe as the steam temperature is usually lower than 400°C and there is no risk of hot corrosion. Nevertheless, special attention must be paid to flue gas cleaning. Most plants are now equipped with cyclone or electric precipitators, sometimes even with gas scrubbers. Variation in fuel quality also poses challenges to fuel handling and feeding.

One of the problems related to grate firing is the melting. Temperatures in the combustion chamber may reach 1300-1400°C. Ash melting problems may be reduced by using mechanical and water-cooled grates and by avoiding the use of preheated combustion air in the final burning area.

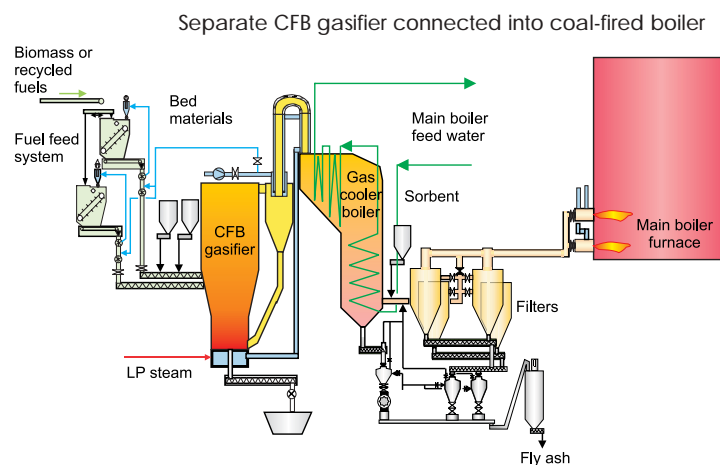
The grate structure is selected according to the fuel properties. The most typical are: fixed flat grate, fixed sloping grate, mechanical sloping grate and chain grate. There are also special grate types for special fuels, such as waste incineration grates or cigar combustion grates for straw.

The key issues in grate firing are homogeneous fuel particle size and quality, proper sizing of the combustion chamber and efficient mixing of the combustion air.

## SEPARATE BIOMASS GASIFIER ENABLES USE OF WASTE-DERIVED FUELS

Gasification makes it possible to use waste-derived fuels and biomass residues also in pulverised coal-fired boilers. Indirect combustion technology enables the utilisation of larger proportions of biomass or waste in pulverised fuel boilers, gas boilers and gas turbines. Instead of comminution, solid biomass is pre-processed in a gasification plant and the product gas is burned in a boiler together with pulverised coal or natural gas, for example. Gasification technology is commercially available and there are many different types of gasification systems, atmospheric fluidised bed gasification being one of the most cited in recent literature. The challenge lies in product gas quality. Gas cooling and cleaning systems increase the investment costs. It is also possible to burn uncleaned, uncooled gas. Gasified recycled fuels contain plenty of dust and tars. If the gas cools down, the condensed tars and dust may form deposit layers.

The main products of gasification are the wet flue gas, biomass ash including alkali metals and trace metals, tars and other condensable organic species. Conventional filters tolerate only low temperatures, therefore the gas must be cooled down to 200-250°C. Also new gas filtration techniques, such as ceramic or metal sinter filters are now available. This makes it possible to use also low-quality fuels in gasification. Fuels with high chlorine content cannot be gasified to be used in co-firing without first cleaning the product gas. Tars in the product gas cause problems in the gas scrubbers. Besides, treatment of gas scrubber waste waters increases operating costs.



*The biomass CFB gasifier with flue gas cleaning. Foster Wheeler.*

# EFFICIENT WAY TO CO-FIRE – GASIFIER FOR A COAL FIRED UTILITY BOILER

An efficient way to use local biomass fuels and even recovered fuels for energy is to gasify these fuels in a separate gasifier and cofire the cleaned product gas in existing pulverised coal fired or fluidised bed boilers. The same concept applies to oil and gas fired boilers. Gasification solutions are also attractive when co-firing straw in a coal fired boiler. In Finland, two fluidised bed gasifiers, one in Lahti and another in Varkaus, are successfully in operation, and several new investments are being planned.

The Lahti gasifier replaces 15 per cent of the fossil fuel and significantly reduces SO<sub>2</sub>, NO<sub>x</sub> and CO<sub>2</sub> emissions. The fuels burnt in the gasifier are different types of solid biofuels. A similar type of the gasifier with flue gas cleaning equipment was installed at a power plant of the Electrabel company in Ruien, Belgium in spring 2003.

### Technical data

|                    |                      |
|--------------------|----------------------|
| Owner              | Lahden Lämpövoima Oy |
| Commissioned       | 1998                 |
| Electricity output | 185 MW <sub>e</sub>  |
| Heat output        | 250 MW <sub>th</sub> |

### Fuel data (gasifier)

|                         |          |
|-------------------------|----------|
| Annual fuel consumption | 1,200 TJ |
| Fuel distribution       |          |
| - Wood residues         | 57 %     |
| - REF                   | 42 %     |
| - Other                 | 1 %      |

### Gasifier data

|                   |   |
|-------------------|---|
| Gasifier supplier | Foster Wheeler Energia Oy   |
| Gasifier type     | Circulating fluidised bed gasifier                                    |
| Gasifier capacity | 40-70 MW depending on the moisture content and heating value of fuels |



*The Lahti CFB gasifier which is connected into 350 MW pulverised coal fired boiler has been in operation since 1998. Lahti Energia.*



*Wood fuel storage at Lahti plant. Roxon.*



*Fuel receiving stations and coal yard. Roxon.*

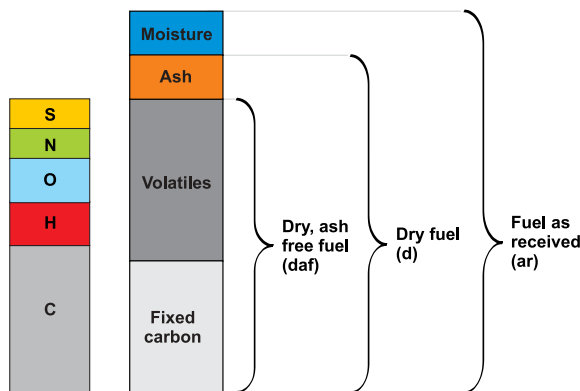


# CO-COMBUSTION – A CHALLENGE TO BOILER OPERATION

## BLENDING OF FUELS EQUALS BLENDING OF FUEL PROPERTIES

Most of the challenges that co-firing poses to boiler operation originate from fuel properties. The differences in characteristics of coal and biomass can be summarised as follows:

- Pyrolysis starts earlier for biomass fuels compared with coal fuels.
- The volatile matter content of biomass is higher compared with that of coal.
- The fractional heat contribution by volatile substances in biomass is approximately 70% compared with 30-40% in coal.
- The specific heating value of volatiles in kJ per kg is lower for biomass fuels compared with coal fuel.
- Biomass char has more oxygen compared with coal and it is more porous and reactive.
- Biomass fuels have ash that is more alkaline in nature, which may aggravate the fouling problems.
- Biomass fuels can be high in chlorine, but typically have low sulphur and ash content.



*Results of traditional fuel analysis. Solid fuels contain carbon, hydrogen, oxygen, water, ash-forming elements, nitrogen and sulphur. Oxygen is chemically bound in the fuel and the concentration is 45% of the weight in wood and 2% in anthracite coal on dry ash-free basis. Fresh wood typically contains 50% of water by weight, whereas the moisture content for bituminous coals is approximately 5%. Wood-based fuels usually have low sulphur content but can have very high chlorine content. In general, the structure and composition of coal differs greatly from those of biomass fuels. However, in both coal and biomass, ash-forming matter can be present in four general forms including easily leachable salts, inorganic elements associated with the organic matter of the biomass, minerals included in the fuel structure and inorganic material - typically sand, salt or clay.*  
VTT Processes.

The aforementioned differences imply that if biomass fuels are blended with coal, the following implications may be expected:

- increased rate of deposit formation
- shorter sootblowing interval
- cleaning of heat transfer surfaces in revisions may be required
- higher risk of corrosion of heat transfer surfaces
- bed material agglomeration (in fluidised beds)
- higher in-house power consumption
- higher flue gas temperature

The magnitude of these implications depends on the quality and percentage of biomass in the fuel blend. The overall result is that operating and maintenance costs may increase, but this can be reduced or even avoided with appropriate fuel blend control: the optimum percentage of biomass fuel in the fuel blend can be defined with appropriate combustion tests accompanied with bed material and deposit quality assessments.

Wood-based fuels usually contain only a few percent of ash, whereas coal typically contains 10w-% or more. Ash characteristics have an important role in boiler design because deposit formation, erosion and corrosion should be minimised and defluidisation avoided.

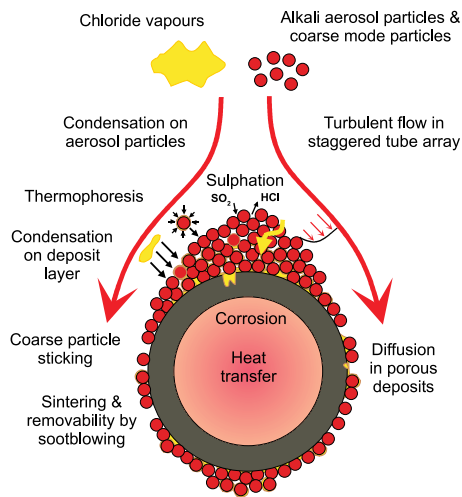
## SLAGGING AND FOULING CAN BE REDUCED WITH APPROPRIATE FUEL BLENDING

Slagging can be defined as the deposition of fly ash on the heat transfer surface and refractory in the furnace volume primarily subjected to radiant heat transfer. Fouling is defined as deposition in the heat recovery section of the steam generator subject mainly to convective heat exchange by fly ash quenched to a temperature below its melting point.

Substances that have vaporised in the combustion zone can condensate on the heat transfer surfaces by the condensation of volatiles or the sulphation of  $\text{SO}_3$ . These deposits may vary from light sintering to complete fusion. The degree of fouling and slagging varies throughout the boiler depending on

- local gas temperatures
- tube temperatures
- temperature differences
- gas velocities

- tube orientation
- local heat flux on particles
- fuel composition.



*Schematic illustration of deposit formation and condensation of inorganic vapours on a superheater tube surface. VTT Processes.*

The existence of alkali metals in fuel ash is recognised to have an important role in deposit formation. In addition to the combustion conditions, deposit formation depends on the release and chemistry of chlorine, sulphur, aluminium silicates and alkalis during combustion.

The fireside behaviour of fuel impurities is a continuous source of slagging, fouling, or corrosion in one way or another. Deteriorated heat transfer of the heat delivery surfaces result in lower combustion efficiency, and obviously corrosion in the fireside has far more serious consequences.

The main factors that contribute to fouling are caused by inorganic materials in the fuel. Biomass ash contains a larger amount of alkalines compared with coal ash. This is particularly true for some agricultural residues and new tree growth. The chemical composition of ash, such as alkali metal, phosphorous, chlorine, silicon, aluminium and calcium content, as well as the chemical composition of the compounds, affect ash melting behaviour. Alkaline metals compounds are easily vaporised during combustion. In biomass fuels, a major proportion of inorganic material is in the form of salts or bound in the organic matter, but for example in coal, a large proportion of inorganic substances are bound in silicates, which are more stable. Additionally, chlorine-rich deposits induce hot corrosion of heat transfer surfaces. Although slagging and fouling may be detected quite quickly, corrosion progresses slowly over a longer period and may also occur without any associated slagging or fouling. However, reliable measurements can be made about

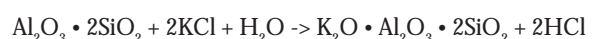
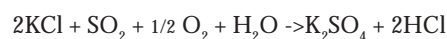
the corrosion risk of a particular fuel blend in short-term tests where exposure times in the order of hours are applied.

Deposits accumulate on heat transfer surfaces mainly by five different means:

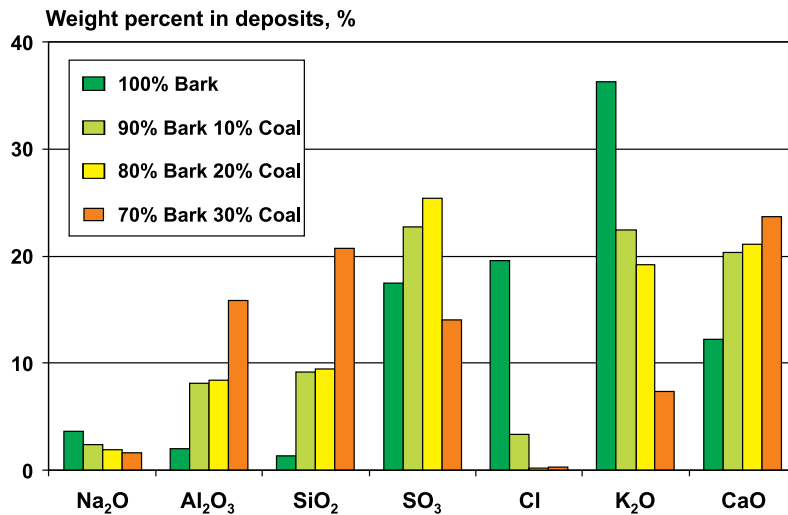
1. Inertial impaction, where the bulk of fly ash cannot follow the stream lines of the gas flow and hit the heat transfer surfaces. The particle size is usually greater than  $10\mu\text{m}$ .
2. Thermophoresis due to temperature difference in the gas. When the thickness of a deposit layer increases, the effect of thermophoresis is reduced as the temperature on the surface of the deposit layer approaches the gas temperature.
3. Condensation of vaporised compounds occurs after reaching heat transfer surfaces of sufficiently low temperature. This mechanism is pronounced in biofuel combustion.
4. Diffusion, an important deposition mechanism especially for vapours and particles smaller than  $1\mu\text{m}$ .
5. Chemical reactions within the deposit layer and between gaseous and solid compounds.

Ash characteristics have an important role also in boiler design, because deposit formation, erosion, corrosion and defluidisation of the bed sand should be minimised. Ash-forming matter in biomass fuels can be present in several forms: as soluble ions, associated to organic matter or as minerals. The form in which the ash-forming matter is present affects the behaviour of a fuel. There are significant differences in how ash-forming elements are distributed in different fuels. In older fuels, ash-forming elements are present as minerals. In relatively young fuels, up to half of the ash-forming elements can be organically associated or present as easily soluble salts or as minerals.

According to present knowledge, control of the rate of deposit formation in biomass combustion is associated with the reactions between compound that contain chlorine, sulphur, aluminium and alkaline substances. High-risk chlorine compounds are of the type NaCl or KCl. These alkaline chlorides can, however, react with sulphur and aluminium silicate compounds releasing HCl.



The S/Cl ratio in the feedstock has often been shown to affect Cl deposition and corrosion. In addition to aluminium silicate reactions, one parameter that has been often referred to is the sulphur-to-chlorine atomic ratio (S/Cl) in fuels or fuel blends. It has been suggested that if the S/Cl ratio of fuel is less than two, there is a high risk of

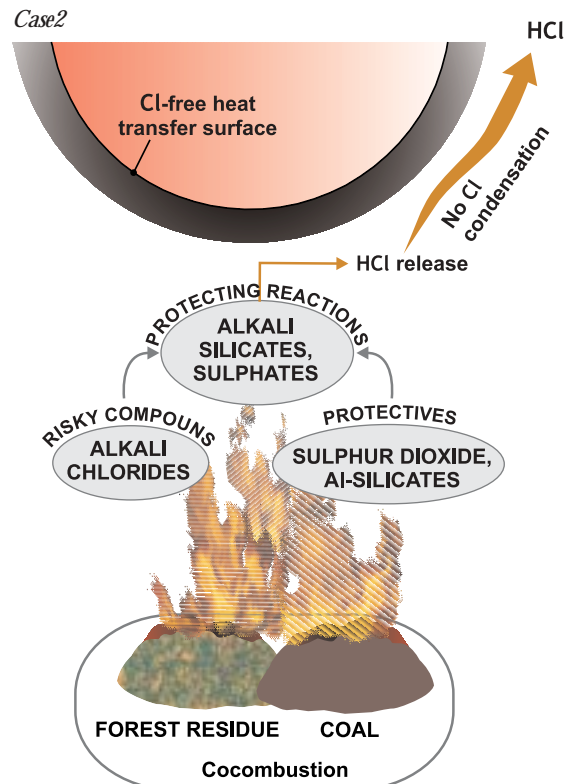
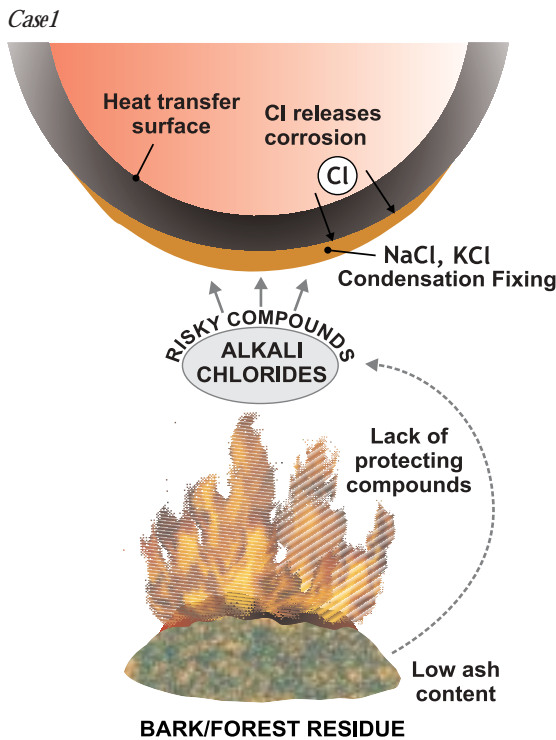


Results from a chemical analysis of deposits. The figure shows the proportion of selected elements in the deposit layer after combustion test with different proportions of pine bark and coal (on the energy basis). When the proportion of coal in the coal/pine bark blend is increased, the amount of chlorine decreases in the deposits. VTT Processes

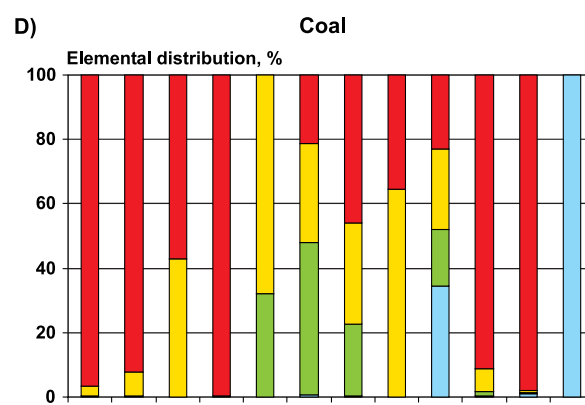
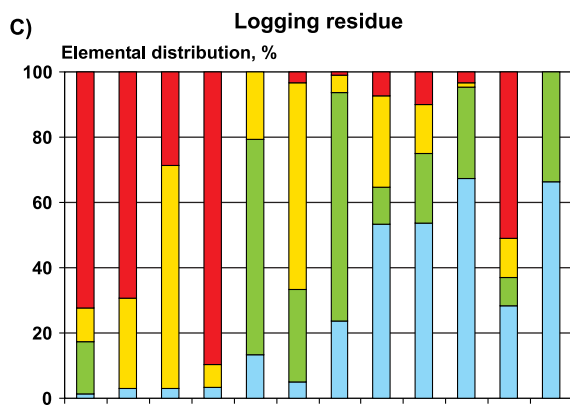
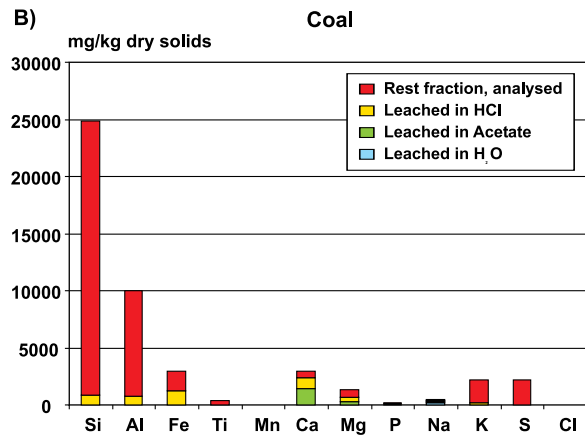
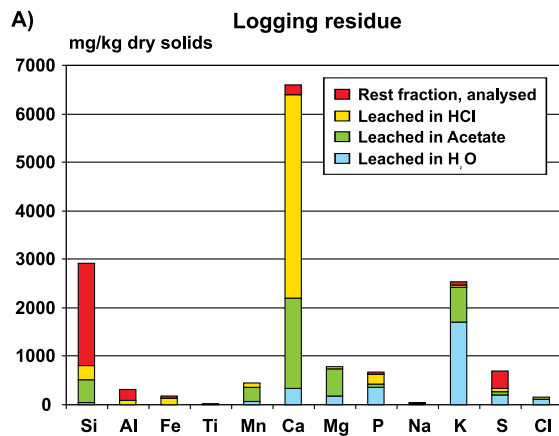
superheater corrosion. When the ratio is at least four, the blend could be regarded as non-corrosive. According to recent studies AlSi/Cl ratio can even dominate over the S/Cl ratio.

Easily leached elements are the main constituents of fine fly ash, i.e. the fraction of ash that is formed from easily volatilised ash-forming matter, and consequently reasonable approximations of fly ash compounds. 'Chemical fractionation' can be applied in determining how ash-forming elements are bound in the fuel. This is done by determining the constituents' solu-

bility in different solvents. Increasingly aggressive solvents, i.e. water (H<sub>2</sub>O), ammonium acetate (NH<sub>4</sub>Ac) and hydrochloric acid (HCl) leach fuel samples into a series of four fractions (including the unleached residue) for analysis. Typical ash-forming components that are leached out by water include alkali sulphates, carbonates and chlorides. Elements leached out by NH<sub>4</sub>Ac are believed to be organically associated, such as Mg, Ca as well as K and Na. HCl leaches the carbonates and sulphates of alkaline earth and other metals. Silicates and other minerals remain in the insoluble residue.



In Case 1, bark or forest residue is combusted alone. The ash of these fuels has high alkaline metal content. When this is associated with high chlorine content, which is often the case, these elements react to form alkali chlorides. This, in turn, induces corrosion rates after deposition of these substances on the heat transfer surfaces. In Case 2, sulphur and aluminium silicates from coal ash are able to form alkali silicates and alkali sulphates. Now chlorine is released as HCl in flue gases and alkali metals are bound in compounds that have a high melting point and no corroding effect. VTT Processes



Results of chemical fractionation. Charts A and B show the proportions of selected elements in the dry fuel. Both logging residue and coal contain the same amount of potassium (K), which is one of the major contributors to chlorine-containing deposit formation. Charts C and D plot the same data but on a relative scale. It is apparent that potassium is in easily leachable form in logging residue, whereas in coal it is bound in a silicate matrix and is thus unleachable. In practice it has been shown that corrosive deposit formation and bed agglomeration are not real challenges in coal combustion, but in logging residue combustion this may well be the case. According to the proportion of a compound in a fuel obtained through a standard fuel and ash analysis (i.e. Charts A and B without coloured highlighting), no significant difference exists in the potassium content. When information from the fractionation is available, the true nature of these elements can be assessed. Åbo Akademi.

## FINNISH CASE STUDY ON POWER PLANT AVAILABILITY

A recent study on the effects of wood fuels on power plant availability showed that use of wood fuels actually involved more problems than expected. Twelve Finnish power plants with fluidised bed boilers, from 100 to 300 MW<sub>th</sub>, answered a questionnaire on power plant availability. All these plants have either increased the use of wood fuels, or recently started it. The objective of the project was to determine critical properties of wood fuels in respect of power plant operation, to determine the optimal conditions for reducing detriments, and to study how storing and processing of wood fuels affect steam boiler operation.

More than half of the plants:

- have had problems in the feed stock's discharging gears, conveyors and feeding gears
- had noticed bed-related problems during the use of wood fuels
- had detected that wood fuels affect furnace temperatures

- have had problems because of the variation in furnace temperature
  - had discovered that wood fuels contribute to deposit formation
  - had noticed that the quality of wood fuel fluctuates
  - had noted that wood fuels change the ash quality
  - said that the increased use of wood fuels had affected plant performance
- On the other hand more than 80% of the plants:
- can feed the fuel smoothly into the furnace
  - can spread the fuel evenly to different sides of the furnace and
  - said that the fuel spreading was not different when wood fuels were used
  - said that the use of wood fuels did not increase the need for soot blowing and
  - said that the increased use of wood fuels had affected to the plant emissions

# CO-FIRING PROVIDES MEANS FOR EMISSIONS REDUCTION

Co-firing of biomass with fossil fuels provides means to reduce  $\text{SO}_2$ , and  $\text{CO}_2$  emissions and it also may reduce  $\text{NO}_x$  emissions. It is assumed that there is no net emission of  $\text{CO}_2$  from biomass combustion as plants use the same amount of  $\text{CO}_2$  during growth that is released in combustion.

Typical consequences of co-firing are modest reductions in boiler efficiency that limit the economic value of biomass fuels.  $\text{NO}_x$  reduction is due to strengthening of reactions reducing NO in the furnace and/or lower nitrogen content in biomass. The  $\text{SO}_2$  reduction results from both substituting a sulphur-bearing fuel for a sulphur-deficient and calcium-deficient fuel for a calcium-bearing fuel.

Every tonne of biomass co-fired directly reduces fossil  $\text{CO}_2$  emissions by over a tonne. If the biomass would otherwise be disposed of in a landfill without methane collection and flaring, the fossil  $\text{CO}_2$  emission reduction can be the equivalent of approximately three tonnes of fossil  $\text{CO}_2$  for every tonne of biomass burned.

## REDUCING $\text{NO}_x$ EMISSIONS

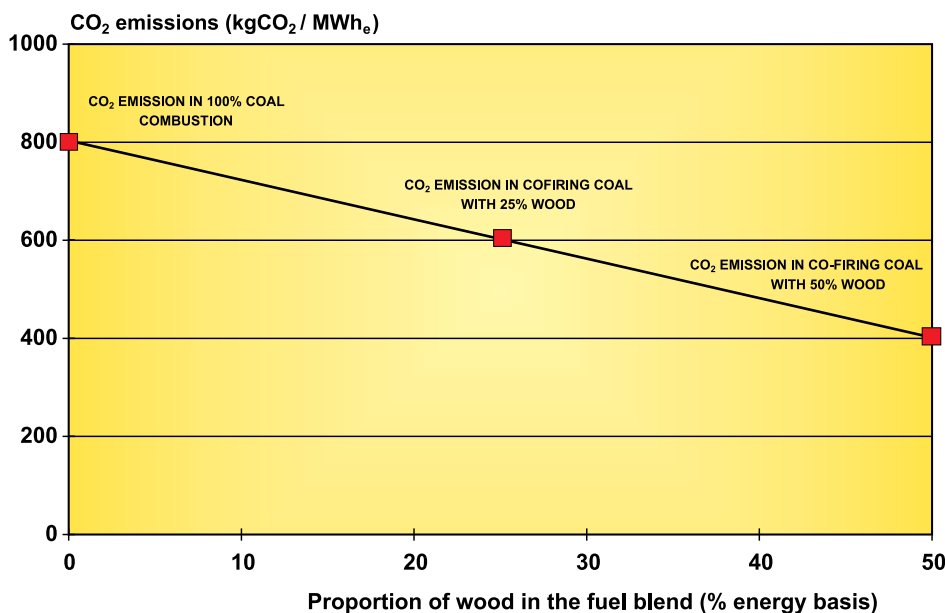
In chemical terms, nitrogen oxides should constitute all oxides of nitrogen ( $\text{N}_x\text{O}_y$ ), including nitric oxide (NO), nitrogen dioxide ( $\text{NO}_2$ ) and nitrous oxide ( $\text{N}_2\text{O}$ ).  $\text{NO}_x$  is generally defined as the sum of NO and  $\text{NO}_2$ . NO is the main contributor of  $\text{NO}_x$  in both pulverised fuel and fluidised

bed combustion. In fluidised bed combustion, the amount of NO (in  $\text{NO} + \text{NO}_2$ ) is 90-98 %. One nitrogen-containing compound that is often omitted in the context of greenhouse gas emissions is  $\text{N}_2\text{O}$ .

Compared to pulverised fuel combustion, the lower combustion temperature in fluidised bed combustion provides an advantage in reducing the formation of thermal  $\text{NO}_x$ . On the other hand,  $\text{N}_2\text{O}$  emissions seem to be higher in fluidised bed combustion. If lower  $\text{NO}_x$  levels are required, adding ammonia or urea into the flue gas stream can be done.

Research results on  $\text{NO}_x$  formation in co-firing are somewhat contradictory. Some research groups claim that  $\text{NO}_x$  levels decrease when biomass is mixed with coal. Some results show just the opposite.  $\text{NO}_x$  formation is a complex process. What is certain is that the combustion process is affected by a number of factors.

Because biomass has a high volatile and hydrogen content, it can be successfully applied in  $\text{NO}_x$ -reducing procedures such as air staging and re-burning. In contrast to the situation in pure coal flames, with coal/biomass blends and air staging, low  $\text{NO}_x$  emissions are attained already under fairly air-rich conditions. In re-burning, biomass is superior to bituminous coal as a reducing fuel with regard to both emissions and burnout. Reduction is based on reactions between hydrocarbon radicals and NO.



Theoretical decrease in  $\text{CO}_2$  emissions by co-firing of wood with coal. VTT Processes.

## N<sub>2</sub>O EMISSION REDUCTION IN FLUIDISED BED COMBUSTION

N<sub>2</sub>O emissions from fluidised bed combustion can vary from less than 5 up to 200ppm. Because of the adverse effect of N<sub>2</sub>O on the atmosphere, a considerable amount of research has focused on N<sub>2</sub>O formation/destruction mechanisms in fluidised bed combustion.

N<sub>2</sub>O emission is strongly dependent on temperature and fuel composition. Contrary to NO<sub>x</sub>, N<sub>2</sub>O concentration in combustion gases decreases as the temperature rises. Adding biomass to the fuel mixture clearly decreases the N<sub>2</sub>O emission. A higher O/N ratio of biomass has a positive impact on N<sub>2</sub>O emissions. The large amounts of calcium, potassium and sodium in biomass have a catalytic effect on N<sub>2</sub>O reduction. The effect of biomass on N<sub>2</sub>O reduction is more significant at lower temperatures.

## BIOMASS BLENDING DECREASES SO<sub>2</sub> EMISSIONS

By blending biomass with coal, SO<sub>2</sub> emissions decrease because of the lower sulphur content of biomass. The reduction can be even higher than this due to interaction of fuel constituents of different origin, i.e. biomass and coal. The ash in biomass is often very high in calcium. Fuel-bound calcium compounds can work as sorbents as they can react with SO<sub>2</sub> and SO<sub>3</sub> to form calcium sulphate.

The efficiency of sulphur reduction in combustion processes depends on several variables such as combustion temperature, excess of air, air staging, fly ash recirculation (in FBC), fuel type, limestone characteristics, limestone and fuel feed distribution and Ca/S ratio. It has been shown in laboratory-scale CFB combustion tests where coal and bark blends were burned that sulphur removal efficiencies from 15% (no bark) up to 80% (80% bark) can be achieved.

In a large EU APAS project, biomass/coal mixtures were burned in many different types of boiler (FB and PF) from laboratory to full-scale industrial boilers. Reductions of up to 75% were observed in SO<sub>2</sub> emissions. This can be mainly attributed to the low sulphur content of biomass, but increased sulphur retention in the ash was also detected.



## HEAVY METALS, DIOXINS AND FURAN EMISSIONS

When recycled fuels are used, halogen, heavy metal, dioxin and furan emissions may need to be controlled by means of combustion temperature, bed composition, dust removal or flue gas scrubbing. Separation of suspended solid particles from the flue gases can be very costly. The standard solution is to equip plants with electric precipitators.

On the other hand, the sulphur and aluminium silicates in coal have been shown to reduce the chlorine content of fly ash particles.

## GOOD RESULTS FROM CO-FIRING BY CAREFUL PLANNING AND PRELIMINARY TESTING

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The advantages of co-firing mainly relate to environmental benefits. Boiler and combustion process control, however, becomes more challenging when biomass-containing fuel blends are introduced into the process. Variations in the physical and chemical properties of wood-based fuels may cause unexpected problems throughout the whole power production chain which in turn poses new challenges for fuel handling systems, boiler design and combustion technologies. If biomass is blended with coal, the maximum safe amount of biomass varies from case to case depending upon fuel properties. As coal-fired pulverised fuel boilers were originally designed for burning pulverised coal, the following assessments should be carried out before starting to use biofuels:

- How is the fuel fed into the boiler and is there a need for a new burner configuration?
- What effects does co-firing have on the chemical composition and quantity of flue gases? The moisture content of biomass is higher than in coal, so the flue gas composition will change and the volume will increase. The capacity of flue gas blowers has to be revised.
- How does co-firing affect boiler operation and temperature profiles within the furnace? The amount of volatiles in biomass is higher compared with coal. This affects flue gas temperatures.
- Is there a risk of deposit formation on the boiler heat transfer surfaces or risk of bed agglomeration (in fluidised bed combustion)
- What is the effect on the desulphuration system? Alkali metals in wood ash work as absorbents. The increased flue gas volume may also affect the functioning of the desulphuration system.
- What effects does co-firing have on SCR or SNCR systems?
- What is the effect on electric precipitators or other types of flue gas filter? The fly ash composition and mass flow rate will change.
- Changes in fly ash quality and volume? How does co-firing change ash utilisation possibilities?
- Depending on the chosen fuel feeding system, some changes have to be made to burners, fuel processing and feeding systems, boiler automation and other boiler plant auxiliary equipment.

Pilot combustion reactors are designed to be a simplified miniature of a real power plant boiler. Pilot reactors are used in combustion research in many research centres and universities all over the world.



*Bubbling bed pilot reactor for testing of fuels and combustion behavior.  
VTT Processes.*

## DEPOSIT FORMATION CAN BE DETECTED WITH APPROPRIATE TOOLS



*Deposit formation test probe for full-scale boilers before and after a test period in a superheater area. VTT Processes.*



*Deposits on superheater tubes. VTT Processes.*

The reactors have been used for studies on:

- combustion profile of fuel in CFB
- fuel reactivity
- boiler material behaviour, durability
- emissions, emission control
- ash chemistry
- slagging, fouling, sintering
- corrosion
- power plant availability

Studies provide information on:

- power plant competitiveness, investment costs, operation and maintenance costs
- environmental effects of power production: emissions
- power plant efficiency
- fuel flexibility



## CO-FIRING BRINGS LOCAL BIOMASS RESOURCES INTO LARGE-SCALE POWER PRODUCTION

In an optimal situation, co-combustion of biofuel with fossil fuels derives benefits from both fuel types and also provides some “extra” advantages. These could be for example the reactions between different chemical elements originating from biofuel and fossil fuel. These interesting reactions include the reactions between sulphur and aluminium silicates in the fossil fuel and alkalis in biomass ash. Alkalis work the same way as lime stone, or dolomite absorbing the sulphur, resulting in lower sulphur dioxide emissions in the flue gas. Another example of mutual interests is the chlorine-binding capacity of fossil fuels. The sulphur level of biofuels is generally quite low. In some cases, the chlorine content of a biofuel may be quite high, which means there is a higher risk of corrosion in the boiler. Another benefit of co-combustion is the better use of local energy sources, decreased demand for waste disposal and landfilling, more effective use of resources and saving of fossil fuel reserves. However, improper choices of fuels, boiler design, or operating conditions could minimise or even negate many of the advantages of co-combustion, and in some cases may even lead to damage to the equipment.

With regard to biomass, co-combustion in large plants creates a potential for high electric efficiencies due to high steam parameters and technical measures for efficiency improvement. Therefore co-combustion in large thermal power plants can lead to an overall saving of fuels in comparison to independent fossil and biomass plants.

The possibility to co-fire biomass in coal-fired boilers offers a huge potential on the European level as well as worldwide. It is probably one of the most realistic ways to contribute to achieving the

objective on doubling the share of renewable energy sources in the EU energy balance.

Co-combustion is commonly used in the USA, Finland, Denmark, Germany, Austria, Spain, Sweden and many other IEA countries. The production capacity of a co-combustion plant is typically 50 to 700 MW<sub>e</sub>, and there are also a few units between 5 and 50 MW<sub>e</sub>.

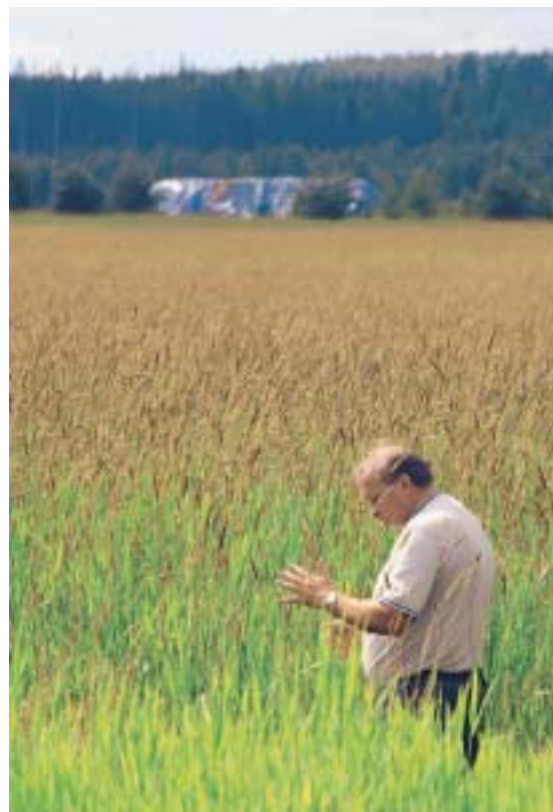
The most common technology is pulverised fuel combustion. The most suitable technology, however, is fluidised bed combustion, at least if the amount of biomass in the fuel flow is high and especially when the moisture content of the biomass is high.

The suitable commercial technology is already available for new co-combustion plants, but the real challenge is to develop suitable technologies for retrofits in existing plants.

Fuel flexibility, i.e. combustion of fuels with varying relative amounts of coal and biomass, pose new challenges for plant operators. Especially understanding the deposition formation and behaviour is a key issue in optimising plant operation and in securing plant performance and high availability.



*Harvesting of small-size trees by an accumulative harvester head, which collects the trees. Timberjack.*



*Reed canary grass yields 5–7 tonnes of dry matter per hectare even in the Nordic conditions. The grass is chopped and usually co-fired with peat. Våpo Oy.*

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## ALTENER PROGRAMME

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The development of renewable energy - particularly energy from wind, water, solar power and biomass - is a central aim of the European Commission's energy policy. There are several reasons for this:

Renewable energy has an important role to play in reducing Carbon Dioxide (CO<sub>2</sub>) emissions - a major Community objective.

Increasing the share of renewable energy in the energy balance enhances sustainability. It also helps to improve the security of energy supply by reducing the Community's growing dependence on imported energy sources.

Renewable energy sources are expected to be economically competitive with conventional energy sources in the medium to long term.

Renewable energy is, by definition, local energy. Its development can create new business, bring employment and encourage economic and social cohesion in regions that otherwise lack industrial development.

There is a considerable export potential for renewable energy technologies, particularly in the developing world.

ALTENER, the only Community programme to focus exclusively on the promotion of renewable energy sources, ended its five-year term at the end of 1997. It has now been succeeded by ALTENER II, an initiative that will extend activities in the renewable energies field and make a major contribution to the Community Strategy and Action Plan outlined in the White Paper 'Energy for the Future: Renewable Sources of Energy'.

The need for Community support for renewable energy is clear. While several of the technologies, notably wind energy, small-scale hydro power and energy from biomass, are economically viable and competitive, and others are approaching viability, initial investment costs are high and investors often lack confidence in technologies that are relatively unknown. As a result, development has been limited, and the sector needs help if it is to 'take off' in marketing terms.

[http://europa.eu.int/comm/dgs/energy\\_transport/index\\_en.html](http://europa.eu.int/comm/dgs/energy_transport/index_en.html)



**Altener**

<http://eubionet.vtt.fi>

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