Workshop on

Options for high percentage biomass cofiring in new power plants

Arranged by:

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June 30, 2009
European Biomass Conference, Hamburg, Germany

IEA Bioenergy

Task 32: Biomass Combustion and Cofiring

IEA Bioenergy Task 32 workshop

Options for high percentage biomass cofiring in new power plants

June 30, 2009, Hamburg , Germany

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Location: European Biomass Conference, Hamburg

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15:35	Torrefaction (Ewout Maaskant, Topell)
16:00	Fluid bed combustion and gasification (Edward Pfeiffer, KEMA)
16:25	coffee break
16:45	Ash related topics in high percentage cofiring (Jaap Kiel, ECN)
17:10	Direct cofiring (Bill Livingston, Doosan Babcock)
17:35	Discussion
17:45	Closing

Background to the workshop

Worldwide, combustion already provides over 90% of the energy generated from biomass. The main benefits of combustion compared to other thermochemical conversion technologies (i.e. gasification, pyrolysis, liquefaction) is that combustion technologies are commercially available and can be integrated with existing infrastructure.

Currently, high quality solid biomass fuels are popular in co-firing applications where high compatibility with coal can lead to significant reductions in investments associated with plant modifications. However, high quality biomass demand for co-firing applications is increasing, which in the end may result in an increasing market price. Furthermore, local circumstances may favour lower quality biomass types above high quality biomass types. These circumstances may include reduction of pre-processing and logistics, use of waste streams, or local governmental incentives to stimulate the production of crops for own use. Therefore, it is expected that whereas the last decade has been mostly aimed at further exchanging coal by biomass that has a comparable properties, for the next decade it is expected that the availability, logistics, processing and conversion of more complex fuel types will be a major issue. Dedicated biomass pre-processing and advanced co-firing systems are getting more and more acquainted. And although a lot of work has still to be done, being flexible to fire a large variety of biomass types, gives co-firing a big advantage to reduce CO_2 emissions fast.

In the power sector "multi fuel concepts" are being developed aiming at maximum fuel flexibility and high biomass share. Approaches differ from combustion to co-gasification in IGCC, using entrained flow or fluidised bed. The market aiming at high efficiency low CO_2 systems is multi billion. In Figure 1, an example is given of a next generation co-firing system.

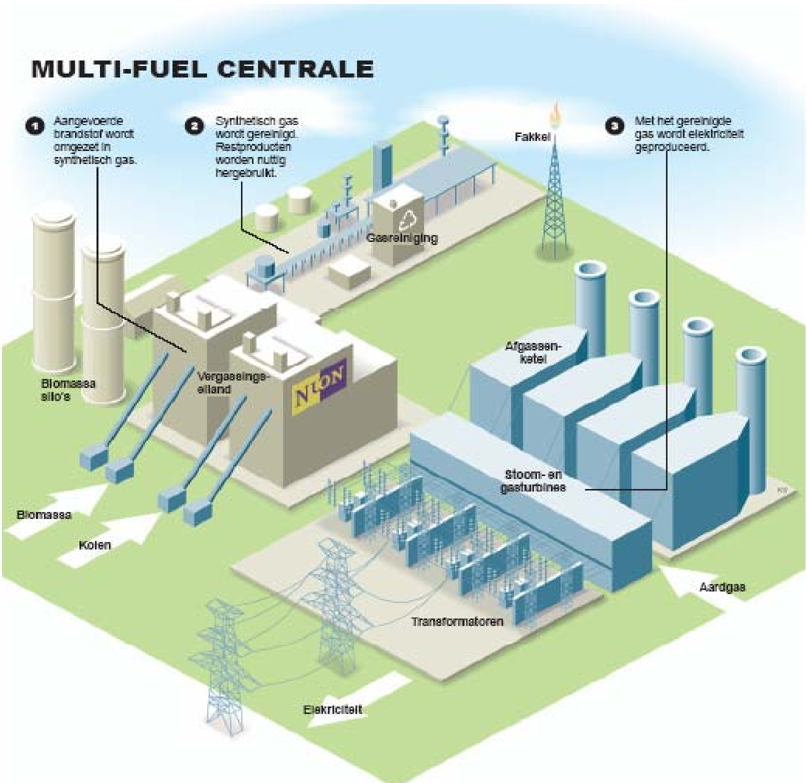


Figure 1. Multi fuel power plant gasification combined cycle (NUON, 2006)

This report summarizes the presentations of a Task 32 workshop, which was held in Hamburg in June 2009. The workshop was on increased co-firing percentages for both existing and new plants, with a specific emphasis on next generation co-firing systems. In the workshop technology developments in relation to next generation co-firing were made indicating the most promising technical concepts. The presentations include key experiences and figures, and discussed experienced and expected performances. The presentations covered a wide variety of topics, covering the whole scale of co-firing techniques and discussing various ways to achieve high co-firing percentages, also for not-normal fuel types, or even new commodity (torrefied) fuel types. The aim of all these presentations was to show the extended possibility and chances for co-firing very high percentages (up to 100% biomass) in large scale units and a fast and effective way. Although there are challenges with respect to fuel preparation, handling, combustion and operation, these presentations showed that when done properly, coal can be exchanged by biomass in a fast way and in many cases for restricted costs and in a limited time.

Report of the workshop

Opening, Sjaak van Loo

Chairman Sjaak van Loo opened the workshop and wished everybody a warm welcome. Task 32 is aiming to increase the implementation of co-firing. This has to be picked up fast.

The focus of the workshop is to discuss new technologies for co-firing, and share the ideas with the audience. Therefore, a number of presentations have been prepared covering the field of new technologies.

Amager #1, Tina Kristensen, Vattenfall A/S

Tina Kristensen presented the first experiences with respect to fuel flexibility in the new coal, biomass and oil fired combined heat and power plant, Amager Unit #1, in Copenhagen, Denmark.

Amager Power Station used to be owned by Energy E2. After the split to Vattenfall and Dong Energy, Amager Power Station is currently owned by Vattenfall. Fuel with a total thermal input of 350 MW_{th} enters the unit. A back pressure turbine can deliver up to 71 MW_e on electricity. The heat is delivered to the district heating system.

Tina Kristensen is project manager of the construction of the boiler and fuel handling system of the new boiler that has been built at Amager Unit #1. The old unit boiler has been replaced by a new boiler in order to make the unit as fuel flexible as possible. The framework, boiler house and electrostatic precipitator were kept in place.

The boiler is constructed to be able to fire a wide range of biomass types, including bio pellets (as straw pellets) and coal, with firing percentage going up to 90 or 100%. Even when firing straw pellets, the unit is able to reach maximum continuous rating. In order to achieve this, the whole boiler and piping had to be constructed such, that it just fits into the present boiler housing.

On the contrast Amager Unit #2 has been firing straw since 2001. Currently, Unit #2 is being decommissioned. During the period from 2001 up to now, Vattenfall has obtained a lot of experience with firing straw.

A temperature of 70°C is the maximum temperature for the mills when milling biomass for reasons of safety. One of the difficulties is that under these conditions (the relatively cold primary air), the bio pellets may be difficult to ignite, and flame attachment has to be ensured.

The system contains of 3 mills, feeding each a burner layer consisting of 4 burners in each layer of the front wall fired boiler. Water canons are used for soot blowing. The general experiences with the soot blowing are good. The most critical component is the material that is used. However, the commissioning experiences up to now are promising.

Torrefaction, Ewout Maaskant, Topell

One of the most promising techniques for obtaining a commodity fuel in order to exchange coal for a coal-like fuel is by means of torrefaction of biomass. Ewout Maaskant of Topell gave an overview of the work that has been done at Topell to producing such a fuel, based on the Torbed technology.

With torrefaction the biomass undergoes a mild pyrolysis. As a result the calorific value of the biomass increases. Various torrefaction processes are under development. Topell employs the Torbed technology. In a torbed reactor intense mixing is achieved between the material and the process air, by introducing a swirling flow. According to Topell, this generates very fast reaction kinetics and efficient heat and mass transfer, resulting in a short torrefaction processing time. The minimum time for obtaining a coal-a-like torrefied material was said to be 90 seconds. With increasing torrefaction time and torrefaction temperature, the calorific value increases, however, does come at a cost of thermal input.

The biomass goes from a hydrophilic to a fairly homogeneous hydrophobic material. After increasing the energy density by torrefaction, the bulk energy density is increased by pelletisation. When torrefied material is then pelletised an approximate 70% higher bulk energy density compared to wood is achieved. Value added was seen for co-firing purposes was mainly seen when biomass has to be transported over a long distance.

Various materials have been torrefied in a small scale batch-type reactor. These fuel types included wood chips, grass, straw, and palm oil kernels. With the experiences from the batch reactor, Topell expects to build a 60.000 Mton torrefaction plant in the Netherlands. This plant is scheduled to be operational in 2010.

Fluid bed combustion and gasificaiton, Edward Pfeiffer, KEMA

Large scale application of biomass includes co-firing high percentages biomass in pulverized fuel boilers. However, how to deal with more complicated biomass fuels, when there are no coal-fired power plants in the vicinity or when biomass combustion needs to be extended or when biomass resources are not close to the plant. Then, there are various options. A promising option is considering fluidized bed combustion or even gasification.

Edward Pfeiffer of KEMA presented the latest developments in fluidized bed combustion and gasification. According to Pfeiffer, the pulverized fuel conversion technology can be adopted, a commodity fuel can be produced, or biomass can be combusted in a separate technology like a fluidized bed, or partly converted in a gasifier with the syngas being combusted in for example a boiler or gas turbine.

The question is then, what the technology can offer for large scale application (> 20 MW_e). For these applications often no subsidy schemes are applicable, and here fluidized bed combustion may come into play. Compared to co-firing in pulverized coal boilers, fluidized bed combustion and gasification offer a greater fuel flexibility (less fuel preparation), reach higher biomass firing percentages (up to 100%), and with dedicated flue gas cleaning can handle polluted fuels.

However, investment costs are higher (500 €/kW$_e$ or more), electric efficiency may be lower (40% or less) and the technology may be more complicated or less proven. Therefore, according to Pfeiffer, fluidized bed combustion and gasification operate in areas where co-firing stops.

A number of fluidized bed combustors up to 250 MW$_e$ were presented , with net electric efficiencies of up to 40%. In these stations coal is either adapted in small amounts (< 20%) or used as a backup fuel. Furthermore, fluidized bed projects that are under construction were mentioned.

It was mentioned that gasification may add fuel flexibility to a coal fired power plant. On the other hand, the majority of gasification projects are mainly performed in the chemicals and liquid fuels industry. Gasification in the power industry adopts mainly petroleum residue and coal as fuel, and the biomass applications are mainly demonstration plants. Also, the investment costs are high (about 3,000 €/kW$_e$) and there are only a few suppliers. Gasifiers may find their use as an up-front installation for application with an existing pulverized fuel unit. But adopting gasifiers in an integrated gasification combined cycle (IGCC) is getting more and more attention. One of the major issues here is how to operate the installation in a good way.

According to Pfeiffer, next to co-firing, CFB combustion is the only mature technology to be adopted on a large scale. However, CFB combustion ranges from 9 to 11 €cts/kWh, while co-firing usually is in the range of 8 to 9 €cts/kWh. Therefore, CFB is an option to fill the technology gaps, for example when fuel flexibility is required or difficult fuels have to be combusted at a high efficiency.

Ash related impacts in high percentage cofiring, Jaap Kiel, ECN

At high percentages co-firing, one shall consider topics related to ash. Jaap Kiel of ECN presented challenges and bottlenecks that are related to the ashes when co-firing, and also presented research and development work that is being done on ash related topics.

Currently, co-firing is mainly done in pulverized fuel boilers. In the Netherlands a lot of experience has been gained on co-firing large amounts of biomass in almost all coal fired boilers. For example, Amer Power Station co-fires hundreds of ktonnes of biomass, mainly wood pellets, per year, both by means of direct and indirect co-firing.

It is understood that there are many technical bottlenecks in biomass co-firing, and many of those bottlenecks are related to the ash. ECN does a considerable amount of research with respect to ash related issues. It is crucial to simulate the ash behaviour, and lab-scale experiments and modelling are performed at ECN. In order to do this research ECN has developed a large-scale combustion simulator, which has a novel reactor design to achieve a proper burnout. Apart from a lab-scale simulator, ECN has also full-scale probes and computational fluid dynamics modelling to study the behaviour of ashes.

In coal the potassium content may be relatively high, whereas in biomass the chlorine content in some cases is very high (as for example in straw). For determination of the effect of the ashes on for example deposition, corrosion, SCR operation, ESP operation and emissions, it is important to know how ashes are formed and how they interact. This depends for example on the ash and mineral content in the fuel, but also on the amount of alkalis, sulphur and chlorine. The potassium enhances the burn-out because of its catalytic character. The alkali metals in meat and bone meal can significantly increase the risk of corrosion and fouling. However, in co-firing applications coal minerals may control the alkali behaviour and decrease these risks.

Experiments have been performed at various steam conditions and with and without the addition of sulphur, by adding SO_2. Deposition rates of coal and coal+straw have been measured under ultra-supercritical conditions, at various temperatures. The conclusion was that it is in principle not so that a higher steam temperature definitely results in a higher deposition rate.

Furthermore, ECN performed initial experiments of ash deposition under oxy-fuel conditions. A higher fouling factor was found. If R&D proceeds this will finally result in a strong tool to prevent fouling, and that is a way forward for higher percentages co-firing.

Direct cofiring, Bill Livingston, Doosan Babcock Ltd.

Various options exist for co-firing biomass. The principal biomass co-firing options for pulverized fuel boilers include direct co-firing as with milling of biomass pellets through modified mills, co-milling of the biomass with the coal, injection into the existing coal lines or through modified or dedicated burners, and indirect co-firing by gasification with co-firing of the biomass product gas. Bill Livingston of Doosan Babcock gave an overview of the direct co-firing options in his presentation.

Biomass co-firing by milling the biomass through modified coal mills is the simplest option. Investment is only modest and in principle, only some receiving and feeding works have to be done. However, co-firing percentages are limited. This is especially a promising route when it comes to co-firing torrefied biomass. In that case, significantly higher co-firing percentages may be achieved.

When co-milling biomass pellets with coal, this often leads to a higher maintenance of the coal mills. Blades have to be exchanged every 3-4 weeks. The maximum heat input is mostly related to the lower energy density of the biomass, with a possible derate of around 50-70% of that with coal. The derate will be smaller when considering torrefied material.

(Pre)-milled biomass can also be injected in the existing coal lines, can be injected directly in the furnace (however not very common) and through new dedicated burners. In that case, always pneumatic conveying is used from the milling equipment or storage to the boiler. A problem with the biomass burners is that they are currently not widely available. In some cases (for example with straw) there is an increased risk of blockage when injecting the milled biomass in the coal lines. In that case, a better option is to use dedicated biomass burners. Also, modification of the existing burners is possible. This is not easy, but can be done.

However, according to Bill Livingston, the favourite route for co-firing is still via direct injection into the coal pipe. One of the advantages is that when the biomass system fails, there is still a stable coal system. One of the best examples of this is the Drax Power Station in the United Kingdom, for which Doosan has supplied a complete injection system. Since 2005 an each year 125000 tons of biomass has been fired at Drax. In the system Doosan has supplied, the biomass is fed by a screw feed, and is injected into the mills by means of a rotary valve. The milled biomass is then transported to the coal lines by means of a pneumatic transport. An actuated biomass shut off valve isolates the biomass system from the coal line. It is thought to be a relatively simple, cheap and flexible system that can co-fire up to 40% of biomass. Higher co-firing ratios can be achieved, but in that case the fuel type has to be controlled.

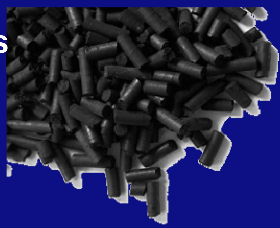
Conclusion and final remarks, Sjaak van Loo

Sjaak van Loo thanks all the speakers of the workshop. He concludes that various options for co-firing have been mentioned, including adapting a plant, adapting a fuel and adapting a technology. We are now moving towards control. The question is how to achieve these high percentages of co-firing, and what is the range for all the options. During the workshop ranges have been mentioned, but it is also important to make cross cuts between these different options.

Local circumstances may influence the choice of co-firing, and this choice is often driven by experience, and we are still in a learning curve. As with coal firing there is no ‘one-technology’, it is not expected that for co-firing a single technology will give the answer. There will be more technologies next to each other.

Annex 1. Introduction,
Sjaak van Loo, IEA Bioenergy Task 32

Options for high percentage biomass cofiring in new power plants



IEA Bioenergy Task 32 Expert Workshop, Hamburg, 30 June 2009

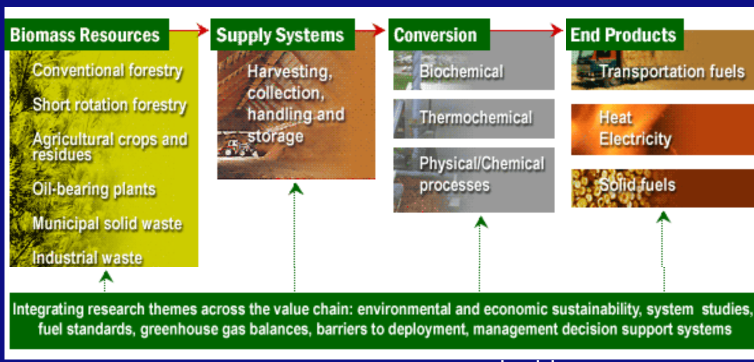
Introduction to IEA Bioenergy (1)

- The IEA was founded to implement an international energy programme in response to the oil shocks.
- Activities are directed towards collective energy policy objectives of energy security, economic and social development, and environmental protection.
- Activities are set up under Implementing Agreements. There are 40 active Implementing Agreements.

IEA Bioenergy

Introduction to IEA Bioenergy (2)

- IEA Bioenergy provides an umbrella organization where experts from research, government and industry work together



www.ieabioenergy.com

IEA Bioenergy Task 32: Biomass Combustion and Co-firing (1)

Objectives:

- To stimulate further expansion of the production of energy from biomass combustion

- Generating and disseminating information on technical and non-technical barriers and anticipated solutions for:
  - **dedicated biomass combustion systems, and;**
  - **biomass co-firing in existing coal fired power plants.**

IEA Bioenergy Task 32: Biomass Combustion and Co-firing (2)

- Experts from 13 countries:
  Austria, Belgium, Canada, Denmark, European Commission, Finland, Germany, Italy, Netherlands, Norway, Sweden, Switzerland, United Kingdom
- Working together in:
  - **Cooperative projects**
  - **Meetings, Workshops, Conferences, Excursions**
  - **Cooperation with other Networks**
- Reports etc. can be found on our website:
  www.ieabioenergytask32.com

Introduction to the workshop

- Cofiring in PC boilers is one of **the largest, most rapidly growing contributor to renewable electricity production** around the world
- Existing power plants have their cofiring limitations
- Newly build coal fired power plants offer opportunities for implementing new cofiring approaches

▶ This workshop provides a platform to exchange ideas and experiences with **new biomass cofiring concepts**, particularly suitable for new power plants

Agenda

15:00 Opening (Sjaak van Loo, IEA Bioenergy Task 32)

15:10 Amager #1 (Tina Kristensen, Vattenfall)

15:35 Torrefaction (Ewout Maaskant, Topell)

16:00 Fluid bed combustion and gasification (Edward Pfeiffer, KEMA)

16:25 coffee break

16:45 Ash related topics in high percentage cofiring (Jaap Kiel, ECN)

17:10 Direct cofiring (Bill Livingston, Doosan Babcock)

17:35 Discussion

17:45 Closing

Sheets available soon on

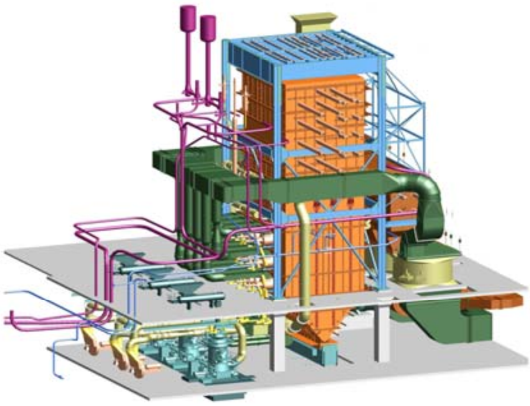
www.ieabioenergytask32.com

Annex 2. Amager #1

Tina Kristensen, Vattenfall

30.06.09. Tina Kristensen. Vattenfall A/S. Heat Nordic.

Fuel flexibility in the new coal, biomass and oil fired CHP plant Amager Unit 1 in Copenhagen



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Agenda

1. Generel information about the AMV1 project
2. Experiences with biomass in Denmark used in the design of the AMV1 boiler
3. Description of the AMV1 boiler – what measures are done to prepare for the biomass firing
4. Commisioning experiences until now..
5. Questions!

VATTENFALL

Generel information about the AMV1-project

- New boiler and fuel handling system
  - Fuels: wood pellets, straw pellets, coal and oil
  - Thermal input: 350 MJ/s
  - Pressure: 185 bar
  - Temperature: 562°C
- New turbine – a back pressure turbine
  - Power net: 71 MW
  - District heat steam: 160 MJ/s
  - District heat water: 200 MJ/s
- New environmental plants
- Reuse of boiler house, boiler frame, fuel silos and electrostatic filter
- New buildings for environmental plants
- New control room

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The multi fuel AMV1… load range with various fuels

- Coal: 35 % - 100 %
- Straw pellets: 35 % - 90 %
- Wood pellets: 35 % - 100 %
- Heavy fuel oil: 20 % - 100 %

- Bio pellets either as single fuel (”campaign”) or as co-firing with coal
- Heavy fuel oil as start up fuel or ”emergency” fuel
- Range restrictions on co-firing due to quality of the ash in combination with boiler load and capacity of the mills

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A little history…

- Project decided in 2004 in the former ENERGY E2 – contract with BWE on the boiler signed in december 2004
- Biopellets was planned to deliver approximately 40 % of the annual energy input
- Fabrication and erection of the boiler 2005-2008 – while prices were on their highest and suppliers extremely busy ..
- Since 1. july part of ENERGY E2 part of the Vattenfall Group
- Commisioning of the unit in 2008-2009 – economical crisis, suppliers crying for extra work!
- The world has become a lot greener – now everyone expects AMV1 to run entirely on biomass!

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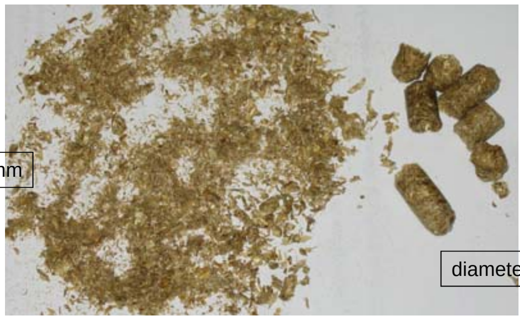
Experiences with biomass in Denmark – small and large scale

- Many small straw fired stoker boilers
- Cofiring wood pellets with oil on the new Avedøre 2 boiler (since 2001)
- Straw pellets since 2003 on the old AMV2 boiler (2071)



diameter~3-5mm

diameter~6-8mm

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Experiences with biomass in Denmark – small and large scale

- Corrosion - which steels can last and which cannot!
- Steam temperature is an important parameter – especially with straw firing
- Slagging and fouling – both in the furnace and in between the super heater tubes
- Self ignition in the mills is seen at quite low temperatures
- Attachment of the flame is an issue
- Burn out
- Care has to be taken in realtion to the risk of explosion in very dusty atmosphere (ATEX)
- Poisoning of the deNOx catalyst with straw ash
- Sootblowing (water and steam) is necessary
- Electrostatic Filter – sensitive to straw ash at temperatures > 135 °C

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Description of the AMV1 boiler – what measures are done to prepare for the biomass

- As large a furnace as possible
- 400 mm split in 1. pass, 200 mm in top of 2. pass, ribbed tubes only in 3. pass
- Fully enamelled air preheaters
- 3 large mills – full load on coal on 2 mills – possible with full load on wood pellets on 3 mills
- Pressure resistant mills and feeders
- Explosion surpressing devices on mills and dust pipes
- 4 water soot blowers in furnace and steam sootblowers in all super heaters, economizer and air preheaters
- Low dust deNOx is chosen (after filter and FGD)
- 3 ”primary air coolers” – to ensure sufficent cooling of the flue gas in the air preheaters
- With drawal of the coarse ash before the 3.rd pass
- Choice of steels – extra material to account for the corrosion
- XL system for removal of bottom ash!

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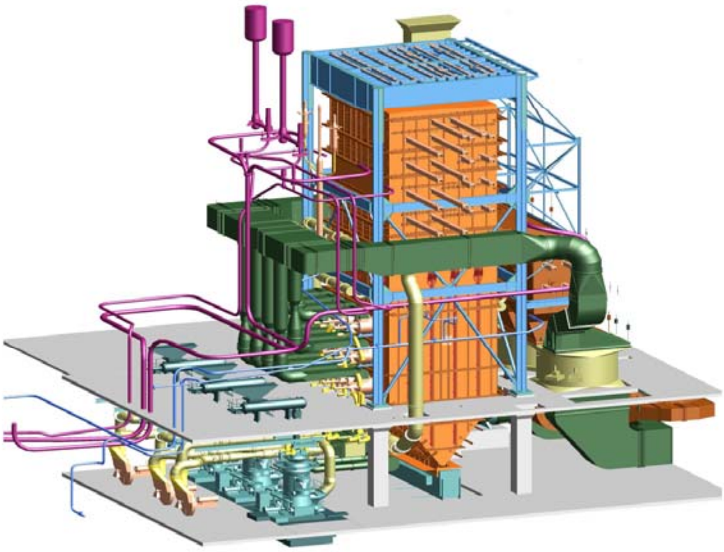
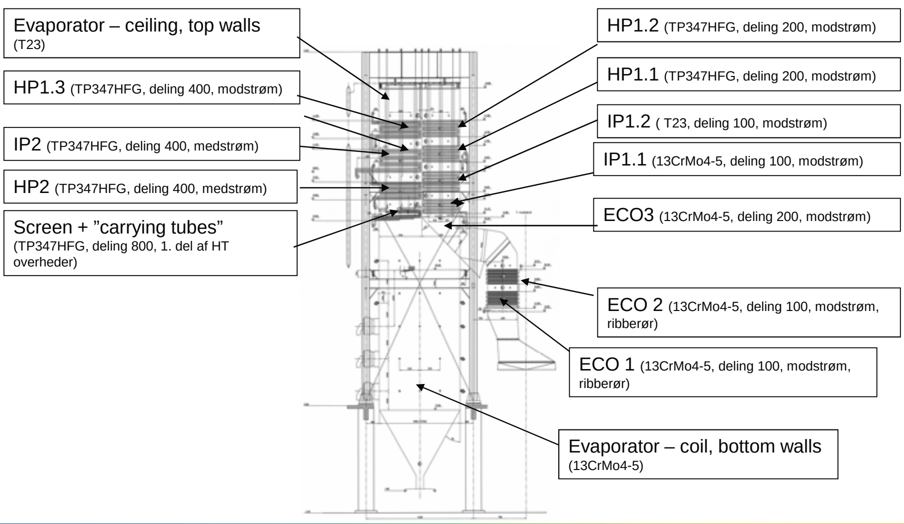
AMV1 boiler – on the outside !



AMV1 boiler – heating surfaces



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Commisioning experiences until now

- Commisioning until now primarily on heavy fuel oil. Approx. 1 month on coal (part load) and 3 weeks on bio pellets (also part load)
- Experiences with bio pellets until now are:
  - As little primary air as possible – flame attachment
  - A conventional Loesche coal mill can handle both straw and wood pellets with only minor modfications
  - Water soot blowing seems very effective
  - Mill performance with bio pellets is comparable with coal
  - Coarse ash removal is effective

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The end…

Thank you for your attention!
Any questions???

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Annex 3. Torrefaction
Ewout Maaskant, Topell

Workshop IEA Bioenergy Task 32 –
New Biomass Co-firing Concepts

Topell on torrefaction

Hamburg, June 30th 2009

TOPELL

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1. Torrefaction – 'by definition'
2. Torrefaction – by Topell
3. Value added by torrefaction

TOPELL

TORREFACTION MAKES BIOMASS 'COAL LIKE'

Caloric value biomass increases as
O and H 'leave' as CO_2, H_2O and organic acids

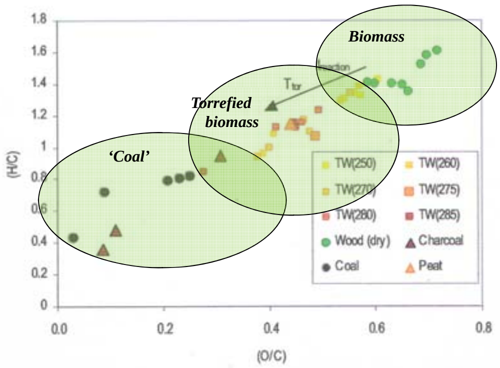

Figure 2.6 *Van Krevelen diagram for torrefied wood (TW) produced at different conditions, untreated wood, coal, charcoal and peat samples. Coal and peat data is taken from Ullmann (1999). Wood and torrefied wood from Bourgois and Doat (1984), Girard and Shah (1989) and Pentananunt et al. (1990)*

Source: Bergman, P.C.A.; Boersma, A.R.; Zwart, R.W.R.; Kiel, J.H.A. Torrefaction for biomass co-firing in existing coal-fired power stations "BIOCOAL". ECN-C--05-013 juli 2005; 72p.

TOPELL

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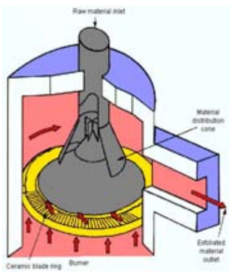
1. Torrefaction – 'by definition'
2. Torrefaction – by Topell
3. Value added by torrefaction

TOPELL

TOPELL EMPLOYS TORBED-TECHNOLOGY TO TORREFY

Torbed-technology superior for heat transfer

Torbed-reactor	How it operates	Advantages
	• High turbulence inside reactor causes intense contact between material and process air • Small bed volumes • No moving parts inside reactor	• Very fast reaction kinetics, very efficient heat/mass transfer, and therefore short duration times for specific processes • Low pressure drops lead to high energy efficiencies • Ability to retain wide particle size ranges, no need for grading

TOPELL

TOPELL TEST PLANT HAS SUCCESFULLY DEMONSTRATED EFFICIENT TORREFACTION

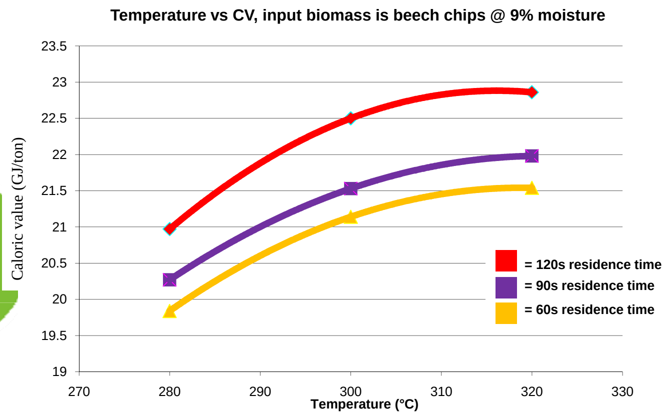
At small scale – batch reactor

A variety of feedstocks have been torrefied at the test reactor: woodchips, grass, straw, palm oil kernels, etc.

TOPELL

TORREFACTION IN TORBED-REACTOR IS FAST PROCESS

22 GJ/ton CV reached at 320 ^{0}C in 90 seconds



Source: Topell test data

TOPELL

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1. Torrefaction – 'by definition'
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TOPELL

COMBINING TORREFACTION AND PELLETING LEADS TO SUPERIOR ENERGY DENSITY (GJ/M^3)
Handling characteristics improve substantially

Torrefaction + **Pelleting** = **Torrefied pellets**

Torrefaction
- Increased calorific value (~22 MJ/kg) when compared to wood (~+30%)
- Hydrophobic nature
- Easy grindability
- No biological activity
- Homogeneous output from heterogeneous input

Pelleting
- Increased bulk density (~ 800 kg/m^3) when compared to regular wood pellet (~+30%)
- Hydrophobic nature

Torrefied pellets
- Increased energy density (~19 GJ/m3) when compared to wood pellets (~+70%)
- Hydrophobic nature
- Easy grindability (*Hardgrove Grindability Index 38-48*)
- No biological activity
- Homogeneous output from heterogeneous input

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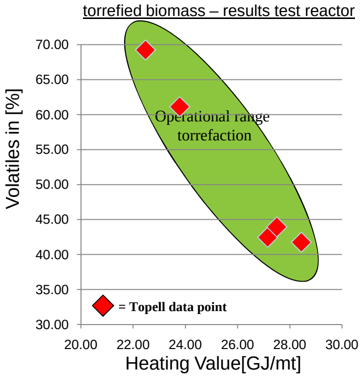
TORREFACTION CONVERTS BIOMASS INTO TAILOR-MADE, CLEAN BIOFUEL
Heating value, among others, is matter of choice

Tailor-made fuel

Volatile content vs. heating value torrefied biomass – results test reactor



Clean fuel

Torrefied biomass compared to coal

	COAL [1]	TOPELL [2]
Caloric value	25 GJ/mt	23 GJ/mt
Ash	10%	3%
Sulfur	3%	0.1%
Nitrogen	1.5%	0.2%
Chlorine	0.05%	0.01%

[1]+[2] *indicative numbers*

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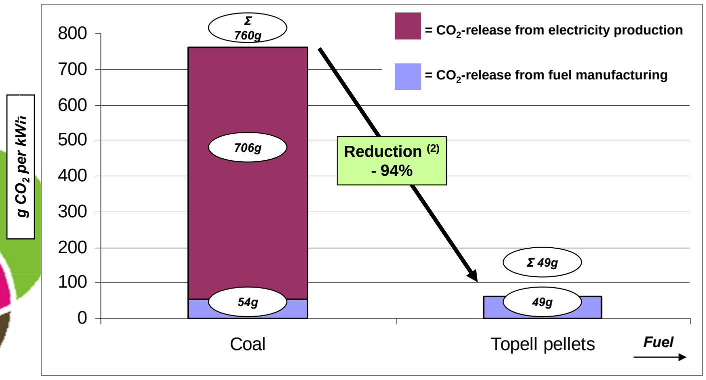
TORREFIED BIOMASS REDUCES CO2-EMISSIONS BY 94% WHEN COMPARED WITH COAL(1)

Eemshaven case, The Netherlands

Quantity of CO_2 (g) released per kWh electricity generated from fuel type



(1) *Preliminary results of study by DHV (The Netherlands) on CO2-emissions of electricity production process based on coal and Topell pellets respectively*

(2) *Reduction CO2-emissie per kWh: (760-49/760*100% = 94%*

TOPELL

TORREFIED BIOMASS WILL BE TAILOR-MADE

Different markets require different specs

Market	Value added in particular market
Large scale co-firing	• Biomass in general a low-cost, low-risk route to lower CO2-emissions; • When high volumes are needed, only torrefaction can make biomass from distant sources price competitive; • Torrefied biomass results in lower handling costs; • Torrefied biomass enables higher co-firing rates; • Product can be delivered in range of LHV's (20 – 25 GJ/ton) and sizes (pellet, briquet).
Steel production	• Fibrous biomass very hard to deploy in furnaces; • To replace injection coal, biomass product needs to have LHV of more than 25 GJ/ton.
Residential/ decentralized heating	• Relatively high percentage of transport on wheels as cost in supply chain makes biomass expensive. Increasing volumetric energy density does decrease costs; • Limited storage space increases need for increased volumetric density; • Moisture content important as moisture leads to smoke and smell.
Biomass-to-Liquids	• Torrefied biomass serves as 'clean' feedstock for production of transportation fuels, which saves considerably on production costs of such fuels

TOPELL EXPECTS TO BUILD 60,000 MT PLANT IN DUIVEN (THE NETHERLANDS)
Operational per Q3 2010

TOPELL

Annex 4. Fluid bed combustion and gasification

Edward Pfeiffer, KEMA

High percentage biomass co-firing

Developments in fluid bed combustion and gasification

IEA task 32, Hamburg, 30th June, 2009

Edward Pfeiffer, Mark van de Ven

Experience you can trust.

Large scale bioenergy applications

- Large scale: above 20 MWe, above 200 kton/a biomass
- Co-firing in coal fired power plants is the reference

But:

- How to deal with more complicated biomass?
- What to do when short in coal fired power plants?
- When biomass combustion needs to be extended?
- When biomass resources are not close to the plant?

Solution: biomass combustion concepts based on fluidized bed combustion (FBC) and gasification

Added value FBC and gasification

Compared to co-firing FBC and gasification offer:

- Greater fuel flexibility, so less fuel preparation needed
- Up to 100% biomass possible …
- Polluted biomass can be used, dedicated gas cleaning

But:

- Investment costs are higher (> 500 €/kWe)
- Electric efficiency may be lower (< 40%)
- Technology may be more complicated, less proven.

FBC and gasification operate in areas where co-firing stops … adds value to power portfolio.

History and milestones

- Foster Wheeler started in ‘79, now 80 boilers up to 750 MWth
- Metso started in ‘80, now 70 boilers up to 455 MWth
- First CCGT based on biomass: Värnamo Sweden, ‘93 (TPS)
- First co-gasification unit: Lahti Finland, ’98 (Foster Wheeler)

Large scale applications, reference projects:

- Alhomens Kraft, Pietersaari, Finland, wood and peat, 550 MWth, built in 2002 by Kvaerner, now Metso Power
- Mälarenergi, Västerås, Sweden, wood and peat, 185 MWth, built in 2000 by Foster Wheeler

Conclusion: the experience in biomass CFB is available!

Alholmens Kraft, Pietarsaari

- CFB combustion
- 550 MWth, 700 ton/h
- 165 bar, 545 ºC
- Reheat at 40 bar
- 250 MWe unit size
- Net electric efficiency 40%
- Boiler efficiency 92%
- Flue gas recirculation
- Availability 90%
- Peat, (waste) wood, bark
- Recovered fuel up to 5%
- Coal is used as back up fuel

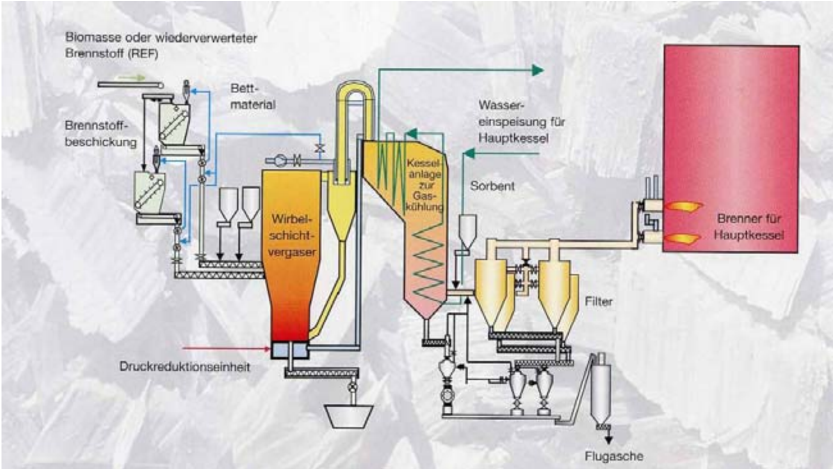
CHP paper mill

Mälarenergi, Västerås

- CFB combustion
- 185MWth, 200 ton/h
- 170 bar, 540 °C
- Reheat at 39 bar
- 72 MWe, efficiency 39%
- Flue gas recirculation
- Availability 91%
- Peat, (waste)wood
- Co-firing coal < 20%
- CHP district heating

Lahti co-gasification

Adding fuel flexibility to coal fired power plant



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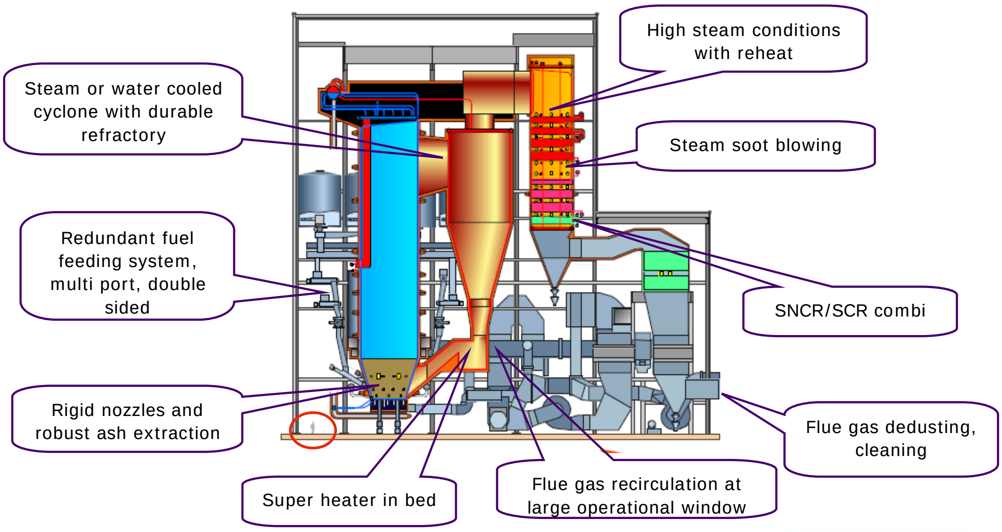
The world of large scale bioenergy

- Ongoing projects in Scandinavia, UK and the Netherlands
- Main players private investors, industry, power utilities
- DRAX in UK: first company to develop both co-firing and large scale stand alone CFB biomass combustion
- Up scaling takes place in area coal firing, Foster Wheeler realizes 460 MWe Lagisza power plant in Poland
- Design studies towards 800 MWe super critical CFB boilers are going on, based on coal combustion

Technology is available, so the initiatives. However economy and fuel sourcing are the bottleneck.

KEMA

Combustion, circulating fluidized bed



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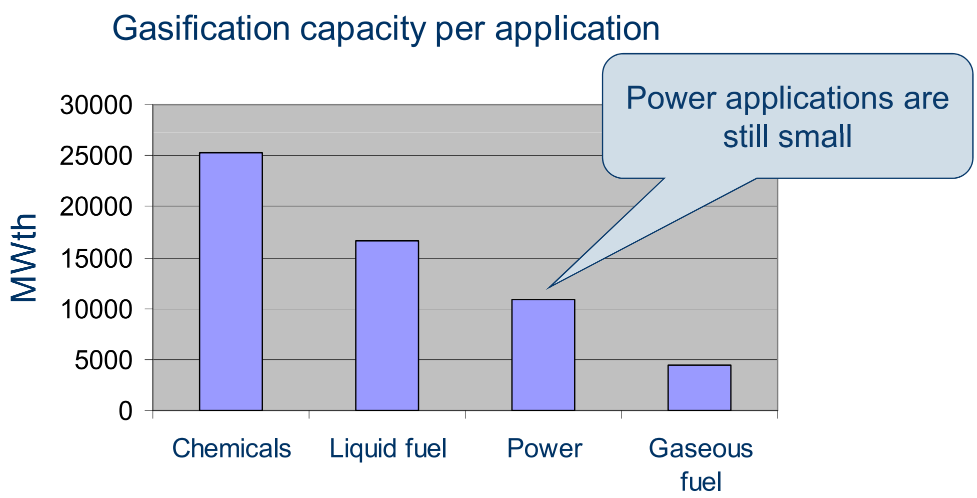
Large FBC, projects under development

Capex: indications, differences are big!

Power plant	Capacity (MW_e)	Capex (€/kWe)	Feedstock
Jyvaskyla, 2010 (Finland)	200	1,250	Large biomass variety
E-on Portbury Dock, 2014 (UK)	150	2,500	Wood chips
MGT Power Teeside (UK)	300	1,700	Wood chips

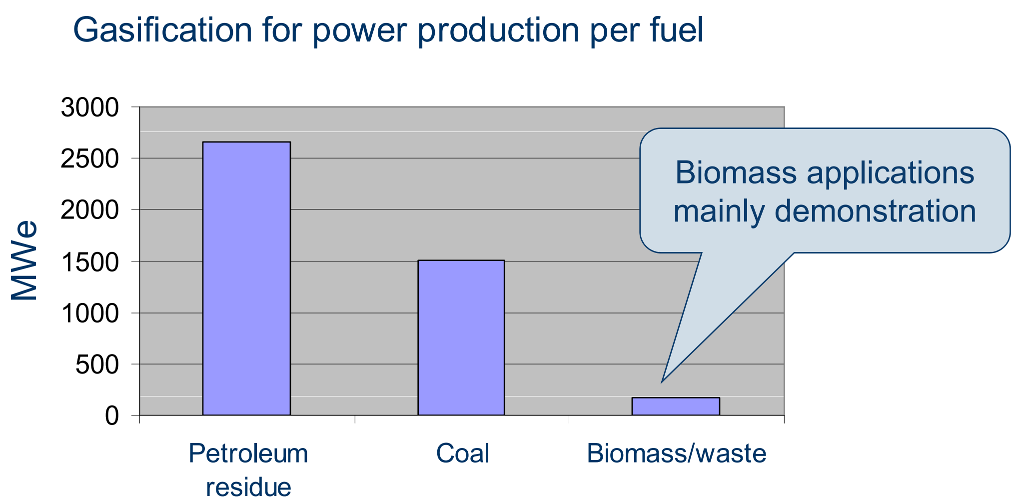
KEMA

Commercial status Gasification in 2007



www.gasification.org

Commercial status 2007, Gasification Power



www.gasification.org

Drivers, barriers Gasification for Power

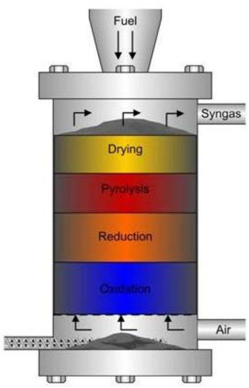
Main drivers:

- Outlook on higher efficiencies than co-firing
  Example: blast furnace gas in CCGT
  Up to 43% net in mid scale (150 MWe) D-class GT
  Up to 47% net in large scale (250 MWe) F-class GT
- Fuel flexibility
  Examples: co gasification Lahti and Geertruidenberg

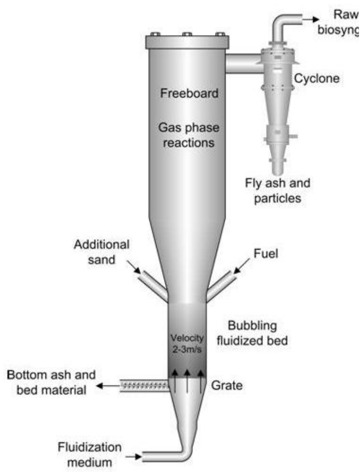
But:

- Investment costs are high, ± 3,000 €/kWe (< 250 MWe)
- Technology still not proven well enough
- Only a few suppliers.

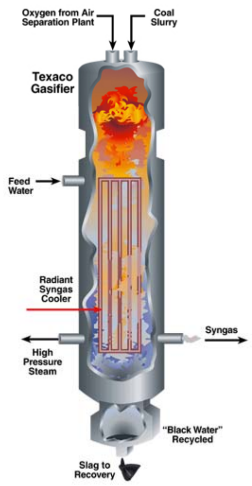
Gasifier types, size determined



Fixed bed

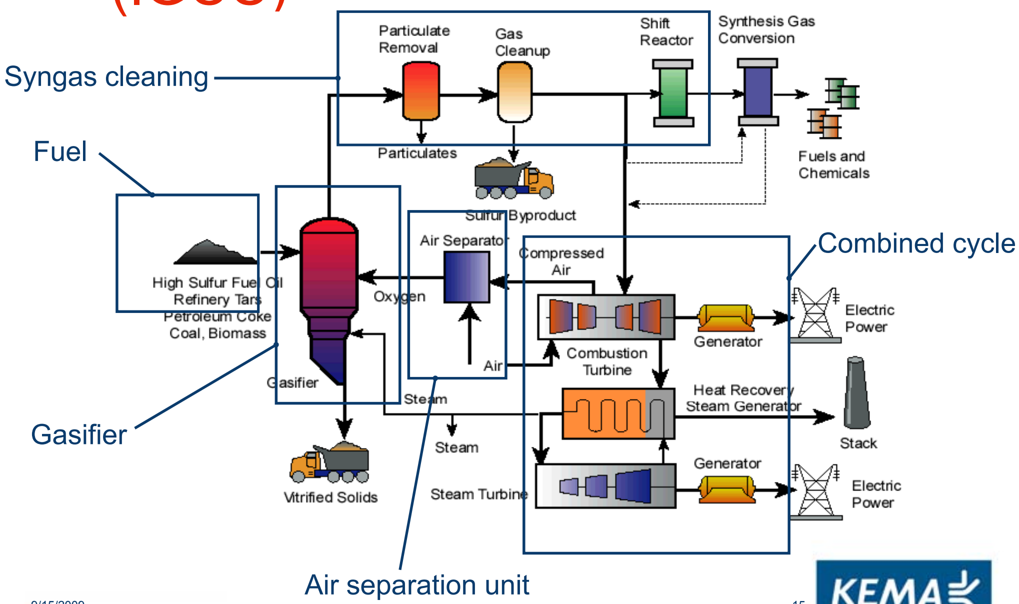


Fluidized bed



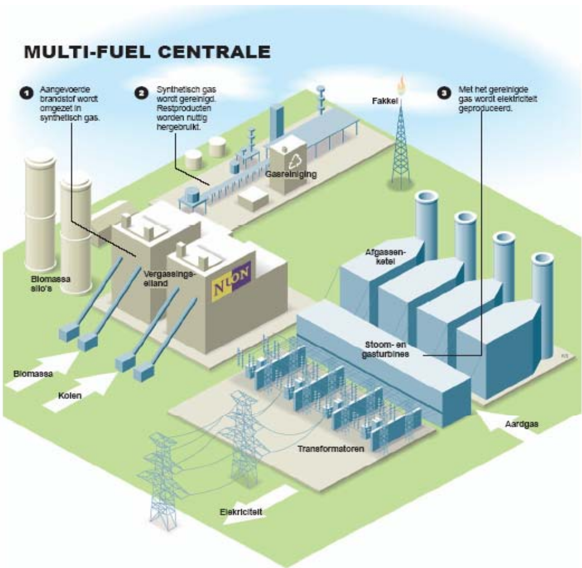
Entrained flow

Integrated gasification combined cycle (IGCC)



Gasification, Magnum concept

- 1,300 MWe
- Based on entrained flow
- Staged project development
- Start with CCGT
- Add coal gasifier
- Finally biomass handling
- Based on experiences with co gasification biomass WAC Buggenum, NL, 1993 Shell process, 253 MWe, efficiency 43%



Status of biomass gasification

Power plant	Capacity (MWth)	Application	Feedstock
Värnamo (Sweden) (1993)	18	Gas turbine SNG (2005)	Wood, straw, RDF
Güssing (Austria) (2002)	8	Gas engine CHP	Wood chips
Skive (Denmark) (2009)	2 times 10	Gas engine CHP	Wood pellets
Freiberg (Germany) (2008)	45	Bio diesel	Waste, clean wood

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Status of biomass co-gasification

Power plant	Capacity (MWth)	Application	Feedstock
Lahti (Finland) (1998)	40 to70	Co-firing in boiler	Wood, paper, cardboard, RDF
Amer 9 (Netherlands) (1999)	85	Co-firing in boiler	Waste wood
Ruien (Belgium) (2003)	50 to 80	Co-firing in boiler	Wood

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Economics of large scale bioenergy

- Challenge: costs have to stay below alternatives like wind energy or small scale bioenergy (CHP)
- Costs above the market price have to be covered by subsidies, governmental support
- Upper limit 10 €cts/kWhe, goal 5 to 7 €cts/kWhe
- Range co-firing 8 to 9 €cts/kWhe
- Range CFB combustion 9 to 11 €cts/kWhe
- Range gasification 10 to 13 €cts/kWhe
- Determining factors: Fuel costs, investment costs and electric efficiency

Pushing η_e up and Capex, fuel cost down

Based on Dutch conditions

Conclusions

- Besides co-firing, CFB combustion is the only mature technology for large scale bioenergy power plants
- However, first of all co-firing opportunities will be developed, since costs are in most cases lower
- When fuel flexibility is required and difficult biomass has to be fired: CFB combustion is the solution
- Large scale CFB initiatives are developed and will be become more common in the near future
- CFB combustion can operate and 40% efficiency
- Gasification is still an option which requires attention, especially co-gasification and small scale applications

Co- and biomass firing: continuously pushing the limits!

As for the future,
your task is not to foresee it,
but to enable it.

Antoine de Saint-Exupéry
Pilot, 1900 -1944, Lyon, France

Experience you can trust.

Thank you for your attention

KEMA is grateful for the information supplied by Foster Wheeler and Metso Power.

Presentations are available on www.ieabioenergytask32.com

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Experience you can trust.

Core business KEMA

- KEMA is an independent, market orientated organization, specializing in high-grade technical and business consultancy, inspection, testing and certification
- KEMA mainly supports clients concerned with the supply and use of electrical power and other forms of energy

The power of KEMA

From the generator to the consumer – one company serving the diverse needs of the energy market place

Production *Power Exchange* *Transmission* *System Operation* *Substation* *Distribution* *Consumer*

Renewable energy is connected to several links in the energy chain!

Company Profile

Key data:

- incorporated 1927
- fifty international offices
- 1,650 employees worldwide
- net turnover 2004:
  173 million €
- net turnover 2008
  227 million €

1 SDG = 0.3 €

1 USD = 0.7 €

Al Taweelah, Abu Dhabi, systems testing

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Annex 5. Ash related topics in high percentage cofiring

Jaap Kiel, ECN

ECN

Energy research Centre of the Netherlands

Ash-related topics in high-percentage biomass co-firing

Jaap Kiel, Mariusz Cieplik and Willem van de Kamp
ECN Biomass, Coal and Environmental research

IEA Bioenergy Task 32 workshop “Options for high percentage biomass cofiring in new power plants”, Hamburg ,Germany, 30 June 2009

ECN

Presentation overview

- Brief introduction to ECN
- Current pulverised-fuel co-firing practice in the Netherlands
- What if higher co-firing percentages, lower quality biomass, and new advanced coal technologies?
- Ash-related technical bottlenecks
- R&D approach and results
- Concluding remarks

ECN

Energy research Centre of the Netherlands

In the dunes of N-Holland - Petten

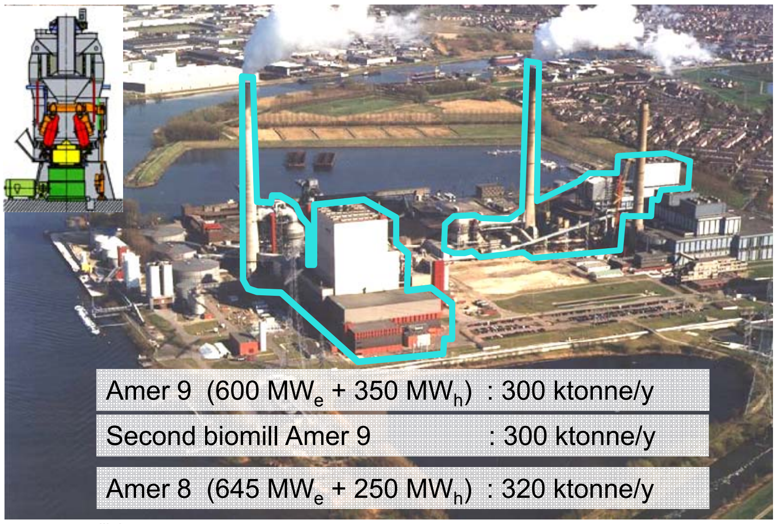
ECN develops high-level knowledge and technology for a sustainable energy system and transfers it to the market

- Independent research institute
- 650 employees
- Activities:
  - *Biomass, Solar, Wind*
  - *Clean fossil fuels (CCS, fuel cells)*
  - *Energy efficiency*
  - *Policy studies*

- 60-70 FTE
- Main R&D topics:
  - *Biomass co-firing*
  - *Upgrading (Torrefaction)*
  - *Syngas & SNG (MILENA, OLGA)*
  - *Transportation fuels*
  - *Biorefinery processes*

ECN

Direct biomass co-firing at Essent Amer power station



Amer 9 (600 MW_e + 350 MW_h) : 300 ktonne/y

Second biomill Amer 9 : 300 ktonne/y

Amer 8 (645 MW_e + 250 MW_h) : 320 ktonne/y

Source: W.Willeboer, Essent

Wood pellets

Citrus pellets

Palm kernel chips

Olive residu

ECN

Indirect biomass co-firing at Essent Amer power station

Lurgi CFB gasifier, 21 tonne/h demolition wood, equiv. 34 MW_e

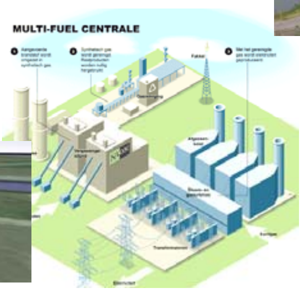
Source: W.Willeboer, Essent

5 Ash-related topics in high-percentage biomass co-firing – Jaap Kiel *et al.* www.ecn.nl

ECN

NUON IGCC plants

- Buggenum-plant
  - in operation since 1994
  - 253 MW_e
  - Up to 30% (w/w) biomass co-firing (saw dust, chicken litter, sewage sludge)
- MAGNUM-plant
  - planned
  - 1200 MW_e
  - Multi-fuel: gas, coal, biomass
  - CO_2 capture



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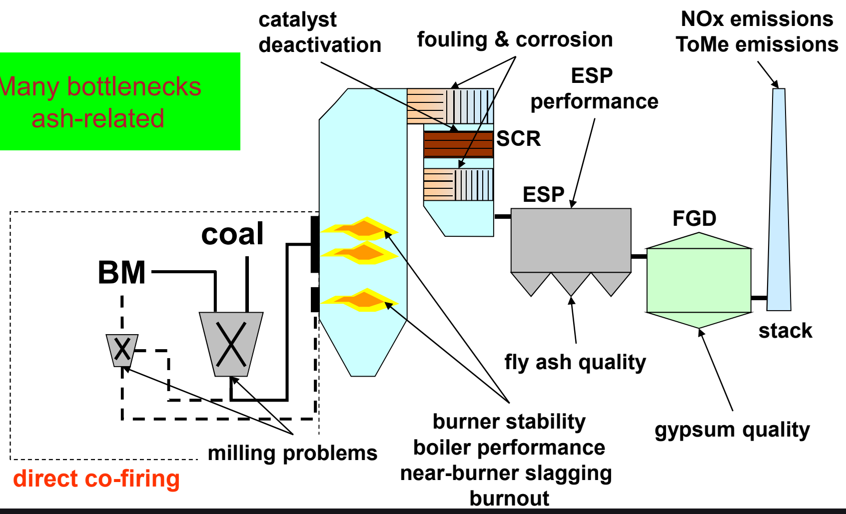
Technical bottlenecks in biomass co-firing

Many bottlenecks ash-related



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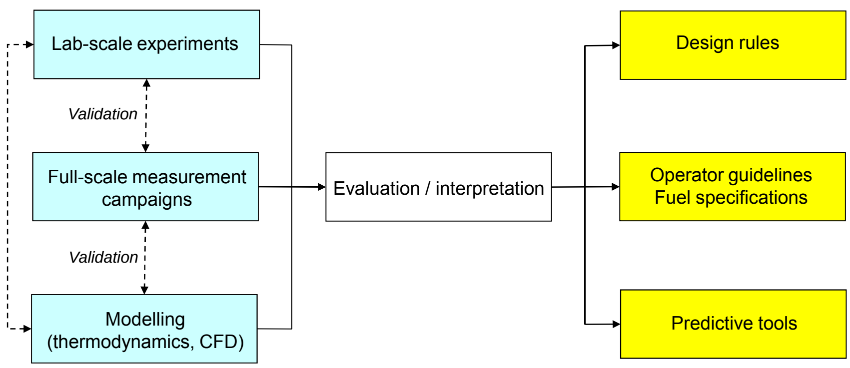
Technical bottlenecks – R&D approach



Lab-scale experiments and modelling allow investigations beyond current full-scale practice (higher co-firing percentages, higher steam conditions, oxy-fuel combustion)

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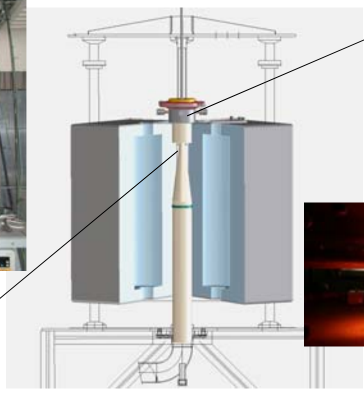
Lab-scale Combustion Simulator (LCS)



Special reactor design: 1-2s residence times with only limited total reactor length

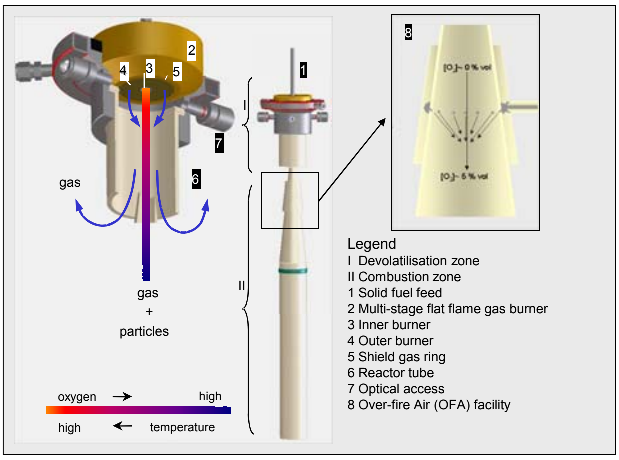
Staged gas burner: high heating rate + proper gas atmosphere

Fouling probe

Particle sampling probe

ECN

Lab-scale Combustion Simulator (LCS)

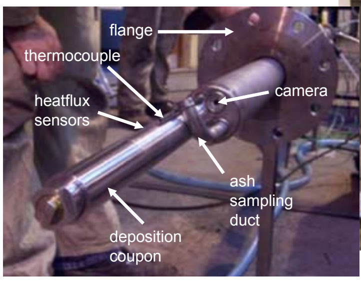


Entrained-flow reactor with integrated, premixed and multi-stage flat flame burner

- high particle heating rates
- high flame/particle temperature
- realistic gas temperature / environment history
- Controllable, long particle residence time

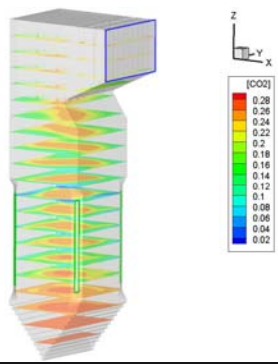
Full-scale probe measurements

ECN mobile heat flux & ash deposition probe

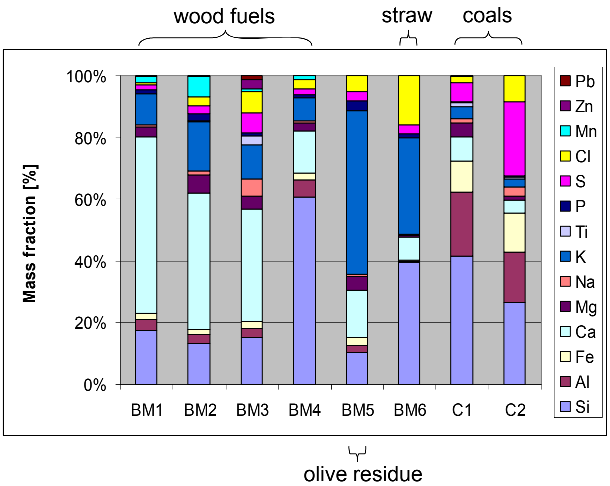


Predictive tools – aggregating mechanistic knowledge

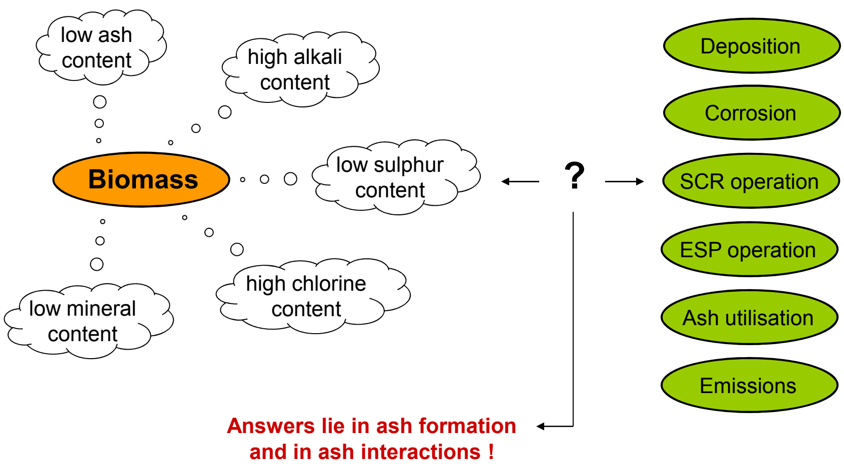
- Empirical biomass impact prediction (ash-related):
  - Co-firing Advisory Tool (CAT): release, formation, deposition and emission of ash compounds
- Ash Deposition Post-Processor (CFD-based)



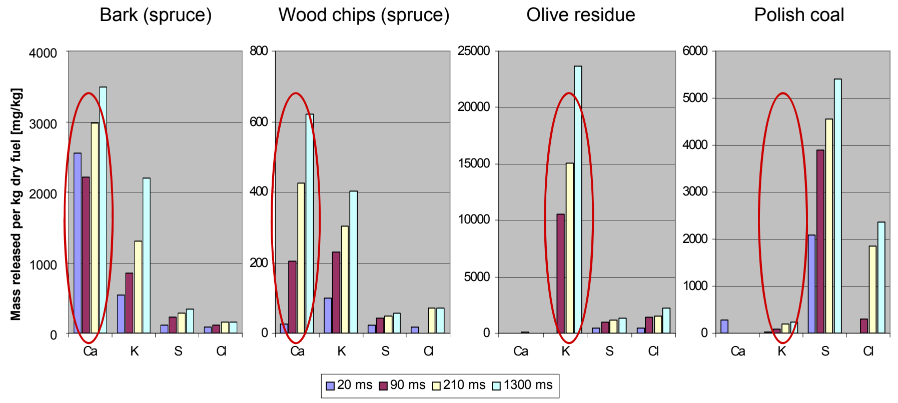
Ash forming elements in biomass vs. coal



Ash related issues to consider for a 'typical' biomass

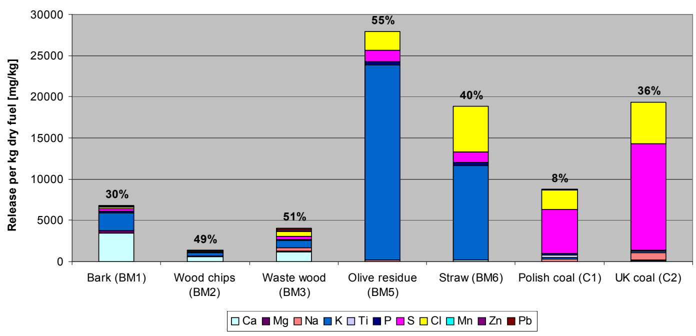


Ash release results – top-4 elements



mineral calcium　organic calcium　potassium salt　mineral potassium

Comparison of ash release between fuels



Release biomass very different from coal:
- total release biomass 30-55% (incl. S and Cl)
- total release coal 0.3-2.6% (excl. S and Cl) or 8-36% (incl. S and Cl)

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Release behaviour and ash interactions in MBM co-firing

Alkali metals in MBM significantly increase risk of corrosion and fouling.
Can coal non-alkaline clay minerals interact with alkalis in MBM?

- 1650-1450°C T profile, residence time (~50 μm particles) ~2.0 s
- MBM and 20% (w/w) MBM in PO56 and DGP coals

Mineral name/content [% w/w]	PO56	DGP
TOTAL ASH	16.6	14.4
Quartz	13.1	6.3
Kaolinite (non-alkali-clay)	20.0	58.9
Montmorillonite (Mg,Na-clay)	19.9	2.4
Illite (K-clay)	18.8	1.4
Al-silicate (not further specified)	5.3	2.7
Dolomite	5.2	4.1
Calcite	0.1	2.0
Pyrite	4.4	4.2
Apatite	0.3	2.0
Ca-Al-silicate	0.2	4.1
Classified sum of minor fractions	8.0	3.9
Unclassified	4.7	2.0
Total clay % of the ash	**64%**	**65.4%**
kaolinite+Al-silicate % in clay	**39% of total clay**	**94% of total clay**

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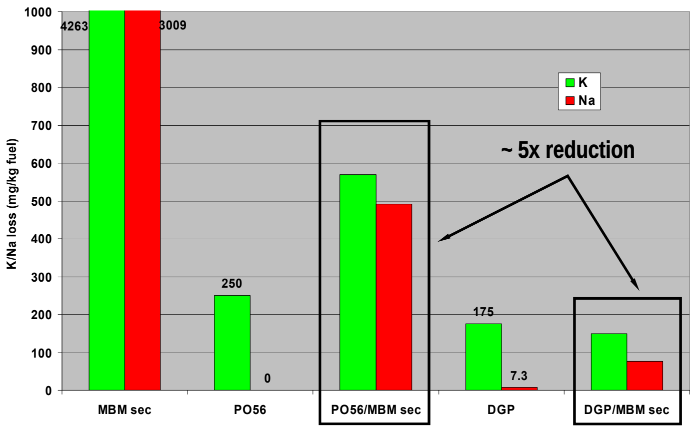
Release behaviour and ash interactions in MBM co-firing

– Interactions with clays are quite significant
– Coal minerals may be used to control alkali behaviour



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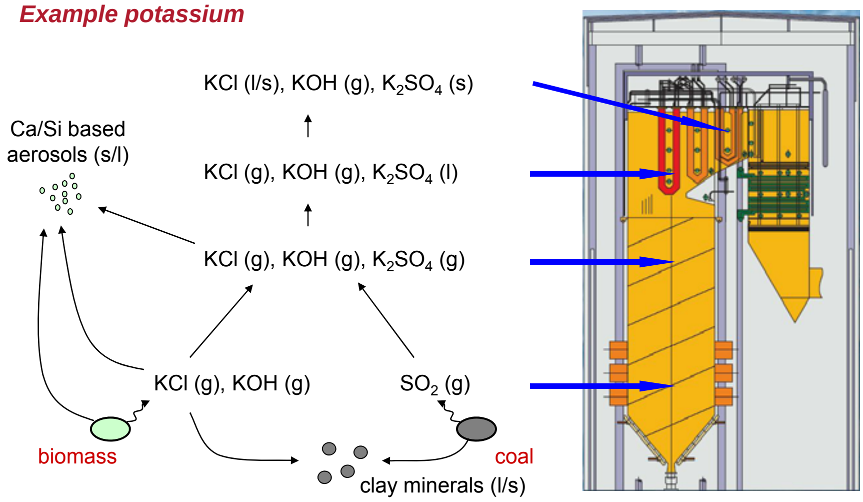
General understanding of fuel interactions

Example potassium



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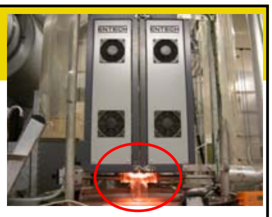
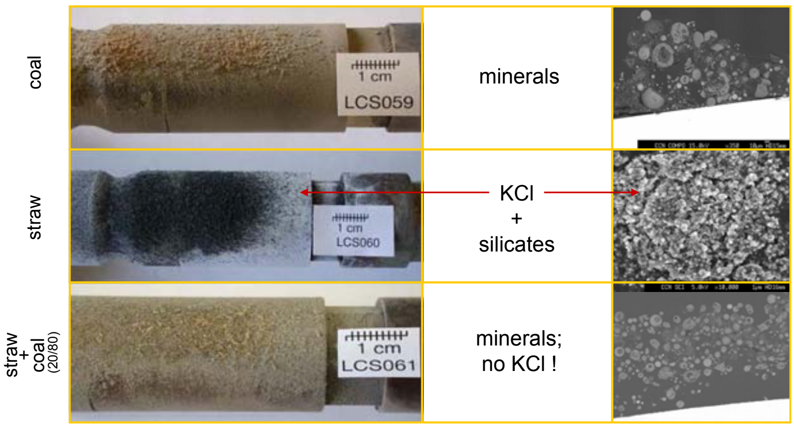
Interactions demonstrated in ash deposition





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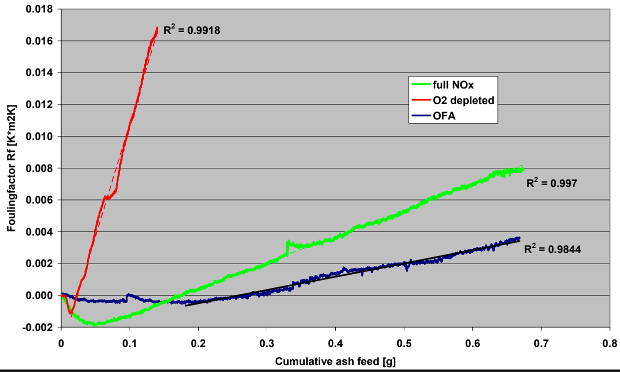
Impact deposition on heat transfer – fouling factor

Combustion conditions	Fuel mass fed	Deposition rate	Deposit thickness @ 0°	Fraction of inorganic matter deposited
	[g]	[g/m²s]	[mm]	% wt
full NOx	7.7	0.018	2.00	61
O_2 depleted	2.29	0.009	3.70	30
OFA	7.64	0.013	1.40	43

Fuel: MVC + olive residue



mass ≠ thickness ≠ fouling factor!

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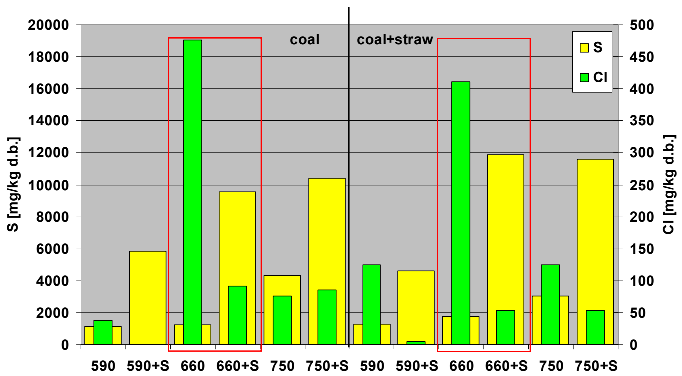
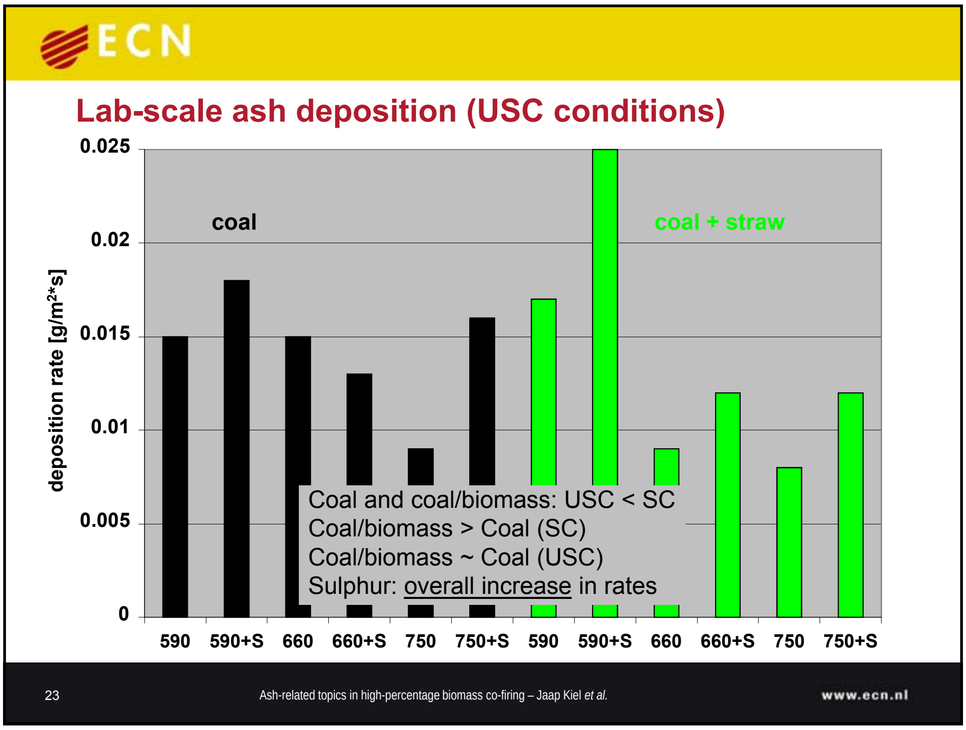
Lab-scale ash deposition (USC conditions)

- Deposit bulk composition: S and Cl vs surface temperature and SO_2(g)

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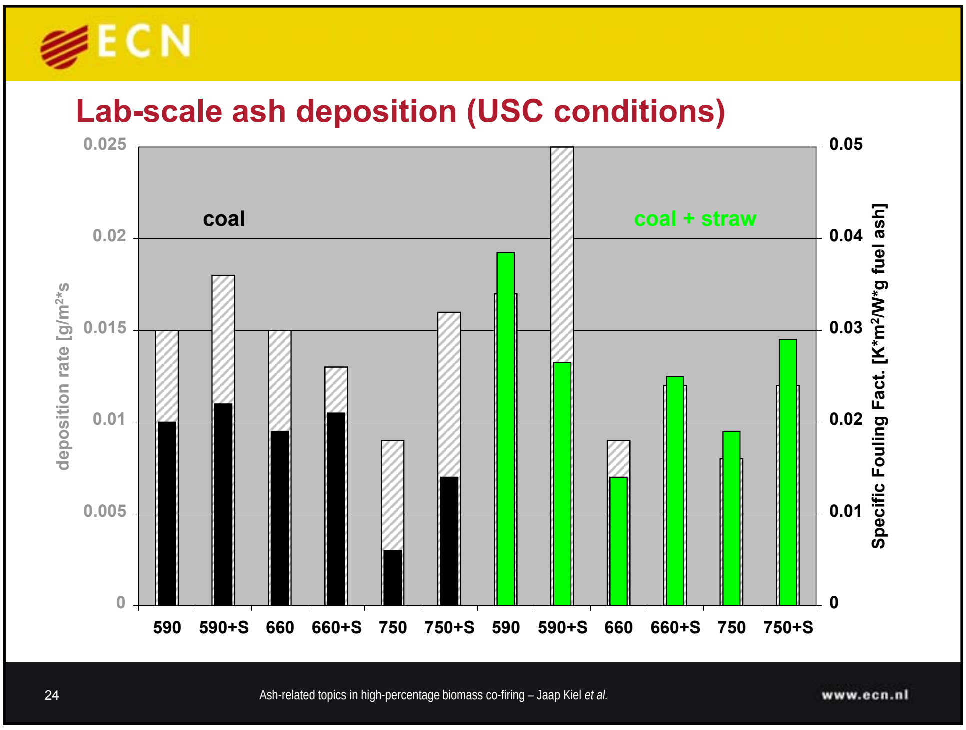
Lab-scale ash deposition (USC conditions)
0.025
0.02
0.015
0.01
0.005
0
deposition rate [g/m2*s]
coal
coal + straw
Coal and coal/biomass: USC < SC
Coal/biomass > Coal (SC)
Coal/biomass ~ Coal (USC)
Sulphur: overall increase in rates
590
590+S
660
660+S
750
750+S
590
590+S
660
660+S
750
750+S
23
Ash-related topics in high-percentage biomass co-firing – Jaap Kiel et al.
www.ecn.nl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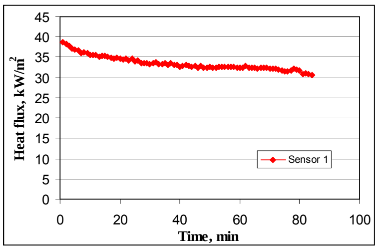
Lab-scale ash deposition (USC conditions)
0.025
0.02
0.015
0.01
0.005
0
deposition rate [g/m2*s]
coal
coal + straw
0.05
0.04
0.03
0.02
0.01
0
Specific Fouling Fact. [K*m2/W*g fuel ash]
590
590+S
660
660+S
750
750+S
590
590+S
660
660+S
750
750+S
24
Ash-related topics in high-percentage biomass co-firing – Jaap Kiel et al.
www.ecn.nl

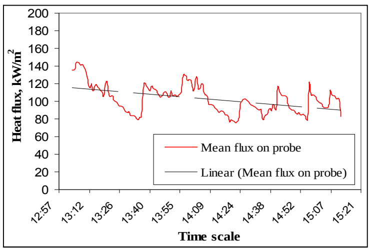
Fouling
lab-scale vs. full-scale

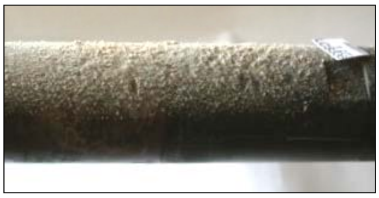
- Fuel: MV coal (70 % w/w), coffee husks (15% w/w), wood (clean/bark) pellets (15% w/w)
- Deep-staged Low-NOx conditions
- Flue gas temperature - 1100 °C
- Simulated steam tube - **USC conditions 660 °C**

Lab-scale

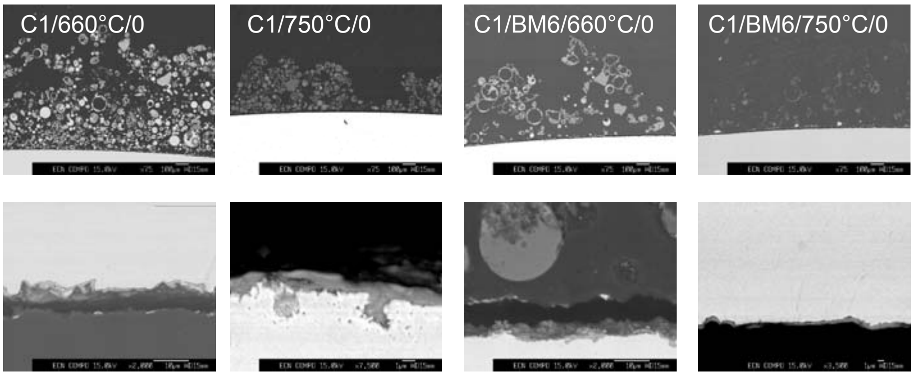


Full-scale





Lab-scale ash deposition (USC conditions) – initial corrosion



Oxide layer on interface	C1/660°C/0	C1/750°C/0	C1/BM6/660°C/0	C1/BM6/750°C/0
Substrate material	SS310	Alloy617	SS310	Alloy617
Thickness [μm]	5	1.5	6.8	0.8
Main elements	**Cr**, Mn, Fe,Ni	**Cr**, **Ni**, Mo, Co	**Cr**, Mn, Fe	**Cr**, **Ni**, Mo, Co
Sulphur [%]	~4	< d.l.	~2	~1

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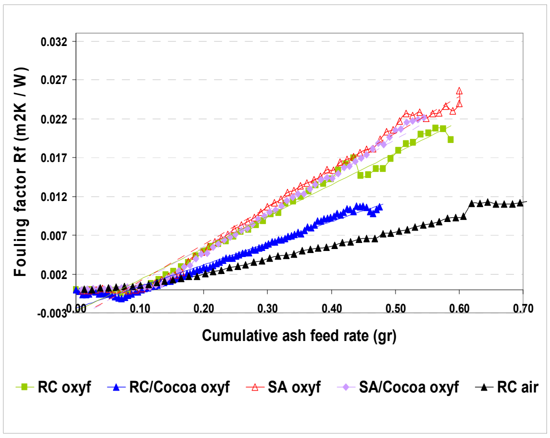
Ash deposition under oxy-fuel conditions – initial results

- Fouling factors tend to be higher, which seems to be partly due to poor burn-out ("sooty" deposits)



Fuel: Russian coal, South African coal, Shea meal (in 80/20 (w/w) blend)
Air: Low-NOx conditions
Oxy-fuel: flue gas 85% CO_2, 3-4% O_2
Flue gas temperature - 1100 °C
Simulated steam tube - **660 °C**

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Concluding remarks

- Biomass co-firing at percentages up to 30% (w/w) common practice in several pf boilers in the Netherlands
- New challenges include:
  - Higher co-firing percentages
  - Lower quality ("salty") biomass
  - Introduction of advanced clean coal technologies
- Many technical bottlenecks in biomass co-firing are ash related; main mechanisms of ash formation and ash behaviour have been mapped for "conventional, low-percentage" co-firing
- R&D focus now on quantification and incorporation of mechanistic knowledge in predictive tools + on addressing the new challenges
- Combination of a detailed mechanistic understanding (through representative lab-scale experimentation), predictive tools and full-scale on-line monitoring (and control) is key to successful management of ash behaviour

ECN

Thank you for your attention!

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- The Dutch power generation sector for their guidance, support and co-operation
- The European commission (FP6/7 and RFCS), the Dutch Ministry of Economic Affairs and SenterNovem for their financial support

Annex 6. Direct cofiring

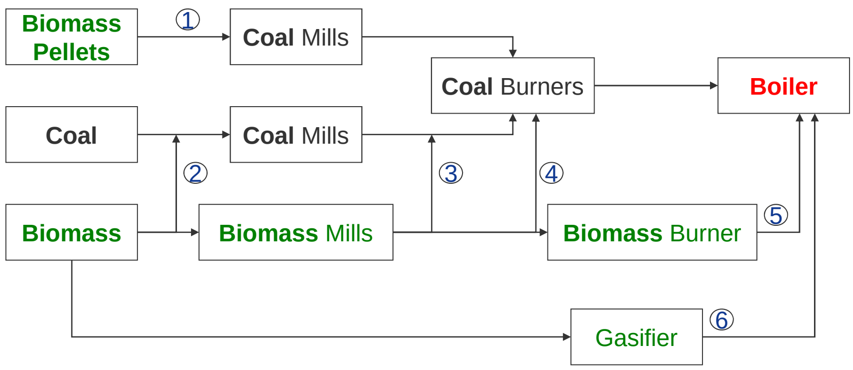
Bill Livingston, Doosan Babcock

Doosan Babcock Energy

The direct co-firing of biomass at high co-firing ratios

W R Livingston
Hamburg
June 2009

The principal biomass co-firing options for pulverised fuel boilers



1. The milling of biomass pellets through modified coal mills,
2. The pre-mixing of the biomass with the coal, and the milling and firing of the mixed fuel through the existing coal firing system,
3. The direct injection of pre-milled biomass into the pulverised coal pipework,
4. The direct injection of pre-milled biomass into modified coal burners,
5. The direct injection of the pre-milled biomass through dedicated biomass burners or directly into the furnace, and
6. The gasification of the biomass, with combustion of the product gas in the boiler.

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Biomass co-firing by pre-mixing the biomass with coal and co-milling

Biomass co-firing by pre-mixing with coal and co-milling

- This has been the preferred approach in many stations embarking on co-firing for the first time.
- The capital investment can be kept to modest levels, and the project can be implemented in reasonable time.
- The expenditure is principally on the biomass reception, storage and handling facilities.
- This is particularly attractive when there are concerns about the security of supply of the biomass materials, and about the long term security of the subsidy payments for co-firing.

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Biomass co-firing by pre-mixing and co-milling

This approach permits co-firing at up to 5-10% on a heat input basis.

The key constraints are:

- The availability of suitable biomass supplies,
- The limitations of the on-site biomass reception, storage and handling facilities and
- The limitations associated with the ability of the coal mills to co-mill biomass materials.

With torrefied materials or chars the co-firing ratio will be increased.

There are also safety issues associated with the bunkering and milling of the mixed coal-biomass material.

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Milling wood pellets in coal mills

Milling pelletised biomass in coal mills

- The milling of wood pellets in coal mills, and the firing of the mill product through the existing pipework and burners, is done at a small number of power stations in Europe, including Hasselby in Sweden.
- The coal mills are very robust, and have high availability/low maintenance requirements.
- At best, the coal mill breaks the pellets back to the original dust size distribution.
- The mill has to be modified to operate with cold primary air. There are generally no requirements for modifications to the grinding elements.
- The maximum heat input from the mill group is significantly derated, commonly to around 50-70% of that with coal.
- With torrefied materials or chars there will be a smaller derate.

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Direct injection of pre-milled biomass

Direct injection co-firing systems for biomass basic options

- The biomass can be pre-milled either off-site or on-site.
- All direct injection co-firing systems involve the pneumatic conveying of the pre-milled biomass from the fuel reception and handling facility to the boiler house.
- There are three basic direct injection co-firing options:
  - Direct injection into the furnace with no combustion air,
  - New, dedicated biomass burners, and
  - Injection of the biomass into the pulverised coal pipework or through modified burners.

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Dedicated biomass burners and modified coal burners for biomass/coal co-firing

Direct injection through dedicated burners

- Appropriate locations for the biomass burners are not easy to find, particularly as a retrofit, and additional furnace penetrations and burner support structures are required.
- Fuel and air supply systems for the biomass burners have to be installed, and flame monitoring equipment for the biomass flames are required.
- The impact of exposure of the 'out of service' biomass burners to the coal-fired furnace gases needs to be assessed.
- The impacts of the biomass burners on the coal-firing system have to be assessed.
- Overall, the installation of dedicated biomass burners is regarded as being an expensive and relatively high risk approach to biomass co-firing.

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Direct injection into modified burners

- This has been achieved successfully for both wall-fired and corner-fired furnaces.
- The quantities of biomass that can be co-fired into a single burner are quite modest,
- Modification of the existing coal burners involves additional cost and risk compared to injection into the pulverised coal pipework.
- This approach may be necessary in some cases, depending on the nature of the biomass, particularly if there is a risk of blockage of the fuel supply pipework at splitters, e.g. with chopped straw at Studstrup in Denmark.

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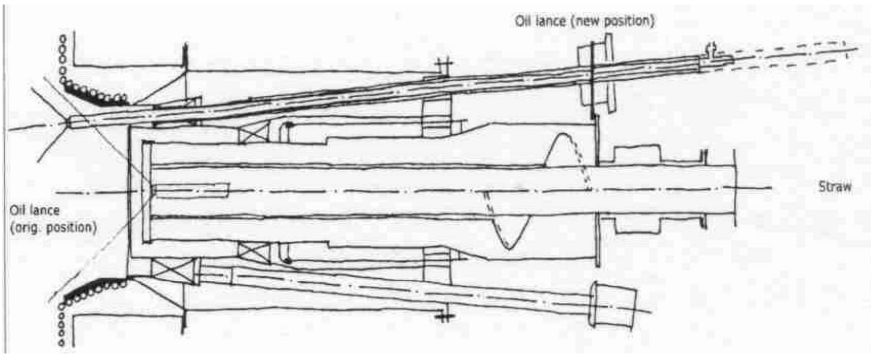
Studstrup coal-straw burner
Modified Doosan Babcock Mark III Low NO_x Burner



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Direct injection into the pulverised coal pipework

Direct injection into the pulverised coal pipework

- Direct injection into the existing coal firing system is relatively simple and cheap to install.
- The mill air and fuel flow rates can be reduced in line with the biomass conveying air flow rate, and the heat input to the mill group from the biomass.
- Both the mill and the burners can be maintained within their normal operating envelopes for both the heat input and primary air flow rate.
- The maximum heat input from the mill group is not affected, and can be increased in some cases.
- There are new interfaces between the mill and biomass conveying system controls, covering permits to operate, biomass system shutdowns, start-ups and trips, etc.

- There is a recent demonstration of a direct firing system at Drax Power Station in Britain. The system has been in successful operation since summer 2005, firing a wide variety of pre-milled biomass materials. This system is currently being extended significantly.

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Drax Direct Co-firing
The biomass metering and feeding system

The prototype direct co-firing system has been in successful operation since summer 2005, firing a range of pre-milled biomass materials.

Drax are now replicating this approach to two mills on all six boilers.

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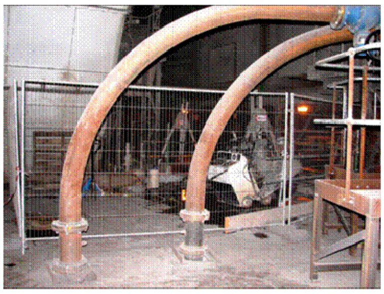
Drax Direct Co-firing
The biomass pipes and the injection point

- The injection point is in the mill outlet pipes, just downstream of the product dampers. The injection point is a simple shallow angle T-in, fitted with an actuated shut-off valve for the biomass,
- Both the mill and the burners are maintained within their normal operating envelopes for both the heat input and primary air flow rate. The maximum heat input from the mill group is not affected.



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CONCLUSIONS

Conclusions

- Large scale biomass co-firing is one of the most efficient and cost effective approaches to generating electricity from renewable sources.
- Biomass co-milling is being practised successfully, as a retrofit to existing plants, by a number of coal plant operators in Britain and continental Europe.
- Direct injection co-firing projects are currently being implemented as a means of increasing the co-firing levels.
- Injection of the biomass into the pulverised coal pipework is the preferred direct firing solution for both retrofit and new build projects.
- To date, the impacts on boiler plant operations have been modest but this will increase with increasing co-firing ratios and with higher ash biomass materials.
- A number of the current new-build coal power plant projects have a biomass co-firing requirement.

Thank you for your attention

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