12th European Biomass Conference
Workshop 5: Biomass Cofiring

Overhead sheets presented

Date:
Thursday June 20, 14:30-18:00

Location:
RAI Conference building, Amsterdam

Co-Chaired by
Sjaak van Loo (TNO, Netherlands),
Suresh Babu (GTI, USA),
Larry Baxter (Brigham Young University, USA)

Organised by

IEA Bioenergy

Task 32: Biomass Combustion and Cofiring
Task 33: Biomass Gasification

European BIOENERGY Networks
Innovative solutions for solid, gaseous and liquid biomass production and use

AGENDA
Workshop5: Biomass Cofiring

PART I: INTRODUCTION (14:30-14:50)

Overview of technical concepts for cofiring
Bill Livingston, Mitsui Babcock, UK

PART II: OVERVIEW OF EXPERIENCES (14:50-16:20)

Results of direct cofiring tests at Naantali Power Plant
Ms. Kati Savolainen, Fortum

Experiences in USA with cofiring
Larry Felix, Southern Research Institute

Ashes from direct and indirect co-firing - utilisation issues
Frans Lamers, KEMA

PART III: TECHNICAL ISSUES (16:20-17:40)

Issues with direct co-combustion (ash deposition, corrosion, etc.)
Larry Baxter, Brigham Young University, USA

Problems and solutions in increasing the share of demanding biomass cocombustion
Martti Aho, VTT Processes

Issues with indirect cofiring (pre-gasification)
Esa Kurkela, VTT, FI

Issues with indirect cofiring (pre-gasification)
Mark Paisley, FERCO, USA

PART IV: DISCUSSION (17:40-18:00)

Plenary discussion with a panel of speakers

Closing by chairman

Summary

As part of the 12th European Conference and Exhibition on Biomass for Energy and Industry, held 17-21 June, 2002 in Amsterdam, a workshop on biomass cofiring was organized by IEA Bioenergy task 32 (Biomass Combustion and Cofiring), task 33 (biomass gasification) and EUBIONET (the European Bioenergy Network). This report shows the overhead sheets that were presented. A summary of the contents of the presentations is provided below.

Bill Livingston (Mitsui Babcock) has presented an overview of cofiring issues. Cofiring biomass with coal is becoming increasingly popular around the globe for various reasons. It is often found to be a relatively low-cost measure for large-scale renewable energy generation. Depending on the specifications of biofuels to be cofired, various configurations exist, varying from directly mixing biofuel with coal and joint firing, pre-gasification and parallel firing. However, there are several barriers that hinder actual implementation, such as uncertainty about the legal and political environment, liberalization of the energy sector, as well as uncertainties about long term fuel supplies at low costs. Another issue is the utilization of fly-ashes, which is often not allowed if the ash is partly from biomass origin.

One of the companies that has practical experience with cofiring biomass fuels is Fortum. **Kati Savolainen** (Fortum) presented the results of test trials in the Naantali Power plant. This showed that up to 2,5% of pine sawdust could be cofired with coal, without investment. For higher percentages, problems occurred with unburned carbon in the ashes, mill drying capacity and mill clogging. In the Suomenoja power plant (Finland), a demonstration project has been initiated aiming at replacement of coal by various types of biomass up to 20%. For this purpose, other biomass pretreatment equipment is necessary.

In the USA, a lot of fundamental research work has recently been performed on the causes and effects on emission reduction when cofiring biomass with coal. **Larry Felix** (Southern Research Institute) highlighted some of the major results. Regarding NO_x reduction, recent R&D has indicated that there one should generally not expect any NO_x reduction beyond that of displaced fuel nitrogen (this was mentioned in the US National Energy Policy as important argument for cofiring). The effects of boiler geometry, fuel specifications etc. on NO_x emission reduction, flame stability, slagging and fouling and other effects are further examined in various R&D projects. In 2000, US DOE has funded 11 new R&D projects, which all aim at better understanding such relations.

One major barrier for many cofiring initiatives worldwide is the marketability of the power plant residues, if biomass is used as a secondary fuel next to coal. In the case of the Netherlands, the EN450 norm for utilization of fly ash in cement is currently being revised, based on maximum percentages of alternative fuels and the technical and environmental performance of the resulting fly-ash. In the presentation and enclosed paper by **Frans Lamers**, the impacts on quality of fly-ash are described in more detail.

Larry Baxter (Brigham Young University) also showed the results of recent research projects in the USA on the characteristics of concrete produced with biomass derived fly-ash (concrete strength, set time, etc.). It generally shows that for biomass fly ash, more aerating agent is required and the set time increases. However, the compressive and flexural strength seem to be hardly affected. Other major technical issues being examined are fuel handling and preparation, NO_x formation, deposition, ash deposition, corrosion, SCR deactivation, carbon conversion and striated flows. Advanced models have already been developed that can be used to predict these effects for various fuels, operating conditions and boiler designs, however further research on such relations are necessary.

Martti Aho (VTT) showed interested results from coal/biomass cofiring tests in practical-size fluidized bed boilers, with focus on emissions, superheat corrosion, ash composition and fouling. For different flue gas components, results from measurements and calculated catchment efficiencies have been analyzed. With regard to superheater corrosion from alkali

chlorides, Martti Aho showed that sulphur dioxide and aluminia silicates derived from coal constituents can have a protective effect. Through a reaction with alkali chlorides under oxidizing conditions, alkali silicates and sulphates are formed, which prevent chlorides from condensing on the superheater tubes or leaving the boiler as fine fly ash. This mechanism was also mentioned in the presentation of Larry Baxter.

Esa Kurkela (VTT) shared experiences with the Lahti CFB gasifier demonstration plant and the Corenso gasifier for plastic wastes. In the Lahti plant, a 60 MW biomass/waste fired CFB gasifier supplies gas to a 360 MW coal/natural gas fired steam generation boiler. The gasifier fuel consists of a mixture of plastics, REF, and (glue containing) wood. It has been commercially operating since 1998 with an availability of 86.6%. The effect of the gasifier on the emissions of the main boiler was that most of the emission components (such as NO_x, SO_x and particulates) decreased, except for HCl and some heavy metals. Investment costs of this type of gasifier are approximately 600 €/kW_e.

Another gasifier successfully operating since 2001 is the 40 MW Corenso installation. This gasifier is fed with plastic waste, consisting of a PE/Al mixture. The aluminum can be recovered at the gasification stage after, while the remaining product gas is burned together with oil to generate steam.

In addition to the experiences shared by Esa Kurkela, **Mark Paisley** (FERCO) explained some more details on biomass gasification in combination with firing the producer gas in a coal furnace. One major advantage of pre-gasification is the fact that the biomass ash does not enter the coal furnace and mix up with the coal fly ash, causing marketing problems. Also, the volume of producer gas is much smaller than that of flue gas, therefore removal of unwanted components is simpler. Producer gas can often be fired in existing natural gas burners without modification. If producer gas can be used as a reburn fuel instead of natural gas, NO_x emissions of an existing boiler could be reduced up to 60%. Experiences gained with the Vermont gasifier and other installations make that there is a growing confidence and familiarity with the concept of biomass gasification, not only in combination with utility owned coal fired boilers but also in other sectors, such as the pulp and paper industries.

OVERVIEW OF BIOMASS CO-UTILISATION

W R Livingston

Mitsui Babcock

Reasons for biomass co-firing in large coal-fired power plant

- Political and social concerns about the environmental impact of fossil fuel combustion.
- Government support and subsidies for renewable energy.
- Biomass utilisation will play a significant role in renewable electricity production.
- Co-firing makes use of existing plant, i.e. can provide power generation from biomass relatively quickly and at low cost.
- May help to create a secure fuel supply infrastructure.

Barriers to biomass co-firing

- High delivered fuel costs and insecure supply infrastructure for most biomass materials,
- Commercial liberalisation of the electricity supply industry, and intense competition between generators,
- Uncertain legal and political background against which investment in renewable energies can be made,
- Changes in the legislative position as regards the environmental performance of power plants,
- The location of many large power plants.

The fuel supply contract

- Poorly developed infrastructure for the supply of biofuels in many countries.
- Many biofuels are seasonal in nature, and require long-term storage,
- The purchaser requires a degree of control over the delivered fuel quality and price.
- The fuel purchaser may have to be more pro-active than with fossil fuels, and may be required to invest in the fuel supply infrastructure.

Biomass pre-processing requirements

- Bulk handling and long-term storage,
- Washing or cleaning to remove tramp material or to reduce the ash content,
- Drying or partial drying, and
- Comminution.

Direct co-combustion options

- Mixing of the biofuel with the coal upstream of the coal feeders,
- Separate handling, metering and comminution of the biofuel, with injection upstream of the burners, or at the burners,
- Dedicated handling and firing system,
- Use of the biofuel as a reburn fuel.

Co-firing options based on gasification

- Usually air-blown, atmospheric, fixed bed or fluidised bed gasification,
- The major products are:

  the wet fuel gas,

  all of the biomass ash materials

  the tars and condensable organic species, and

  the Cl, N and S species.
- The key issue is the degree of cooling and cleaning of the gas prior to co-firing.

Impacts on boiler operation

- Minimising risks to plant operation would favour low co-firing ratios, high quality fuels and the options which represent the fewest interfaces with the coal firing system, both mechanical and C&I-related.
- Combustion/NO_x issues
- Ash effects
- Environmental and regulatory issues.

Ash effects

- Increased ash deposition in the furnace and convective section,
- Increased rates of gas-side corrosion,
- Reduced collection efficiency of particulate collection equipment,
- Interference with the operation of the SO_x and NO_x emission control equipment, and
- Impacts on the utilisation/disposal of the solid discards.

Conclusions

- Government subsidy schemes and other financial instruments can provide the required incentives for coal-fired power plant operators to convert to biomass co-firing.
- The development of a secure supply infrastructure for biofuels is a major prerequisite of the successful application of co-firing technologies.
- The key technical issue is the quantification and control of the risks to normal power plant operations.

DIRECT CO-FIRING - Fortum experiences

Kati Savolainen

Fortum

Fortum Engineering Ltd.

Why to co-fire in Finland ?

- **Biofuels cheaper than coal due to taxation. No energy tax has to be paid (6 €/MWh), when district heat is produced by biofuels**
  - **Price of biofuel 4-8 €/MWh**
  - **Price of coal 12-14 €/MWh**
- **To reduce CO_2 emissions**
- **To reduce SO_2 emissions**
- **Green image**

Fortum

Co-firing experiences at Naantali Power Plant

Naantali Power Plant, boiler no 3

- **Owned by fortum**
- **Fuel input 315 mw$_f$**
- **Sulzer once-through boiler**
- **Tangentially firing system with**
  - **3 loche roller mills**
  - **12 RI-JET low-NO_x burners**
  - **Single-stage OFA**
- **Wet FGD, gypsum sold to board factory**
- **Fly ash reused in concrete industry**

Fortum

Full-scale co-firing tests with sawdust

- Target:
  - Is it possible to co-fire without investments?
  - To find optimum proportion of sawdust in naantali
- Three month tests 1999 and 2000
- Main fuel: hardcoal
  biofuel: sawdust (pine)
- Sawdust injection through the mills

Fortum

Tested sawdust proportions

Sawdust proportion	Blend 1	Blend 2	Blend 3
By fuel input	2.5 %	4 %	8 %
By mass	9 %	14 %	25 %
By volume	24 %	33 %	52 %

Fortum

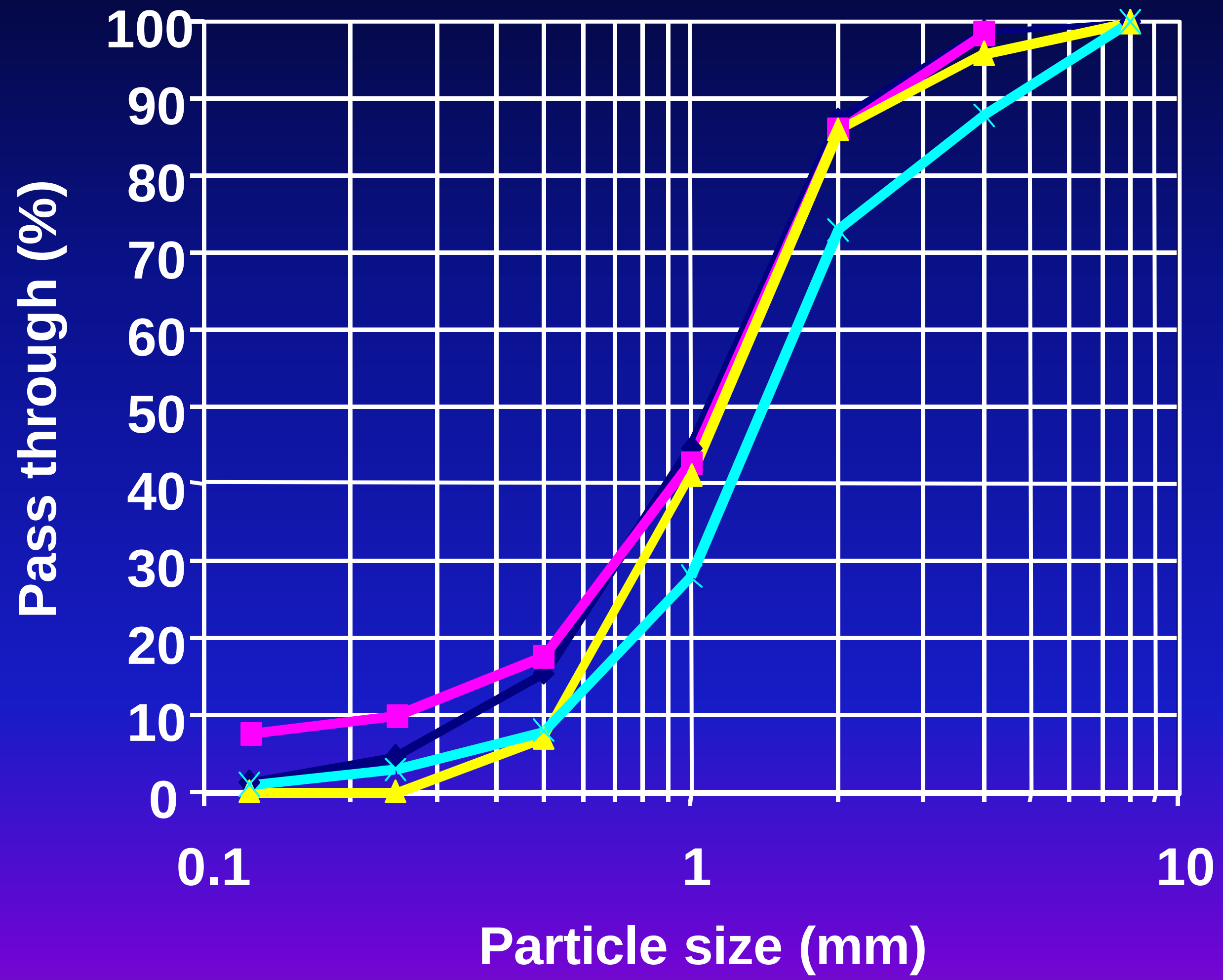
Fuel properties

	Russian Kuznetsk	Polish Coal	Sawdust
Moisture, m-% (ar)	9…11	10…12	51…58
Volatile, m-% (dry)	26…29	31…34	68…70
Ash, m-% (dry)	9…11	12…15	0.3…0.5
FR-ratio (-)*	2.1…2.2	1.7…1.8	0.43…0.47
LHV (MJ/kg)	25…26	24…25	6…7
Sulfur, m-% (dry)	0.3…0.35	0.8…1.0	< 0.1

* FR-ratio = Fixed carbon/volatile matter

Fortum

Sawdust particle size distribution



100 % < 8 mm

40 % < 1 mm

Fortum

Blending and feeding of sawdust

- Sawdust was blended with coal at the coal yard by using bucket charger. Depending of the desired blending ratio the the amount sawdust and coal was transported to the feeding hopper (volume ratio)
- Sawdust was feeded to the boiler through the mills
- Inaccurate blending method
- No investments needed

Fortum

Results - Mill behavior

- Mill drying capacity was limiting factor

  ➡ Maximum sawdust portion 4 % of fuel input

- Sawdust had a negative effect on **coal fineness**, resulting higher UBC in fly ash

  ➡ Optimum sawdust portion 2.5 % of fuel input

- Sawdust particles bigger than 8 mm caused the mill clogging

- Coal mill reject was very flammable

Fortum

Results - Coal mill performance

Particle size	Polish coal			Sawdust 4 % of fuel input		
	Mill 7	Mill 8	Mill 9	Mill 7	Mill 8	Mill 9
> 2 mm	0	0	0	0.2	0.2	0.7
> 0.6 mm	0.3	0.3	0.2	3.1	2.0	6.0
< 150 µm	94	93	89	89	88	81
< 75 µm	78	74	73	73	67	63

Fortum

Results - Emissions and UBC

- No_x-emission (sawdust 2.5...8 % of fuel input): no effect
- So_2-emission (sawdust 2.5...8 % of fuel input): reduced, because of low sulfur content of sawdust
- Dust emission (sawdust 2.5...4 % of fuel input): no effect
- UBC (sawdust 2.5...4 % of fuel input):
  - Bottom slag: no effect
  - Fly ash: increased

Fortum

Results - FGD and ESP performance

Effect of co-firing on FGD and ESP performance was measured with sawdust proportion 4 % of fuel input

FGD:

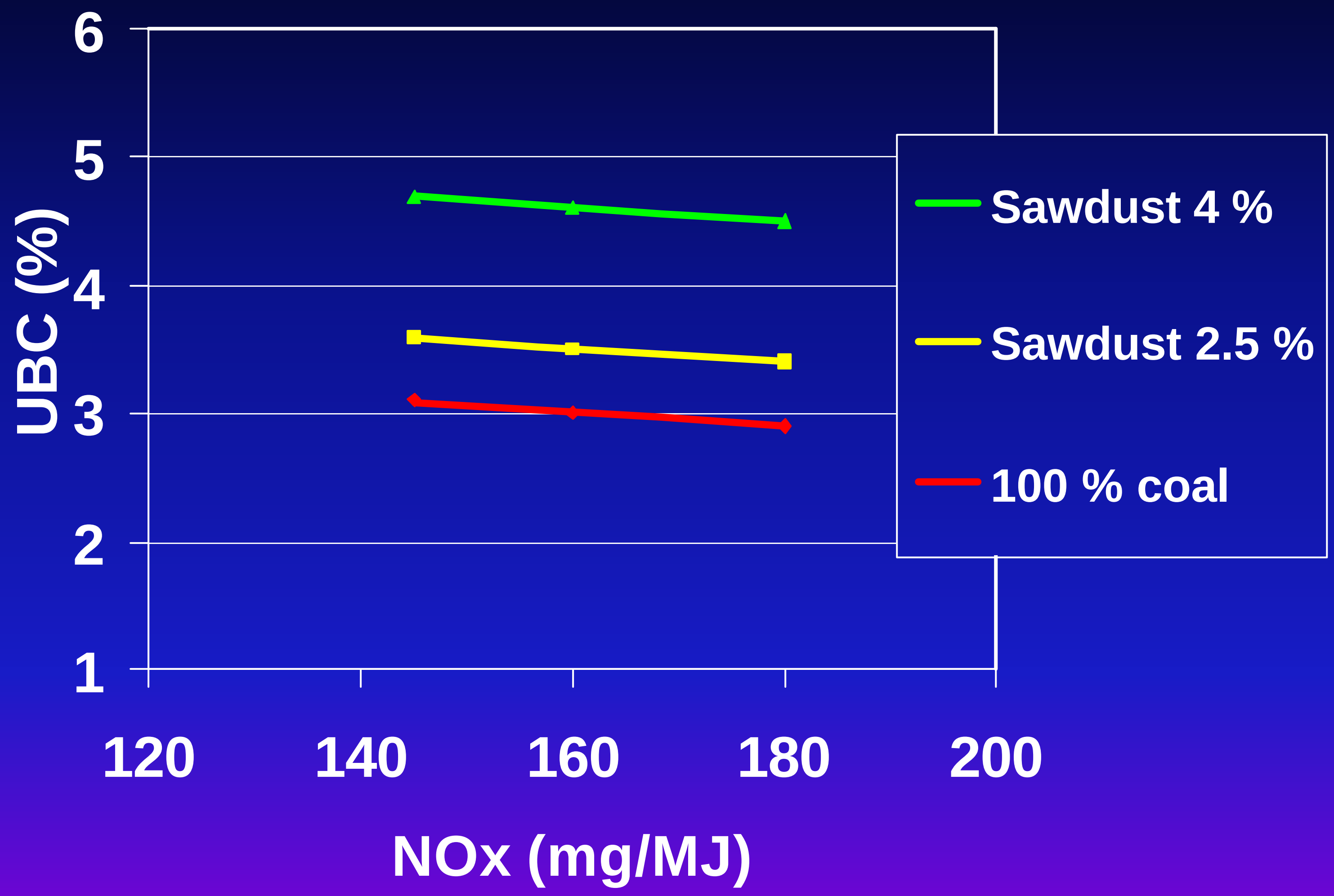
- No effect on the performance of FGD
- No effect on gypsum slurry
- No effect on gypsum end product

ESP:

- No effect on dust emission
- Dust emission < 20 mg/m3n
- No effect on the ESP operation parameters

Fortum

Results - NO_x and UBC



Results - Boiler behavior

- Flame stability (sawdust 2.5...8 %): no effect
- Furnace slagging (sawdust 2.5...4 %): no effect or reduced
- Superheater fouling (sawdust 2.5...4 %): no effect
- Flue gas temperature after LUVO (sawdust 2.5...4 %): no effect*
- General (sawdust 2.5...4 %): big fluctuation in boiler load and boiler parameters due to uneven mixing of sawdust and coal

**LUVO balance was changed due to feeding of wet fuel to the mills*

Fortum

Conclusion

- It is possible to co-fire sawdust without investments, through the mills
- Only small portions possible, < 2.5 % of fuel input
- Limiting factors:
  - Increased UBC
  - Mill drying capacity
  - NO big particles allowed, otherwise mill clogging
- Inaccurate blending method caused fluctuation in boiler load and boiler parameters

After the tests, Naantali has continued co-firing sawdust, with the sawdust proportion 2.5 % of fuel input.

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Future development

Future development on direct co-firing

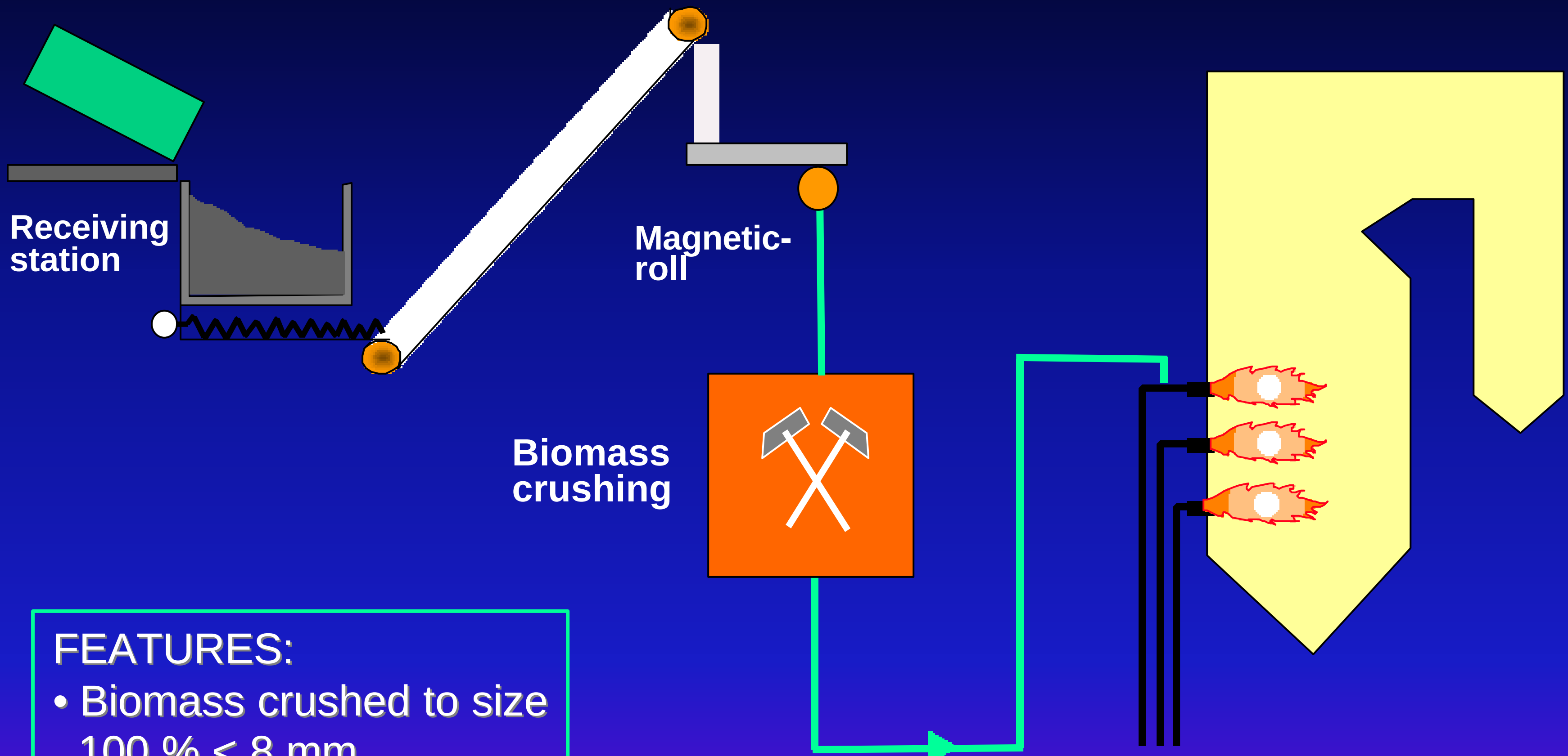
In order to

1. Use other biomass than sawdust
2. Substitute bigger portions of coal with biomass (10...20 % of fuel input)

The separate grinding and feeding system for biomass is needed.

Fortum

Grinded Biofuel Direct Co-Combustion



FEATURES:
- Biomass crushed to size 100 % < 8 mm
- Bio-coal burners

Demonstration project

Target:

- To substitute 10...20 % (fuel input) of coal with biomass
- To reduce the pre-treatment costs of biomass below 2 €/MWh

Demonstration:

- At suomenoja power plant in finland
- Fuels: demolition wood, forest residual, sawdust, bark

Fortum

Demonstration - Suomenoja Power Plant

- **Owned by EON**
- **Fuel input 265 mw_f**
- **Natural circulation**
- **Tangentially firing system with**
  - **3 ball mills**
  - **12 RI-JET low-NO_x burners**
  - **Single-stage OFA**
- **Semi-dry FGD**
- **Fly ash reused in concrete industry**

Fortum

Demonstration - project schedule

PHASE I - year 2002 :

- Target: substitute 10 % of coal
- Investments on bio-coal-burners (4 pcs) and pneumatically feeding system
- R&D on biomass crushing
- Study: Effect of co-firing on total power plant process
- Tests with pre-crushed biofuels

PHASE II - years 2003-2004

- Target: substitute 20 % of coal
- Investments on biomass receiving, unloading and crushing stations

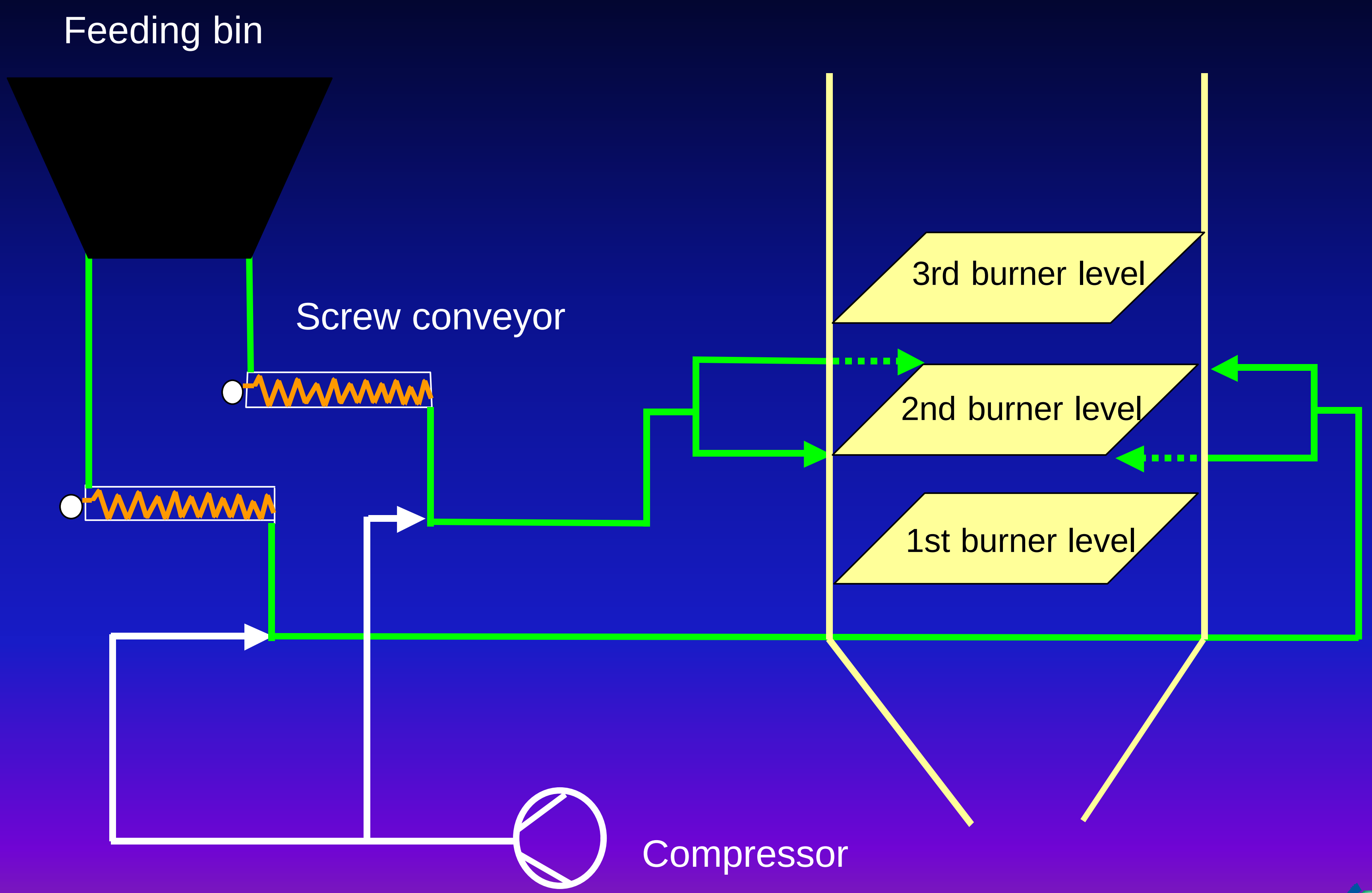
Fortum

Phase I - Fuel properties

	Forest residual	Bark	Sawdust	Demolition wood
Moisture, m-% (ar)	max 60	max 60	max 60	15…30
Ash, m-% (dry)	1…3	1…3	1…3	1…5
Bulk density kg/m3	250…400	250…350	250…350	150…250
LHV (MJ/kg)	6…9	5…9	6…9	12…13
Energy density MWh/m3	> 0.7	> 0.5	> 0.5	> 0.7

Fortum

Phase I - Process diagram



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Effect of co-firing on total power plant process

- Boiler
  - Furnace exit gas temperature
  - Steam temperatures
  - Spray water amounts
  - Flue gas end temperature (after LUVO)
- Flue gas fans
- Combustion air fans
- Flue Gas Desulfuration Plant
- Electrostatic Precipitator
- DeNOx catalyst

Fortum

Summary

- Grinded Biomass Direct Co-Combustion will be demonstrated at Suomenoja Power Plant, Finland
- Phase I, 1-12/2002
  - Target: substitute 10 % of coal with biomass
  - Pre-crushed biomass
  - Biomass: demolition wood, bark, sawdust, forest residual
- Phase II, 11/2002-5/2004
  - Target: substitute 20 % of coal with biomass
  - Total system
- Cost < 2 €/MWh

Fortum

Experience in the USA with Cofiring

Larry G. Felix
Southern Research Institute

From the U.S. National Energy Policy

"Co-firing coal power plants with biomass has environmental benefits since co-firing can significantly reduce emissions. Biomass accounts for 76 percent of renewable electricity generation and 1.6 percent of total U.S. energy supply."[1]

[1] National Energy Policy, Report of the National Energy Policy Development Group, May, 2001, pp 6-5

Why Biomass Cofiring?

- Climate Protection – Global Warming
- Renewable Energy may be Mandated at a percentage of a Utilities Energy Output
- U.S. Tax Advantages for the Production of Energy from Renewable Fuels
- Cofiring Helps to Reduce SO_2 and NO_X Emissions Legislatively Targeted for Reduction

Emissions Benefits of Biomass Cofiring

- CO_2 Reduction from Unburned Fossil Carbon
- SO_2 Reduction from Displaced Sulfur
- Lower NO_X Emissions (at Least from Reducing Fuel Nitrogen)
- Higher Fuel Volatility from Biomass

US Consensus

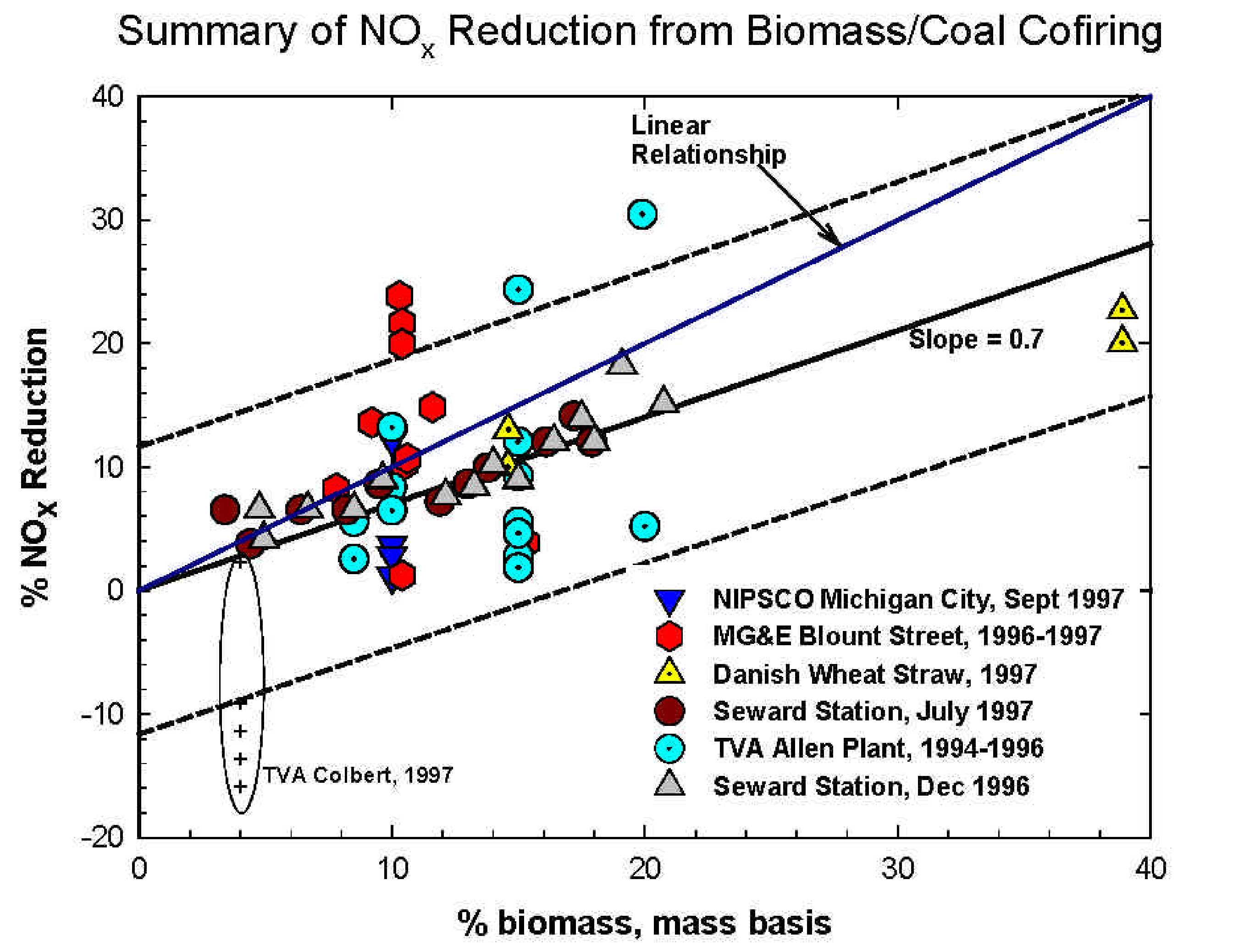
"The addition of biomass has been shown to reduce NO_X emissions in most commercial facilities, usually beyond the reductions expected because of a lower overall fuel-bound nitrogen content. The high volatiles content of biomass can effectively establish a fuel-rich zone early in the flame that can reduce NO_X emissions. Adding biomass can reduce flame temperatures, leading to lower levels of thermal NO_X. The high moisture content of some biomass may also be effective for NO_X reduction at full-scale."[1]

[1] Drayton, David, *A Summary of NO_X Emissions Reduction from Biomass Cofiring*, DOE Contract DE-AC36-99-GO10337, NREL/TP-510-32260, National Renewable Energy Laboratory, Golden CO, May, 2002, p.3

Full-Scale Experience in the US

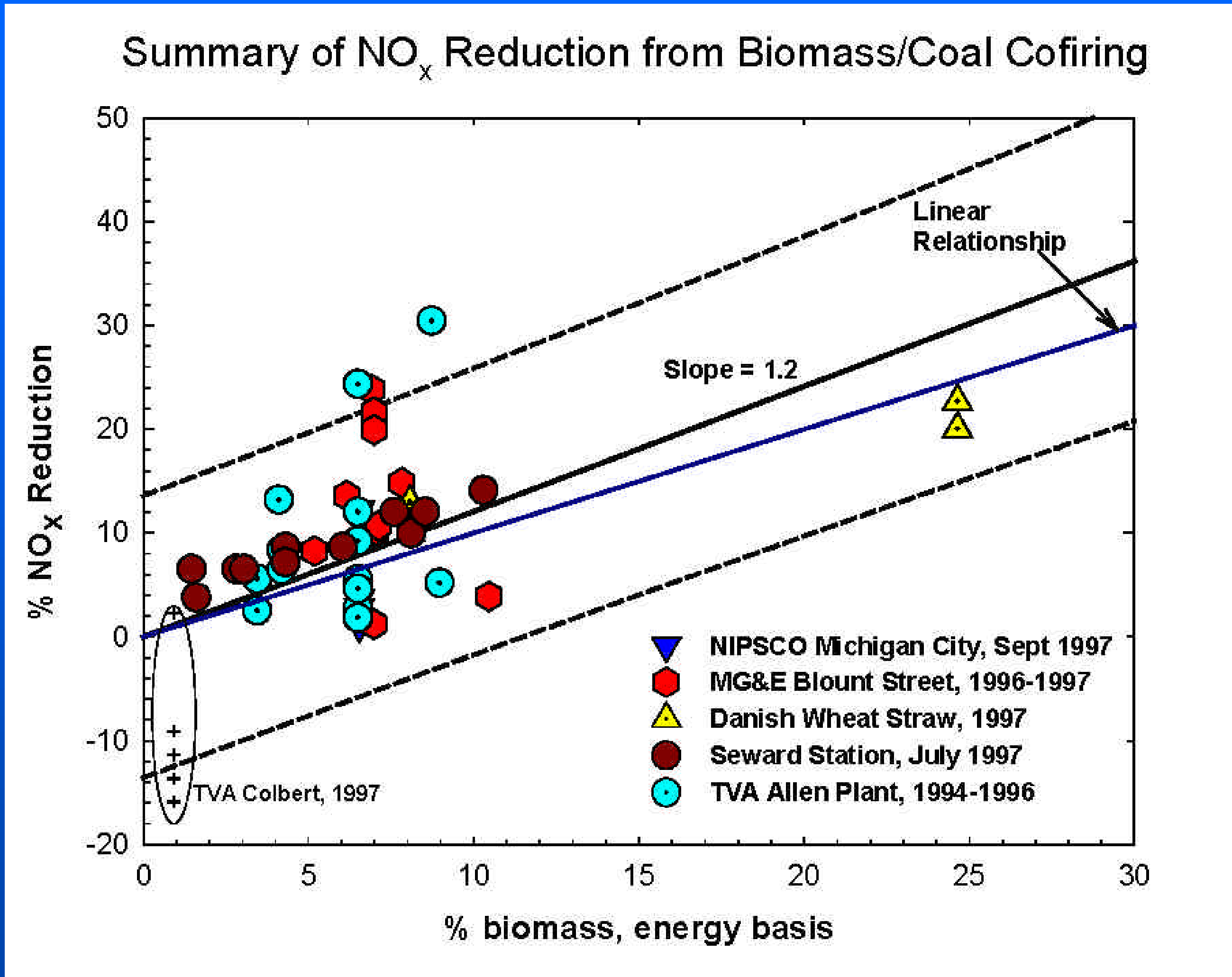
Plant	Biomass	%	NO_X Result	Reference
Hammond	Wood	13	No effect	Boylan, et al., 1992
Kraft	Wood	0-30	Reduced > fuel N	Boylan, et al., 1994
Greenidge Station	Dry wood	10	No effect	Prinzing et al, 1996
Greenidge Station	Wet wood	10	Reduced	Prinzing et al, 1996
Madison Gas & Electric	Switchgrass	14	No to slight effect	Ragland et al, 1996
Allen Fossil Plant	Wood	0-20	Reduced > fuel N	Tillman et al, 1996
Sandia Pilot	Wood, switchgrass	0-66	Reduced $\propto$ to fuel N	Baxter and Robinson, 1999
Seward, Allen, Michigan City	Wood	0-20	Reduced < fuel N on average	Tillman, Plasynski, and Hughes, 1999
Gadsden	Switchgrass	10	No effect	Boylan, 2001
Colbert	Wood	1-5	Up to 16% Increase	Dayton, 2002

US Results – Mass Basis (Dayton – NREL, May 2002)



A summary of NOx reduction from a number of biomass/coal cofiring full-scale and pilot-scale demonstration tests, based on the mass input of biomass. Dashed lines are 95% prediction limits that encompass the range of variability in the measured data.

US Results – Energy Basis (Dayton – NREL, May 2002)



A summary of NOx reduction from a number of biomass/coal cofiring full-scale and pilot-scale demonstration tests, based on the energy input of biomass. Dashed lines are 95% prediction limits that encompass the range of variability in the measured data.

U.S. Reality

- Full-Scale Test Results Provide No Guarantee that NO_X Emissions will be Significantly Reduced (Beyond Reductions from Displaced Fuel Nitrogen) when Coal is Cofired with Biomass
- There is No Clear Body of Data that has Identified the Pertinent Interactions that Exist in Biomass Cofiring with respect to Boiler Operating Parameters, Cofiring Geometry, Biomass Choice, and Coal

U.S. Reality

- Research Continues
- In 2000, The U.S. DOE National Energy Technology Laboratory, through the Office of Energy Efficiency and Renewable Energy's Biomass Power Program has Funded 11 New Research Grants to Study Biomass Cofiring
- Several of these Grants are Directed Toward Gaining a Better Understanding of the Nature of the Interactions Mentioned Above

U.S. DOE Research

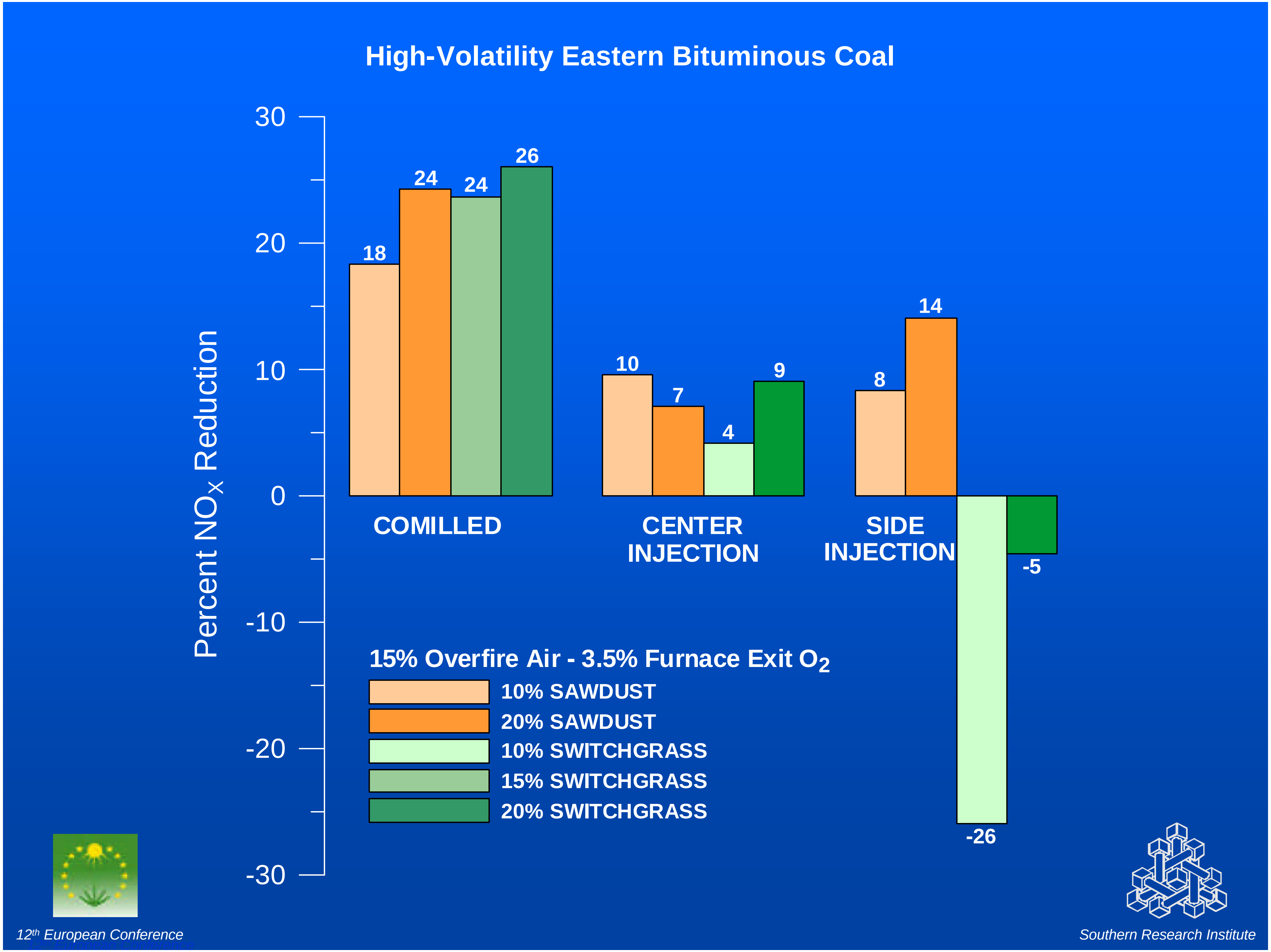
We Have Reported on One of These Programs:

U.S. DOE Cooperative Agreement
No. DE-FC26-00NT40895

Development of a Validated Model for Use in Minimizing NO_X Emissions and Maximizing Carbon Utilization When Cofiring Biomass with Coal (Paper O2.D2)

Specific Program Objectives

- Develop a consistent, extensive biomass cofiring database
  - relationships between NO_x and biomass cofiring parameters
  - effects on flame stability, carbon burnout, slagging and fouling, and particulate and gaseous emissions
- Develop and validate a biomass cofiring model
  - forecast NO_x and LOI for given fuel combination with specified cofiring configuration
  - optimize cofiring configuration to minimize NO_x and unburned carbon for specified fuels


High-Volatility Eastern Bituminous Coal
Percent NOx Reduction
30
20
10
0
-10
-20
-30
18
24
24
26
10
7
4
9
8
14
-26
-5
COMILLED
CENTER INJECTION
SIDE INJECTION
15% Overfire Air - 3.5% Furnace Exit O2
10% SAWDUST
20% SAWDUST
10% SWITCHGRASS
15% SWITCHGRASS
20% SWITCHGRASS
12th European Conference
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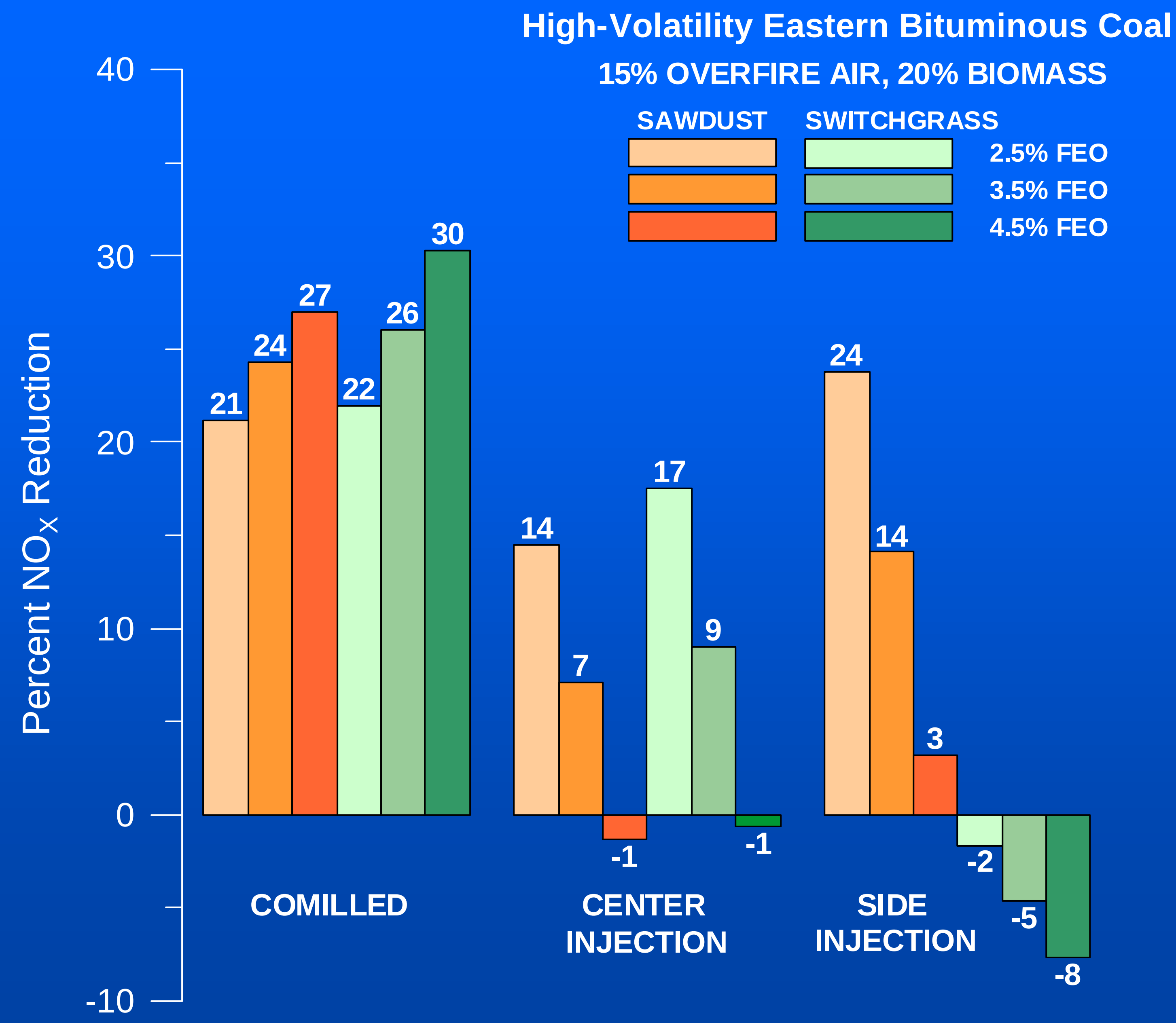


High-Volatility Eastern Bituminous Coal
15% OVERFIRE AIR, 20% BIOMASS
SAWDUST
SWITCHGRASS
2.5% FEO
3.5% FEO
4.5% FEO
Percent NOx Reduction
40
30
20
10
0
-10
21
24
27
22
26
30
14
7
-1
17
9
-1
24
14
3
-2
-5
-8
COMILLED
CENTER INJECTION
SIDE INJECTION

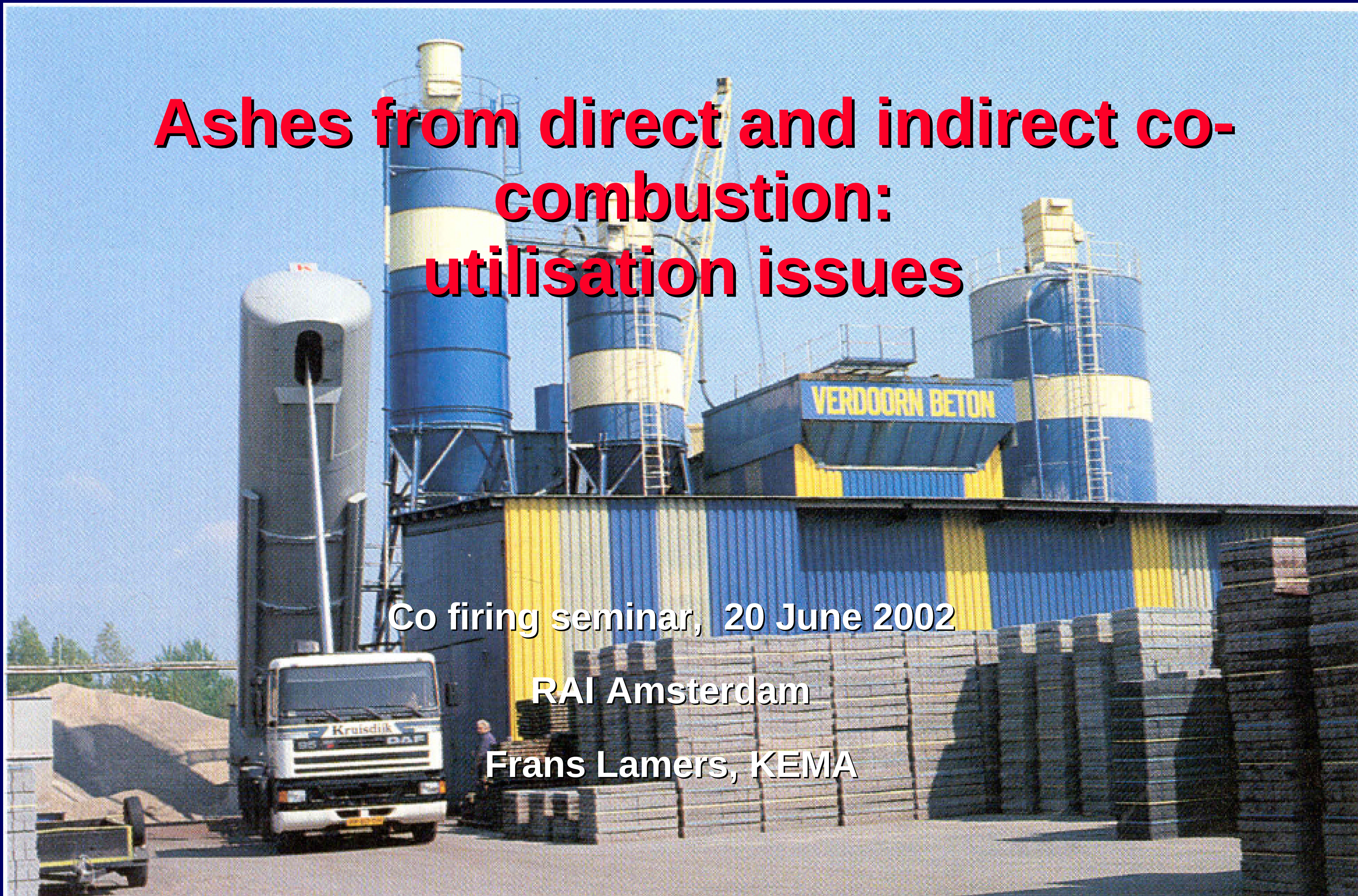
What Do These Data Reveal?

- There Appears to be No Guarantee that NO_X Emissions will be Reduced when Coal is Cofired with Biomass
- NO_X Reductions from Adding Biomass can be Much Greater than, Equal to, or Much Less than than the Amount of Fuel Nitrogen Replaced when Biomass is Cofired with Coal
- Complex Relationships Exist Among Furnace Operating Parameters, Cofiring Geometry, Biomass Choice, and Coal (not shown)

General Conclusion

In Order to Understand the Nature of the Interactions that have been Observed, Fundamental Questions of Fuel Chemistry and Combustion Must be Addressed

The Author would like to Thank the Organizers of the 12th European Conference and the Members of Our Audience for the Opportunity to Make this Presentation



Ashes from direct and indirect co-combustion: utilisation issues

Co firing seminar, 20 June 2002

RAI Amsterdam

Frans Lamers, KEMA

KEMA

Dutch situation

- 100% utilisation of coal ashes
- strive towards highest possible co-combustion
- condition:

  level of utilisation of ashes should be continued and protected
- since 1995 supportive research by KEMA, granted by the Dutch power plants
- market has allowed utilisation of ashes from indirect co-combustion

KEMA

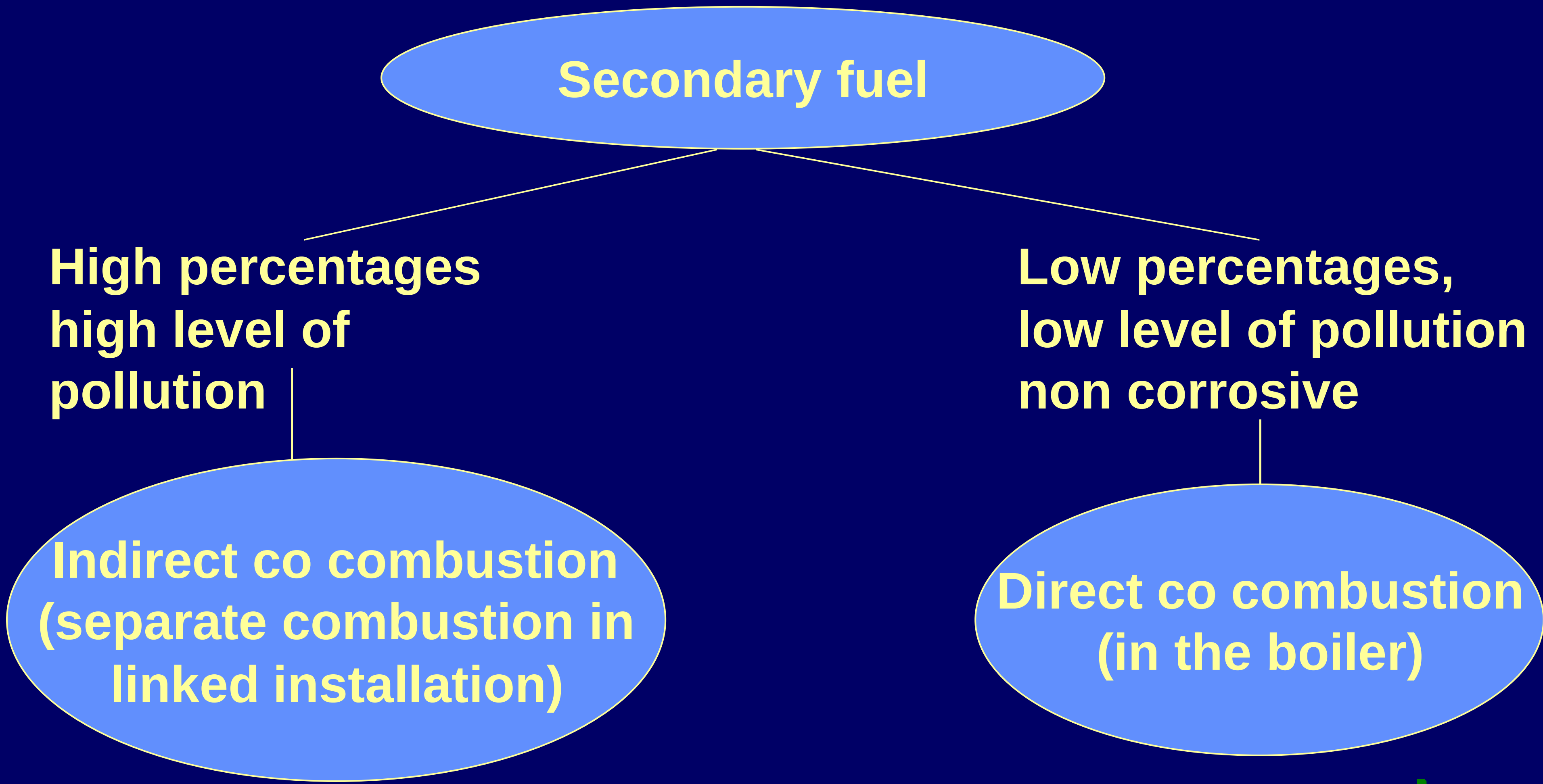
Topics

- Introduction
- Direct en indirect co-combustion
- Ashes from direct and indirect co-combustion
- Marketability / utilisation potential
- Theses and R&D questions

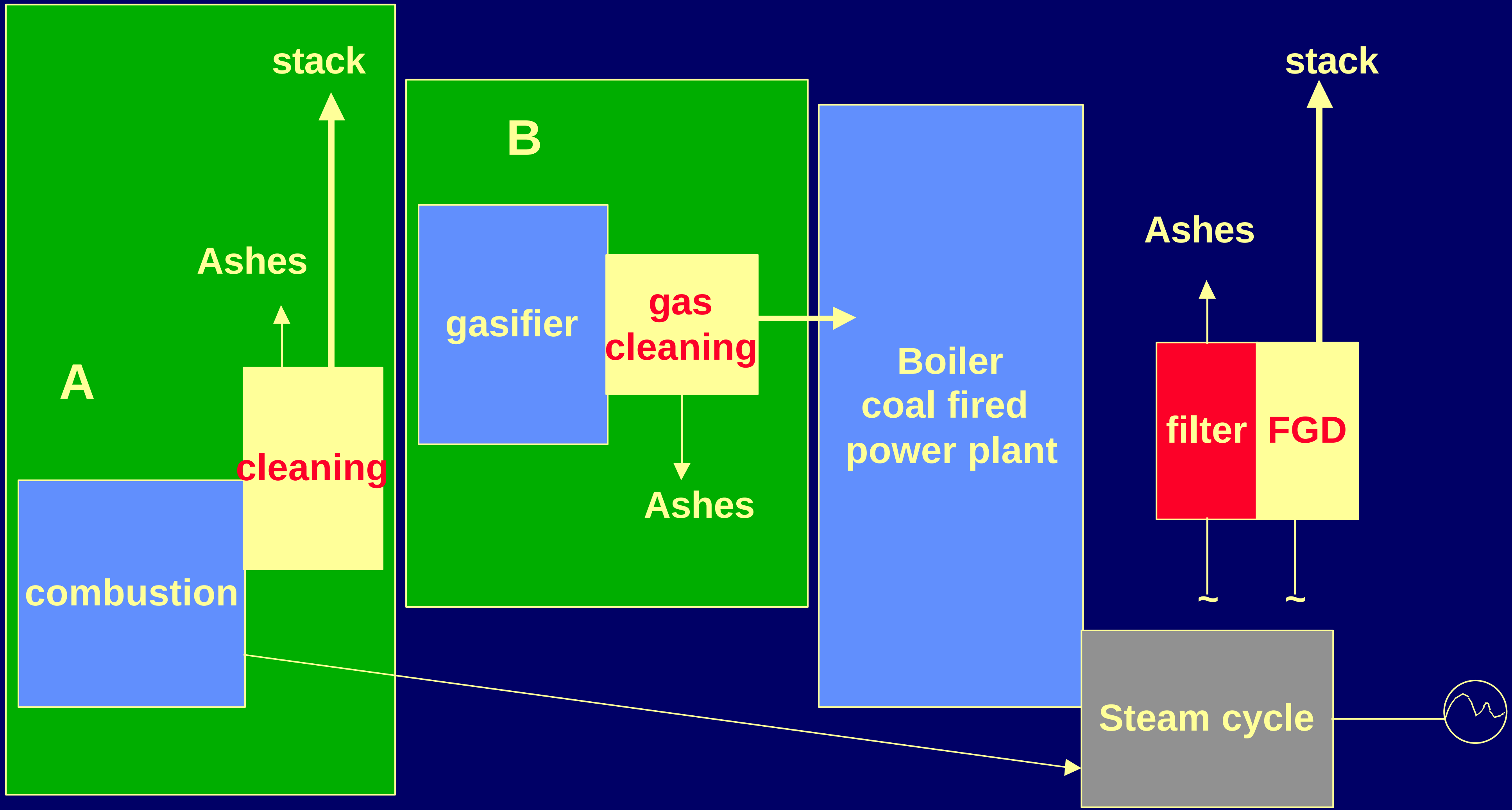
Incentives for co-combustion

- Co-combustion of biomass in a coal fired power plant saves CO2 (short cycle carbon instead of long-cycle carbon)
- contribution towards Kyoto goals
- tax deduction or other financial support options
- Directive on Waste Incineration opens possibilities for co combustion of waste with an added value for power plants

Direct or indirect co-combustion



Indirect co combustion



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Trends for by products from coal fired power plants

- Trends:
  - direct co-combustion, high percentages
  - indirect co-combustion optimise to higher percentages
- Possible consequences:
  - traditional markets not completely accessible (definition fly ashes)
  - search for new markets

By products from co combustion

- Direct co combustion

  Coal fly ashes, bottom ashes, FGD gypsum

- Indirect co combustion

  FBC ashes: fly ash, cyclone ash, bottom ash, FGD residues

  FBG ashes: fly ashes, bottom ashes

  (FGD through coal power plant)

Direct co combustion (low percentages) present status

- Netherlands: standard for all power plants utilisation in cement / concrete arranged in certification; technically conformous,
- environmentally OK
- Utilisation in cement / concrete according to EN 450; not yet standardised
- Coming revision of EN 450: co combustion at low percentages
- Higher percentages of co-combustion: no possibilities under EN 450

Indirect co combustion possibilities EN 450

Co combustion material	Max perc dry mass
Vegetable fibres (wood, straw, olive shells etc)	20
Cultivated biomass	8
Bone meal	2
Municipal sewage sludge	3
Paper sludge	5
Petroleum coke	10

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Direct Co-combustion (high percentages), present status

- Start with test runs in a medium scale test boiler; tests have been done with chicken manure, RDF and waste wood
- high concentrations of CaO, P_2O_5, alkalies, SO_3 require attention
- starting practice experience
- No possibilities for utilisation in cement / concrete
- new markets should be found

KEMA

Indirect co combustion

- Netherlands: several upcoming installations such as:
  - gasification of waste wood 150.000 tons
  - circulating fluidised bed combustion RDF and sludges 600.000 tons
- No indications about the ash quality
- Worries about SO_3 content, free lime, MgO, grain size distribution
- Alternative markets necessary

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Utilisation possibilities

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Present markets coal ashes

- Cement and concrete: 75% (EN 450) - based on long years experience on quality
- asphalt filler: < 10%
- alternative utilisation 15%
- road foundations (bottom ashes) 10%

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Future:

- direct co-combustion, low percentages:
  cement and concrete + alternatives
- direct co combustion, high percentages
  alternatives (road building / civil engineering?)
- indirect co combustion:
  alternative markets (road building / civil engineering)
  comparable: boiler ashes - fly ashes from MSWI, disposal costs 50 - 150 EURO / ton

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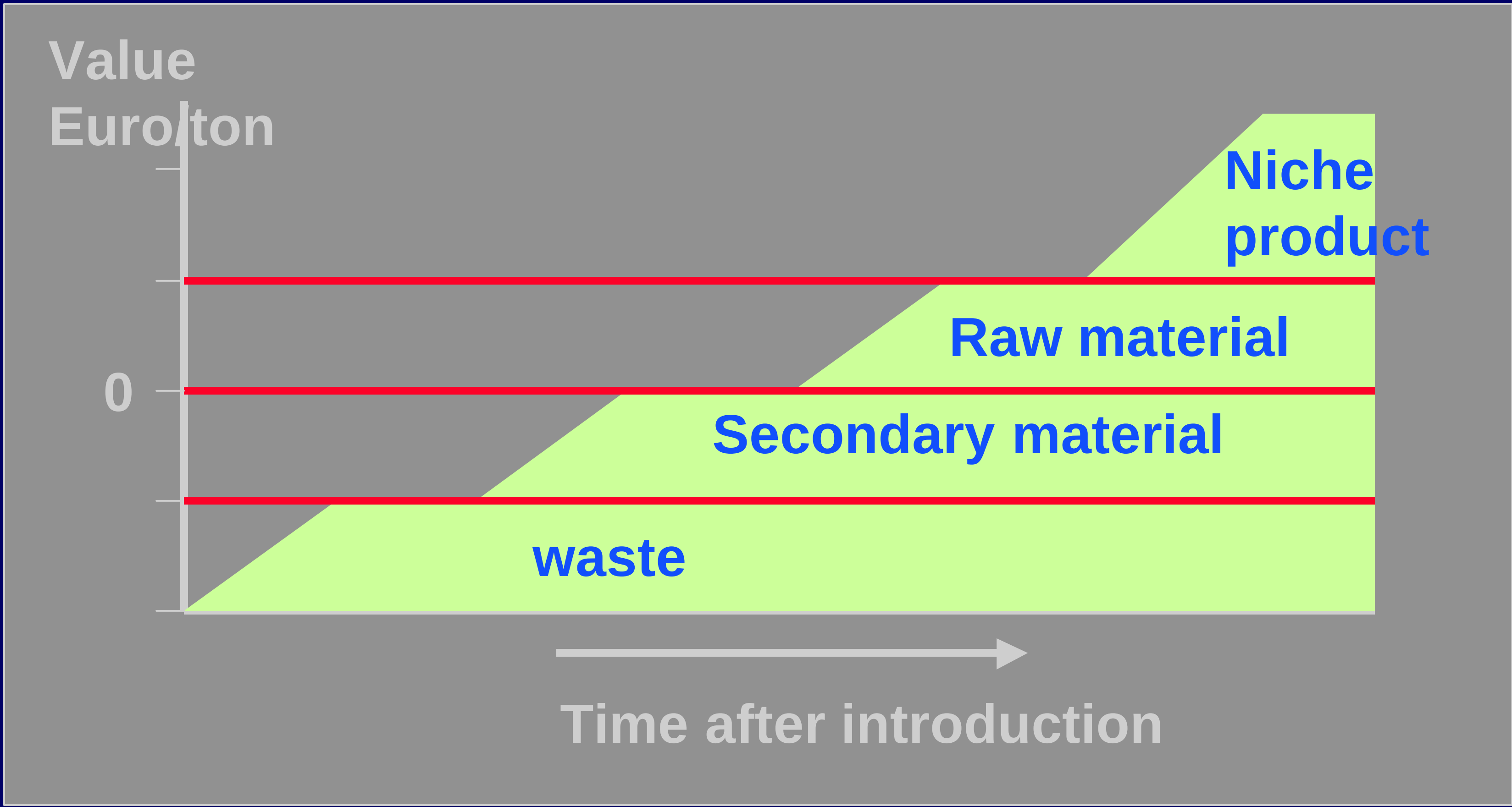
Marketing ashes



Questions for utilisation

- Is there a utilisation / market?
- Do the ashes meet the quality requirements for this utilisation?
- Environmental standards met?
- Necessary upgrading?
- Quality controlled?
- Price?

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R&D questions indirect co combustion

- Characterisation
  - Eur Waste Catalogue (yes / no hazardous components)
  - leaching behavioour
  - physical properties
- Utilisation possibilities / market
- Upgrading

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Knowledge boost?

- International exchange (FBC installations Scandinavia)
- Sewage sludge ashes and MSWI ashes
- Test installations
- Experiences on direct co-combustion

Theses (1)

- In future biomass and waste will be used as secondary fuel for direct co combustion in power plants in percentages > 10%. A high level of utilisation of ashes must be sought
- The quality of ashes is not yet known
- After 3 - 5 year high quantities of ashes from indirect co combustion (>100000 ton) will be generated. The quality is not yet known

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Theses(2)

- The market utilisation of a large quantity of ashes is not safeguarded
- alternative utilisations of these ashes have to be developed. Preferentially by a market partner
- If utilisation - other than concrete or asphalt - is chosen, leaching behaviour becomes more important

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Theses (3)

- There is a need for a R&D programme, focussed at quality and utilisation of “new” ashes.
- To make utilisation in cement concrete possible (ashen direct co combustion, high percentages), lobby work at CEN is necessary

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Goal:

ashes co combustion:

proven quality →

maximum utilisation

Effects Of Co-Combustion Of Secondary Fuels On Fly Ash Quality

F.J.M. Lamers[1], J.L.J. Vissers[1] and J.W. van den Berg[2]

[1]KEMA Nederland B.V.
P.O. Box 9035
6800 ET Arnhem, The Netherlands

[2]Dutch Fly Ash Corporation
P.O.Box 301
3730 AH De Bilt, The Netherlands

Synopsis In the Netherlands the government allows the co-combustion of a maximum of 10% of secondary fuels together with coal. To show whether the quality of fly ashes is affected by co-combustion, a broad research program was performed in which both the technical and the environmental quality of concrete with fly ashes from co-combustion were evaluated in comparison to the quality of concrete with reference fly ashes. In the research program, fly ashes from co-combustion of sewage sludge, paper sludge, pet cokes, several types of biomass and a type of liquid hydrocarbon were evaluated. Both the technical and the environmental quality of most ashes from co combustion were shown to be comparable to that of regular fly ashes. As a result of the outcomes of the research program the Dutch regulations for fly ash as a filler or part of the cementitious material were adjusted to make utilisation of fly ashes from co-combustion possible. European legislation is in preparation.

Keywords: alternative fuels, co-combustion, concrete, durability, fly ashes, leaching, mortars, strength development, regulations

Frans Lamers is a senior consultant in the field of waste management and by-product utilisation. He is author and co author of several papers on leaching, by products from coal fired plants and by products from Municipal Waste Incineration. Since 2000 he works as a market manager in the field of waste management.

Leo Vissers works as a senior specialist in the field of by product management He author of the report on co-combustion to CEN TC 154. He is author and co-author of several papers regarding by product management.

Jan van den Berg is by product manager at the Dutch Fly Ash Corporation since 1988. He is member of several national and international committees on by-products characterisation and fly ash utilisation. He is author and co-author of several papers on fly ash utilisation and fly ash management.

INTRODUCTION

Since 1995 Dutch coal fired power plants have considered the utilisation of secondary fuels in combination with hard coal. The economic advantages that arise from co-combustion of secondary fuels are large, and they compensate possible drawbacks. An additional advantage is that the combustion of non fossil fuels leads to lower CO_2-emissions into the atmosphere. Until recently the Dutch government allowed a maximum of 10% co-combustion of secondary fuels. Since 2000 higher percentages are allowed in principle. In 1995 – 1996 an extensive testing program has been carried out to test several types of secondary fuel in combination with hard coal. In large-scale tests, co-combustion was increased in steps from 0 to maximum 10%, and tested and reported (including the reference situation of 0% co-combustion).

A prerequisite for the co-combustion is that the extent of utilisation of fly ashes (and bottom ashes) is not reduced because of co-combustion. Up till now, the Dutch Fly Ash Corporation that is responsible for marketing the ashes has been able to sell 100% of the Dutch ashes as a construction resource. Dutch government does not allow disposal of fly ashes. Therefore the Dutch Fly Ash Corporation has to sell fly ashes from co-combustion to their regular market. To accomplish this it was necessary to assess the suitability of fly ashes from co-combustion for utilisation as a construction raw material in cement and concrete, since cement replacement and use as a filler form the prime markets for fly ash. Both the technical and the environmental quality had to be assessed.
The total procedure that was followed for the assessment of the suitability of ashes from co-combustion for use as a filler and cement replacement consisted of four parts:

- verification whether the quality of fly ashes from co-combustion meets the normal quality requirements for utilisation of fly ash as a filler and as a cement replacement
- additional verification of the influence of each of the fly ashes from co-combustion on concrete properties that are relevant for the market such as the durability of

concrete and the action of (super)plasticisers and air-entraining admixtures in concrete
- verification of the influence of co-combustion on the leachability of concrete that contains fly ashes resulting from co-combustion
- drafting of a standard for the assessment of conformity of fly ashes from co-combustion (compared to regular fly ashes) and subsequent acceptance as fly ash in the market.

A committee consisting of representatives from the cement industry, the concrete industry, government and the fly ash producers supervised the total research program. Based on the procedure that was drafted in the Netherlands, a change of the European standard (EN 450) is in preparation.

SECONDARY FUELS AND SELECTION OF ASHES

In 1995 / 1996 tests were performed at the power plants with secondary fuels. All secondary fuels have been added to coal in quantities up to 10% by mass. For every test mixture coal – secondary fuel, minimum 3 days of operation was maintained to make sure that steady operation was reached. The following types of secondary fuels were tested:
- Several types of biomass pellets:
- Pellets, prepared from paper sludge, composted sewage sludge and thinning wood
- Paper sludge (not dried, with a caloric value of about 4MJ/kg)
- Pet-cokes: Cokes from oil refining operations, showing a high caloric value but also a high content of Ni and V.
- Dried sewage sludge (caloric value of about 12 MJ/kg)
- Wood chips (primarily leaching behaviour was tested)
- Liquid hydrocarbons – a specific liquid hydrocarbon from industry that is used in one of the power plants in quantities up to two percent

From each of the test runs, ash samples were selected. If possible, also the reference fly ash was selected. This specific reference fly ash is a fly ash resulting from combustion of exactly the same coal mixture in the same power plant in the same period, but without co-combustion of secondary fuel. Ash samples were always taken from a steady operation situation. Sample codes are shown in Table 1.

POTENTIALLY DELETERIOUS EFFECTS?

The following components with a potentially deleterious effect (both technically or environmentally) can be increased in specific fly ashes resulting from co-combustion:
- Phosphates (in fly ashes from co-combustion of sewage sludge)
- Calcium oxide (in fly ashes from co-combustion of paper sludge and sewage sludge)
- Zinc (in fly ashes from co-combustion of sewage sludge)
- Vanadium and Nickel (co-combustion of Pet cokes)

Furthermore, possibly the content and the type of unburned coal could be influenced by co- combustion. Phosphates and zinc can potentially influence the setting time and early strength development (l, 2, 3, 4), that could also lead to higher susceptibility for carbonation. Further increase of the calcium oxide content can lead to lower soundness, that influences durability. The form and content of unburned coal in the fly ashes can influence the action of cement chemicals such as (super) plasticisers and air entraining admixtures.
In the quality assessment of the fly ashes from co-combustion these aspects are taken into account.

CHARACTERISATION OF ASHES FROM CO-COMBUSTION

An extensive characterisation of fly ashes was performed, consisting of the following analyses:

- chemical composition: SiO_2. Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2, P_2O_5, Cl, SO_3, trace elements, LOI, content of free lime and the glass content.
- physical properties: content > 45μm (sieve residue), soundness, density,
- morphology – by scanning electron Microscope

Results of the chemical characterisation are shown in table 2 (macro element composition), 3 and 4 (Trace element composition). Table 3 is based on quality control according to the demands in the European Standard EN 450 “Fly ash for concrete, definitions, demands and quality control” and the additional Dutch standard CUR 70 “coal fly ash for mortar and concrete”.

Fly ashes from co-combustion showed no significant differences in chemical composition from their reference ashes, except for the calciumoxide contents of PA10 and the phosphate content of RWZI. The demands of EN 450 and CUR 70 were met except for the LOI in some of the ashes. LOI was however not dependent on the extent of co-combustion but rather on the type of installation. Regular fly ashes and fly ashes resulting from co-combustion showed no differences in morphology.

Fly ashes from co-combustion were enriched in trace elements like V and Ni (PET-cokes), Mo (liquid hydrocarbon), Cd, Cu, Hg, Pb, Zn (sewage sludge). The contents of trace elements are shown in Table 4.

ARE THE TECHNICAL STANDARDS FOR REGULAR FLY ASHES MET? ASSESSMENT OF THE BASIC QUALITY

The quality of fly ashes from co-combustion should meet the demands of the European Standard EN 450 “Fly ash for concrete, definitions, demands and quality control”.
Demands are set for the following properties: Setting time and soundness of cement pastes and activity index at 28 days and 91 days for mortars. Furthermore the Dutch standard CUR 70 also set guidelines to the Activity Index in concrete and the so-called k-value of fly ash in concrete.

Cement pastes

The normal consistency and the setting time were tested with pastes consisting of 80% CEM I 32,5R and 20% of fly ash, conforming to agreement with the client (EN 450 leaves the choice of cement type open. Some Dutch standards for admixtures prescribe CEM I 32,5R and some CEM I 42,5). The consistency and the setting time of pastes with fly ashes from co-combustion showed no significant differences to their references. It was not necessary to test the soundness since none of the samples showed a free lime content > 1%.

Mortars

The workability and the strength development were tested on standard mortar prisms of 40x40x160 mm in size. Mortars were prepared according to EN 450 from 450 gr cementitious material (CM) (consisting of 75% CEM I 42,5 and 25% fly ash), 1350 gr standard sand and a W/CM of 0.5. Mortar prisms were demoulded after 24 hours and stored at 99% RH.

The Activity Index is the ratio between the strength development of fly ash mortar and of reference mortar (without fly ash, containing a cementitious material consisting of 100% CEM I 42,5).

Strength development was tested after 3, 7, 28 and 91 days. The Activity Indexes are only relevant for 28 and 91 days old prisms. The results of the tests are shown in Table 5.and Fig. 2. For all fly ash samples (both reference samples and fly ashes from co-combustion) the activity indices 28 days and 91 days easily met the requirements of the Standards (minimum 75 and 85% after 28 and 91 days, see Table 5). The strength development was almost equal for all ash samples, which leads to the conclusion that there is no significant influence from co-combustion on strength development of ashes.

Concrete

Strength development was tested on standard concrete cubes. Concrete cubes of 150x150x150 mm in size were prepared according to CUR 70. The concrete had a cementitious material content of 320 kg / m^3 (80% CEM I 32,5R and 20% of fly ash), a maximum aggregate size of 31.5 and a water content that was adjusted to reach a standard slump of 70 +/- 10 mm (see Table 6). Activity Indices meet the requirements set in CUR 70 for all samples that were tested ($\geq$ 70% after 7 days and $\geq$ 80% after 28 days) (see Table 7 and Fig 3). K-values were tested as an indication of the extent of contribution from the fly ashes to strength development. K-values of fly ashes from co-combustion showed no differences with k-values of regular fly ashes.

Conclusions

It can be conclusively stated that the fly ashes from co-combustion meet the technical standards, and are comparable in this respect with regular fly ashes.

INFLUENCE OF FLY ASHES FROM CO-COMBUSTION ON CONCRETE DURABILITY

For concrete with conventional fly ashes, there is sufficient certainty that the concrete is durable, provided that the concrete is produced according to the standards and fly ash meets the requirements of CUR 70. This certainty is based on experience. For fly

ashes from co-combustion, this experience is not available, and therefore there is insufficient certainty that the concrete produced with it is, in fact, durable.
An indicative assessment of the influence of fly ashes from co-combustion on concrete durability was based on the following properties: water suction after 28 and 91 days, carbonation, chloride penetration and freeze-thaw-salt resistance (sulphate resistance was not measured since it is assumed to show comparable behaviour with chloride resistance). All tests were performed on single samples. All concrete samples for durability testing were prepared according to the details given in Table 6.

Water-suction

Water suction was determined according to RILEM method CPC 11.2 after 28 and 91 days. 28 Days results are shown in Fig.4. Only for FOG and PET references are available. For both these secondary fuels, the concrete with fly ashes from co-combustion showed lower water-suction than their reference. After 91 days the results were almost comparable.

Carbonation

Carbonation was assessed in an indicative way by comparing the results of a fast test and testing under normal circumstances.
Concrete cubes of 100*100*100 mm in size were cured for 7 days at 20^{o}C and 95% RH. After curing they were stored for 7 weeks at 20^{o}C and 65% RH. Half of the concrete cubes were put in a CO_2-closet afterwards and subjected to a CO_2 concentration in air of 3%, for 8 weeks. For the other half of the samples storage at 20^{o}C and 65% RH was continued for 8 weeks.
Afterwards carbonation depth was determined according to RILEM method CPC18.
Carbonation was only determined for samples PET 1 and 2 and their reference, LHC and REF 95. No significant differences could be shown between fly ashes resulting from co-combustion and their references.

Resistance to the penetration of chloride ions.

The resistance to the penetration of chloride ions was measured in two ways:

- Direct measurement according to Danish Standard APM 302. After 28 days of standard moist curing, concrete cubes 15*15*15 cm are cut in two halves. Both halves are stored in a lime-saturated solution. After reaching equilibrium weight one half is dried, coated at 5 sides, resaturated and afterwards stored in a 16.5% sodium chloride solution. After 35 days both the sample from the lime-saturated solution and the sample from the sodium chloride solution are dried. Subsequently samples are drilled from 1, 2 and 3 cm depth and analysed for chloride content.
- Indirect measurement based upon progressive impedance measurements of concrete bars of 10*10*30 cm, that are stored at 20^{o}C and 99% RH. The proposed procedure states that the average electrical resistance of samples should be lower than that of a blank sample without fly ashes, at an age of 91 days or older.

The results of both measurements showed that the reistance to the penetration of chloride ions of the fly ash concrete is higher than that of the concrete without fly ash. This agrees with the data from the literature. Furthermore the results show that there is no significant difference between fly ashes from co-combustion and reference fly ashes. Figure 5 shows some results.

Freeze-thaw salt resistance

The freeze-thaw salt resistance was measured according to the so-called Scandinavian slab test (RILEM, 1995). Freeze thaw resistance was only measured for samples PET. There were no significant differences between concrete samples with fly ashes from co-combustion and concrete samples with their reference fly ashes.

Conclusion

No significant differences could be shown between fly ashes from the co-combustion and their reference fly ashes, that is, fly ashes resulting from combustion of the same coal in the same power plant, but without co-combustion of the secondary fuels.

ACTION OF SUPERPLASTICISERS, AIR-ENTRAINING ADMIXTURES AND RETARDING ADMIXTURES ON CONCRETE WITH FLY ASHES

From literature it is known that the carbon fraction from fly ashes affects the action of admixtures. In the case of co-combustion, the type of carbon in the fly ashes could be different from the reference situation. Indicative tests were performed regarding the action of superplasticisers, air-entraining admixtures and retarding admixtures. All tests were based on the Dutch standard NEN 3532 “Admixtures for mortar and concrete, definitions, demands and analysis”. The concrete composition is given in Table 6.

Superplasticisers

Tests were performed regarding the action of three types of superplasticisers, namely naphthalene formaldehyde (addition 0.8%), melamine resin (addition 0.8%) and lignosulphonate (addition 0.2%). The test procedure comprised measurement of the following items:

- Measurement of workability directly after preparation, both for concrete with and without superplasticiser
- Measurement of workability 30 minutes after preparation for the concrete with superplasticiser.

For a superplasticiser the requirement is:

- A minimum ratio for the workability with and without superplasticiser
- A minimum ratio for the workability after 30 minutes and the workability directly after preparation

The workability of concrete with fly ashes from co-combustion, after addition of superplasticisers is not significantly different from the workability of concrete with reference fly ashes. An example of the test results is shown in Fig. 6. The test results showed no differences in influence of the ashes on the three types of superplasticisers. For the future the measurement of the influence of only one superplasticiser should be sufficient.

Air-entraining admixtures

Tests were performed with one type of air-entraining admixture. A standard addition of 0.2% (as a percentage of cement content) was used. The test procedure comprised of the measurement of the air content (demand: 4.5 – 6.5%), measurement of the 28 days strength and measurement of the so-called distance factor, which is a summation of microscopic counts of air pores. The results are summarised in table 8. It can be shown that the action of air-entraining admixtures is influenced by the Loss on Ignition (LOI) of the fly ashes. This is in agreement with data published in the literature. Only those fly ashes that showed an increased LOI (higher than 5%) showed the necessity for a higher addition of air-entraining admixtures or an increased distance factor. Differences between fly ashes from co-combustion and reference fly ashes could not be shown.

Retarding admixtures

Tests were performed with one type of retarding admixture (0.3% addition). Start of setting was measured. The demand is that the start of setting takes place between 8 and 36 hours after normal setting time. All samples met this demand. Sample PA10 showed a setting time that was relatively high in comparison with the other fly ashes. Results are shown in table 9.

Conclusion

Fly ashes from co-combustion did not show significantly different behaviour in combination with superplasticisers, air-entraining admixtures or retarding admixtures. In the case that there were differences they could be attributed to higher LOI in these samples.

LEACHING BEHAVIOUR

Leaching of concrete cubes with coal fly ashes resulting from co-combustion was measured through a diffusion test based on and according to the Dutch standard NEN 7345. The chemical analyses were performed on a single mixed fraction of leachates. Only the measured leachability after 64 days was determined.

Only for some co-combustion situations leaching results were measurable. The high leachability of the concretes prepared with fly ashes from co-combustion of dried sewage sludge is remarkable since high leachability also occurred for reference concrete of that series. Fig. 7 shows the average rate of leaching between concretes prepared with fly ashes from co-combustion and those with “normal” fly ashes. As can be seen, fly ashes from co-combustion show a slightly increased leachability only for a few components. For all those components leachability compared to the Dutch leachate standards was low.

It can be concluded that the application of coal fly ash, originating from the co-combustion operations described in this report, does not lead to a significant change of the leaching behaviour of concrete, when compared to the application of coal fly ash which is formed during "normal" coal combustion (i.e. without co-combustion). These types of coal co-combustion fly ash can be applied without any ecological objection to the preparation of concrete, which is to comply with the most stringent Dutch requirements for construction materials.

For the Dutch power plants, a good environmental quality of concrete with fly ashes from co-combustion, is a boundary condition for the implementation of co-combustion. Only after the environmental quality is shown, continued sales of the fly ashes to the construction market can be considered. The verification and certification of the technical behaviour is only useful after it has been proven that the environmental quality meets the requirements.

CONFORMITY PROCEDURE

A procedure was developed to show that fly ashes from co-combustion (maximum 10% of co-combustion) are technically equal to fly ashes without co-combustion. This procedure consists of the tests of the EN 450 standard extended with a “conformity analysis”, in which the effects of the fly ashes from co-combustion on durability and on the action of cement additives are established. This procedure has been made part of the Dutch technical standards (CUR, 1999).
If the allowance program is passed, fly ashes from co-combustion are shown to be conforming to other fly ashes and they can be sold to the market as regular coal fly ashes, under the normal quality control for EN 450.
Since 1999 a sub Commission of CEN Technical Committee 154 is developing a new version of European Standard EN 450 in which the use of ashes from co-combustion is regulated. The procedure to show that fly ashes from the co-combustion are conformous with regular fly ashes will be probably simplified in comparison with the Dutch Procedure.

EVALUATION

The purpose of the research program that has been executed was to show the quality of fly ashes from the co-combustion of secondary fuels for use in concrete as filler and / or as cement replacement.
The research program consisted of three parts:

- Assessment whether the existing standards for fly ash for use in concrete can be met for fly ashes from co-combustion. This assessment has been closed with a positive answer.
- Execution of durability tests and tests regarding the action of cement chemicals, with the purpose to get an indication whether fly ashes from co-combustion show differences from conventional fly ashes in that respect. The test results showed no significant differences between fly ashes from co-combustion and their reference fly ashes (fly ashes from combustion of the same coal blend in the same power plant but without co-combustion). From the experience that was gained during this part of the program, it was established that only a part of the tests that were executed are necessary for future characterisation of an unknown fly ash from co-combustion:
    - For durability testing, only testing of the resistance of concrete to the penetration of chloride ions and the freeze-thaw salt resistance is necessary
    - For testing of the action of superplasticisers only one type of superplasticisers needs to be used
- Leachability tests of concrete with fly ash from co-combustion. The concretes with fly ashes from co-combustion showed to be comparable to “normal fly ash concretes

Based on the research program, a conformity procedure was developed to show that fly ashes resulting from co-combustion of a specific secondary fuel are comparable to "normal" fly ashes. This procedure is made part of the general Dutch testing procedures for fly ash in concrete. A new version of the European Standard EN 450 when accepted will contain a simplified conformity procedure.

Since 1999 fly ashes from co-combustion of paper sludges and fly ashes from co-combustion of biomass pellets have been shown to be conforming to the established standards. Conformity tests for fly ashes from co-combustion of poultry litter, cocoa shells, coffee grounds, sewage sludge and demolition wood are in progress.
All the Dutch coal fired power plants are now successfully co-firing on a large scale, thus reducing their operational costs and contributing to a reduction of CO2 – emissions.
Because the utilisation of fly ashes from co-combustion is subjected to relevant quality control and based on that is considered safe, the road is made free for large scale co-combustion of secondary fuels.
Future plans for co-combustion in Dutch power plants consist of a introducing a growing share of secondary fuels. The maximum that was set at 10% co-combustion by the Minister of the Environment in 1994 will be withdrawn, in favour of a decrease in fossil CO_2-production. The secondary fuels that are now considered (wood, poultry litter, sewage sludge, coffee grounds, cocoa shells) all contribute to lowering the emission of fossil CO_2, since they all contain so-called short cycle CO_2. In this way Dutch coal fired power plants contribute to reaching the targets of the Kyoto Agreements on climate change.
Future research on the coal combustion by products will therefore be focussed at the influence of higher percentages of co-combustion on the technical and environmental quality of the by products

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Table 1 Sample codes for fly ashes from co-combustion that were tested,

Code	Secondary fuel	% co-combustion	Location of tests
PET 1 PET 2 REF-PET	Pet cokes 1 Pet cokes 2	10 10 0	Geertruidenberg
PA 10 REF-PA	Paper sludge	10 0	Geertruidenberg
RWZI REF-RWZI	Dried sewage Sludge	6 0	Amsterdam
BIO	Biomass pellets	5	Rotterdam
LHC	Liquid hydrocarbons		Rotterdam
REF - 1995			

Table 2 Content of major elements in fly ashes from co-combustion and in reference fly ashes

	content of macro-oxides, in percents								
code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5
PET 1	65,3	20,8	9,1	1,51	1,43	0,57	1,97	0,88	0,18
PET 2	66,3	20,4	8,8	1,46	1,39	0,55	1,92	0,86	0,18
REF-PET	65,9	21,1	8,8	1,55	1,20	0,48	1,89	0,87	0,19
PA10	46,7	26,6	5,7	14,7	1,6	0,45	1,5	1,2	0,79
REF PA	58,2	27,9	6,1	3,0	1,1	0,39	1,9	1,5	0,13
RWZI	53,2	21,0	10,3	5,6	1,0	0,41	1,0	1,1	3,6
REF RWZI	58,4	23,0	8,2	3,4	0,9	0,42	1,1	1,1	0,39
BIO	51,7	27,6	8,7	5,4	1,5	0,64	1,46	1,4	0,8
LHC	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
REF - 1995	60,0	23,0	5,6	3,7	1,24	0,37	1,30	1,2	n.a.

n.a. no analysis results available

Table 3 Content of sulphate, LOI (unburned carbon content), content of free lime, glass content, reactive silicon oxide and fineness of fly ashes that were analysed (mass percent) All values are based on single measurements; REF-1995 forms the yearly average (1995) for conventional fly ashes with a quality certificate

Property	SO_3	LOI	Free lime	Glass content	Reactive silicon oxide	Fineness (%>45µm)
Unity	% m/m	% m/m	% m/m	% m/m	% m/m	% m/m
Method / standard	CUR 70 EN 450	EN 450	EN 450	NEN 5435	Draft NEN-EN 196-21	EN 450
Demand	≤3,0	≤5,0	≤1,0	≥50	≥25	≤40
PET1	0,86	3,3	<0,1	69,0	47,6	13,8
PET2	0,43	2,3	<0,1	69,0	50,2	14,3
REF-PET	0,98	1,6	<0,1	71,0	50,8	13,6
PA10	1,30	4,35	0,52	48,0	36,0	34,9
REF-PA	-	6,12	0,07	62,0	40,1	32,8
RWZI	0,09	1,51	0,26	59,2	38,2	30,0
REF-RWZI	0,15	1,85	0,63	56,1	40,7	23,0
BIO	0,60	6,70	0,23	55,8	-	26,8
LHC	1,15	5,43	0,05	-	-	22,2
REF-1995	0,61	2,56	0,29	56,6	-	27

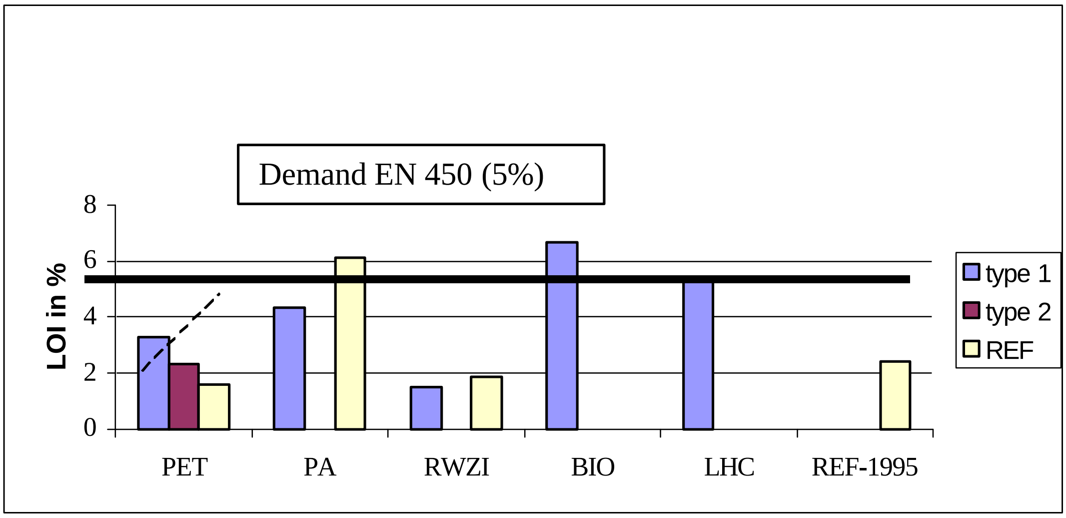


Fig. 1 Loss on ignition for several types of fly ashes from co-combustion

Table 4 Contents of minor elements in fly ashes from co-combustion. From Bio and LHC no contents of minor elements were determined.

Property	As	Cd	Cr	Cu	Hg	Mo	Ni	Pb	Sb	Se	V	Zn
Unity												
PET1 PET2 REF-PET						25 16 11	358 172 64					1730 559 186
PA10 REF-PA	33 43	1.00 0.62	129 150	108 137	0.26 0.17			64 68	<6 8			174 107
RWZI REF-RWZI	39 38	1.88 0.59	101 69	292 95	0.82 0.56		103 97	202 63		5 4.6		740 168
REF-1995												

Table 5 Compressive strength of mortar prisms of fly ashes from co-combustion

	Compressive strength in N/mm^2					Activity index in %	
AGE (days)	1	3	7	28	91	28	91
demand						**75**	**85**
BLANK	17,8	40,1	50,0	61,2	69,9		
PET1 PET2 REF-PET	11,9 12,7 12,1	29,8 29,9 28,8	41,3 40,3 40,1	51,8 51,8 51,8	62,5 62,2 65,7	**85** **85** **85**	**89** **89** **94**
PA10 REF-PA	12,7	31,9 30,3	40,7 40,4	55,4 54,6	65,7 64,0	**91** **85**	**95** **92**
RWZI REF-RWZI		29,4 29,7	39,1 39,1	53,9 51,9	71,1 68,6	**86** **82**	**105** **102**
BIO	12,7	31,2	40,8	54,0	63,6	**88**	**91**
LHC	13,2	31,3	42,1	54,6	65,9	**89**	**94**
REF-1995	13,2	31,8	42,3	54,3	62,7	**89**	**90**

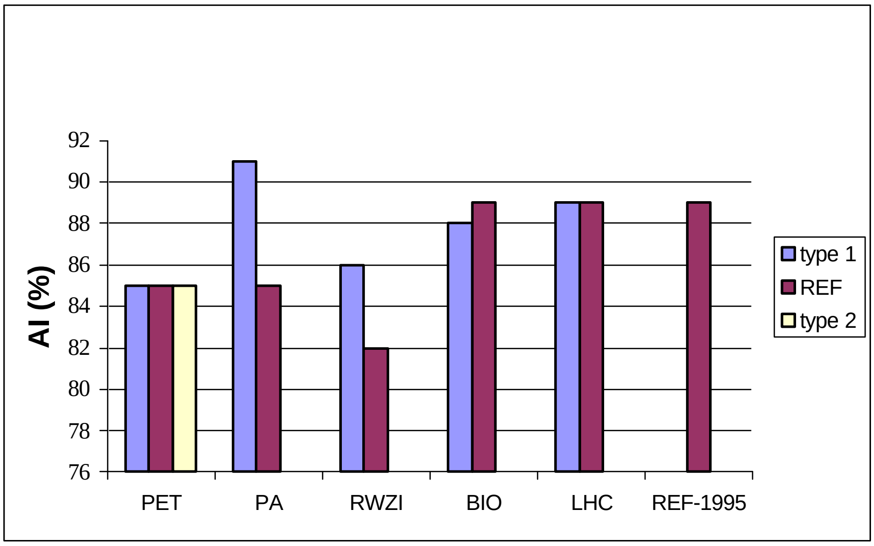


Fig. 2 28 Days Activity Index (%) for fly ashes from co-combustion

Table 6 Concrete composition for durability research and all other tests

	Durability research	All other concrete research
Cement content	340 kg/m^3	320 kg/m^3
type of cement	Portland cement (CEM I 32,5R)	Portland cement (CEM I 32,5R)
aggregate	Sand and gravel (max 31.5 mm)	Sand and gravel
water	W/C ratio=0,45	Water content necessary for a slump of 70mm
Concrete chemicals	0,3% superplast	No

Table 7 Compressive strength development and activity index (AI) of concrete

	Compressive strength		Activity Index (AI)	
Age	7d	28d	7d	28d
Unity	N/mm^2	N/mm^2	%	%
Demand	-	-	≥70	≥80
PET1	29,2	40,1	82	88
PET2	30,2	41,3	84	90
REF-pet	30,6	41,4	85	91
PA10	30,9	41,0	83	87
REF-PA	30,0	38,2	80	81
RWZI	31,1	45,3	80	89
REF-rwzi	28,9	42,4	74	83
BIO	28,8	41,5	80	91
LHC	27,3	37,8	76	83
REF-1995	29,7	40,4	83	88

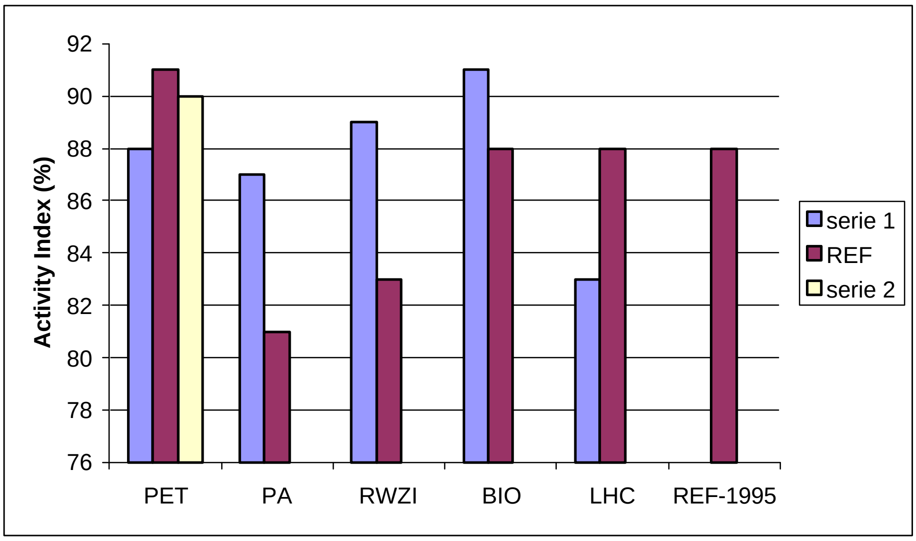


Fig. 3 Activity Index 28 and 91 days for concrete with fly ashes from co - combustion

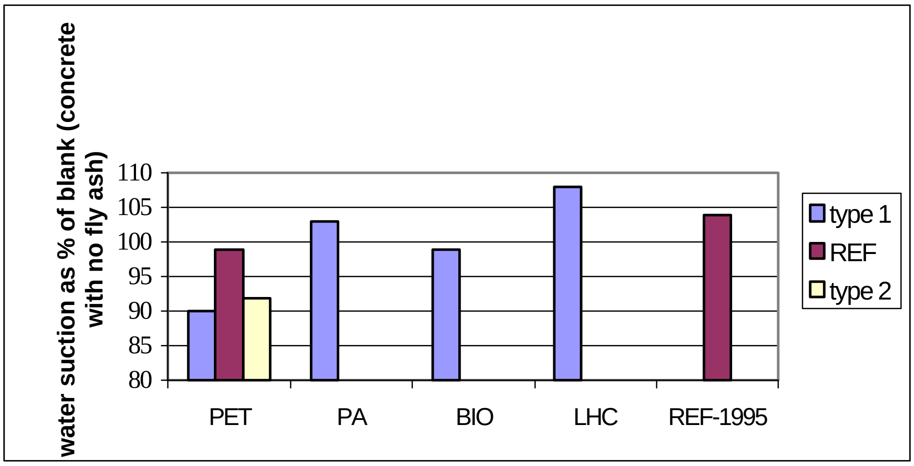


Fig. 4 Water suction 28 days for concrete with fly ashes from co-combustion

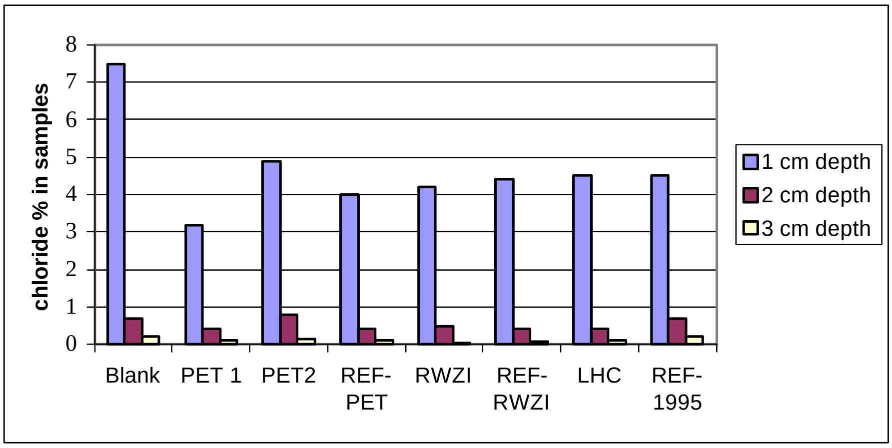


Fig. 5 Chloride content of concrete samples at several depths after 35 days of chloride immersion

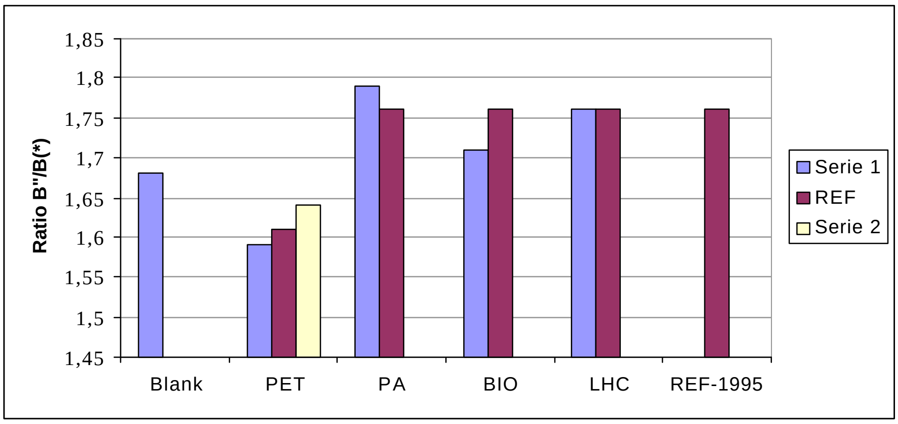


Fig. 6 Action of naphtalene phormaldehyde: increase of workability

(*) B = workability (slump) for concrete without superplasticiser
B" = workability with superplasticiser
Demand: Ratio > 1.45

Table 8 Influence of air entraining admixture in concrete with fly ashes from co-combustion and reference concrete

Mixture		Air content (demand 4.5 – 6.5%)		Compr. strength 28 d.	Distance factor
	% admixture	Result %	% of blanc (at 0.2%)	MPa	mm
Blanc	0.2	4.7	-	26.2	0.16
PET 1	0.2	5.3	115	13.7	0.13
PET 2	0.2/0.25	4.4/6.0	96	12.5	0.11
REF-PET	0.2	5.5	120	13.0	0.15
PA10	0.2	5.4	70	22.2	0.14
Bio	0.2/0.3	3.2/5.2	87	15.7	0.15
LHC	0.2/0.25	4.0/4.8	122	15.6	0.27

Table 9: Influence of retarding admixtures.

Mixture	W/CM	Setting time (hr/min)	% of reference
Blanc	0.24	12:30	78
PET 1	0.25	14:301	91
PET 2	0.25	16:00	100
REF-PET	0.25	15:00	94
PA10	0.24	20:00	125
Bio	0.266	17:00	106
LHC	0.26	15:30	97
Reference	0.266	16:00	-

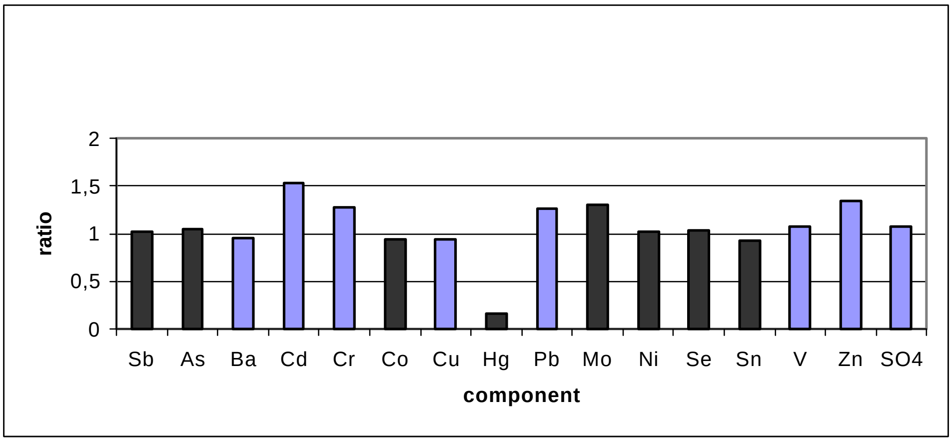


Fig. 7 Ratio Leaching with / without co-combustion
(dark bars all data below detection limit)

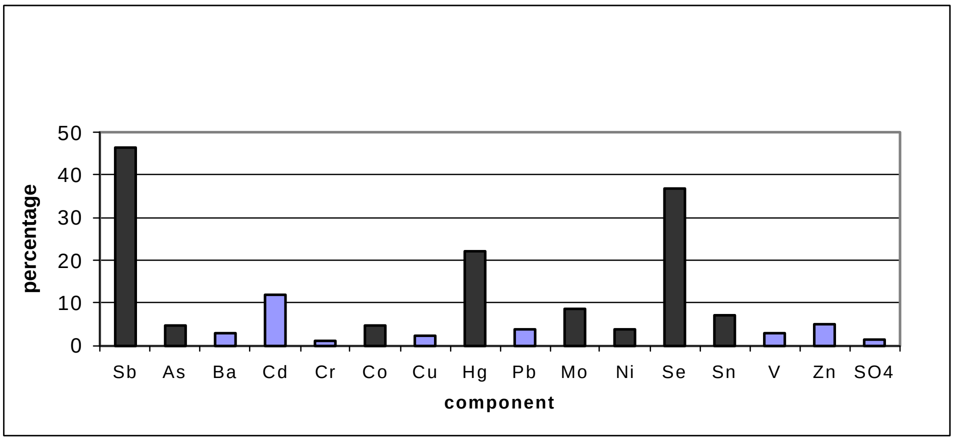


Fig. 8 Leaching of concrete with fly ashes: percentage of Dutch Limit Values
(dark bars all data below detection limit)

Cofiring Biomass and Coal

Larry Baxter, Søren Kær, Matt Hall

Brigham Young University

Provo, UT 84602

June 20, 2002

Outline

- Summary of previously reported impacts
- Corrosion in reducing atmospheres
- Modeling and impacts of striated flows
- Mixed coal-biomass fly ash
- SCR performance

Major Technical Cofiring Issues

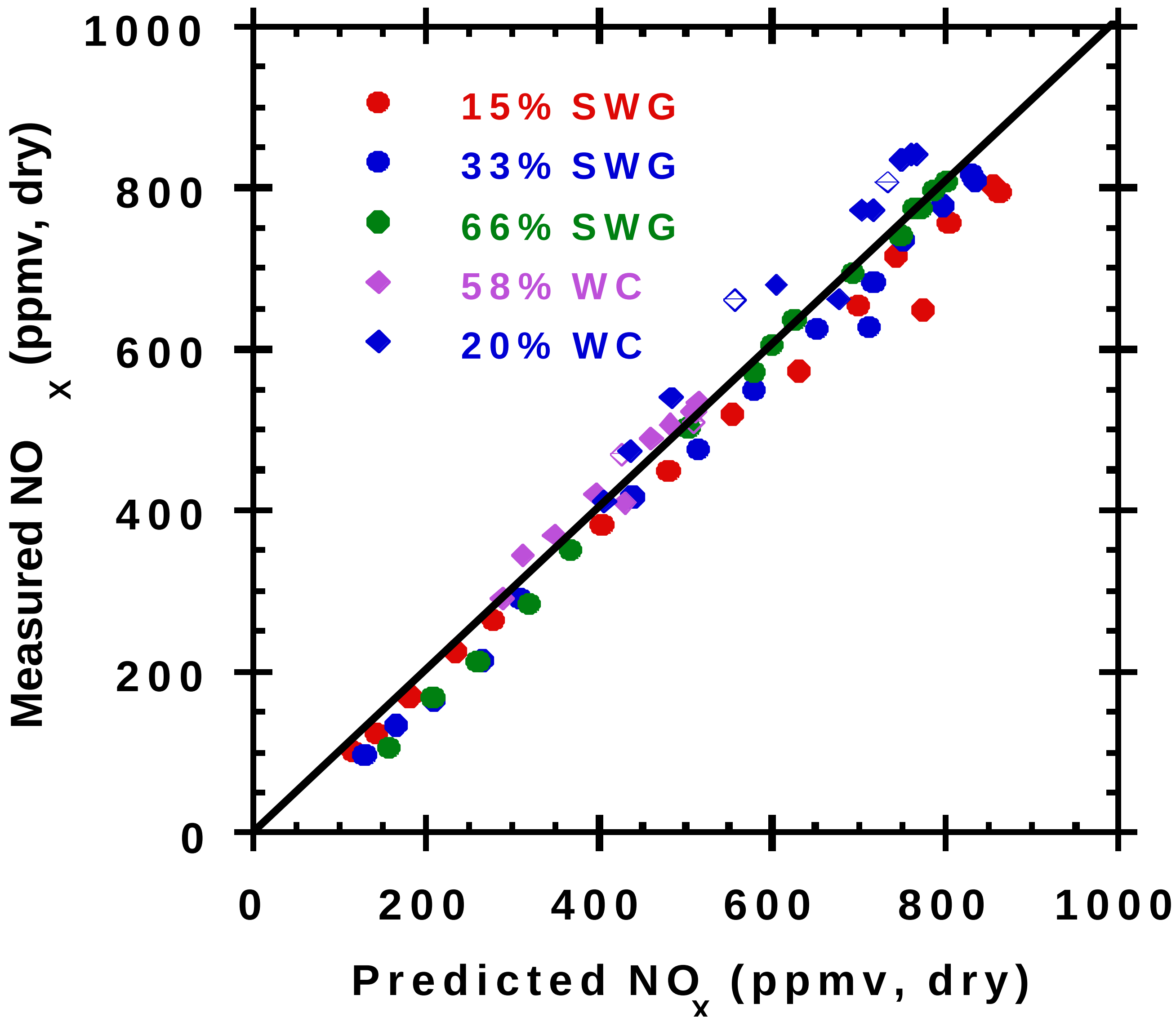
- Fireside Issues
  - Pollutant Formation
  - *Carbon Conversion*
  - *Ash Management*
  - Corrosion
  - SCR and other downstream impacts
- Balance of Process Issues
  - *Fuel Supply and Storage*
  - *Fuel Preparation*
  - Ash Utilization

Lab and field work indicate there are no irresolvable issues, but there are poor combinations of fuel, boiler, and operation.

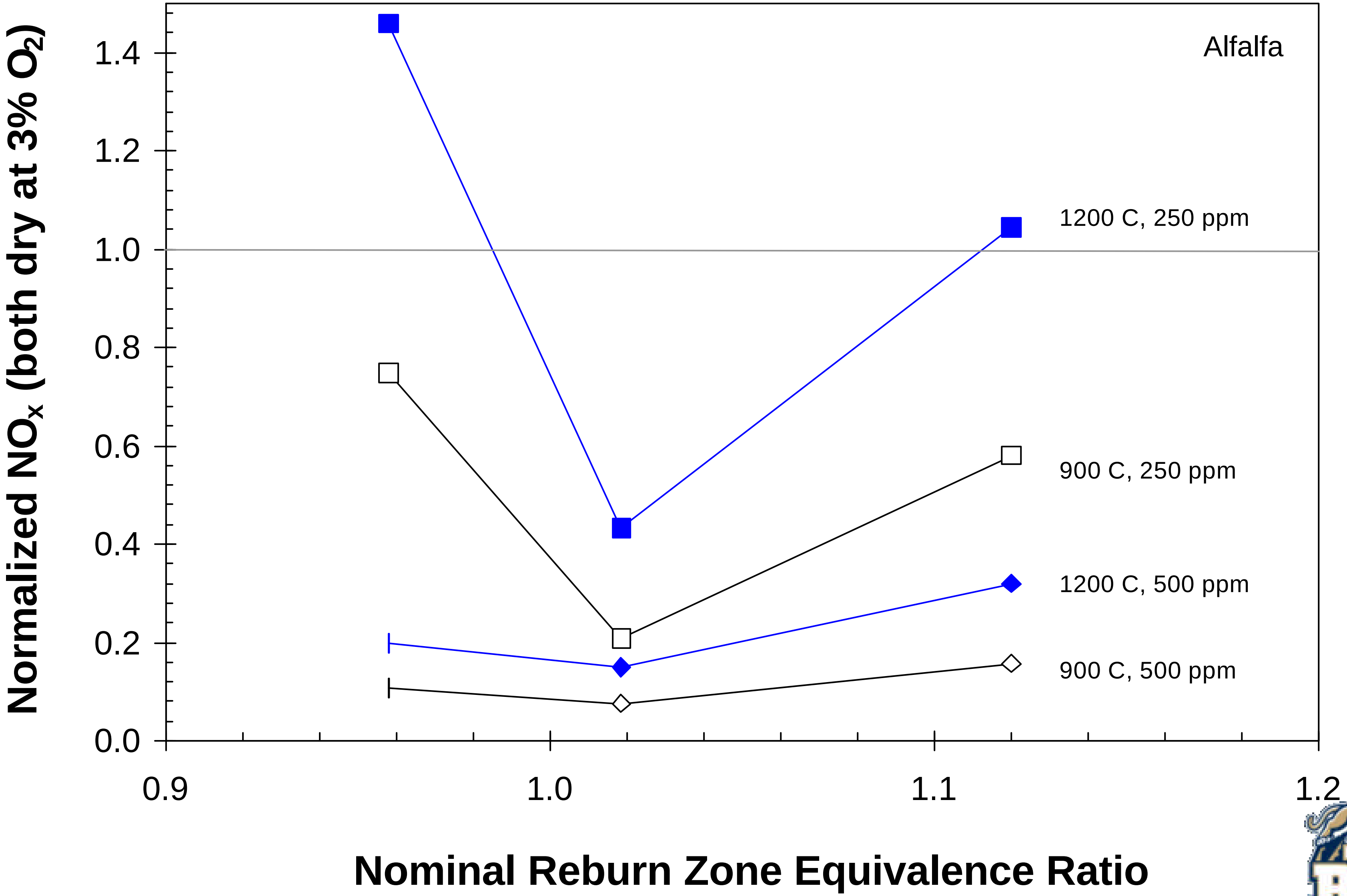
US Commercial Experience

- Over 40 commercial demonstrations
- Broad combination of fuel (residues, energy crops, herbaceous, woody), boiler (pc, stoker, cyclone), and amounts (1-20%).
- Good documentation on fuel handling, storage, preparation.
- Modest information on efficiency, emissions, economics.
- Almost no information on fireside behaviors, SCR impacts, etc.

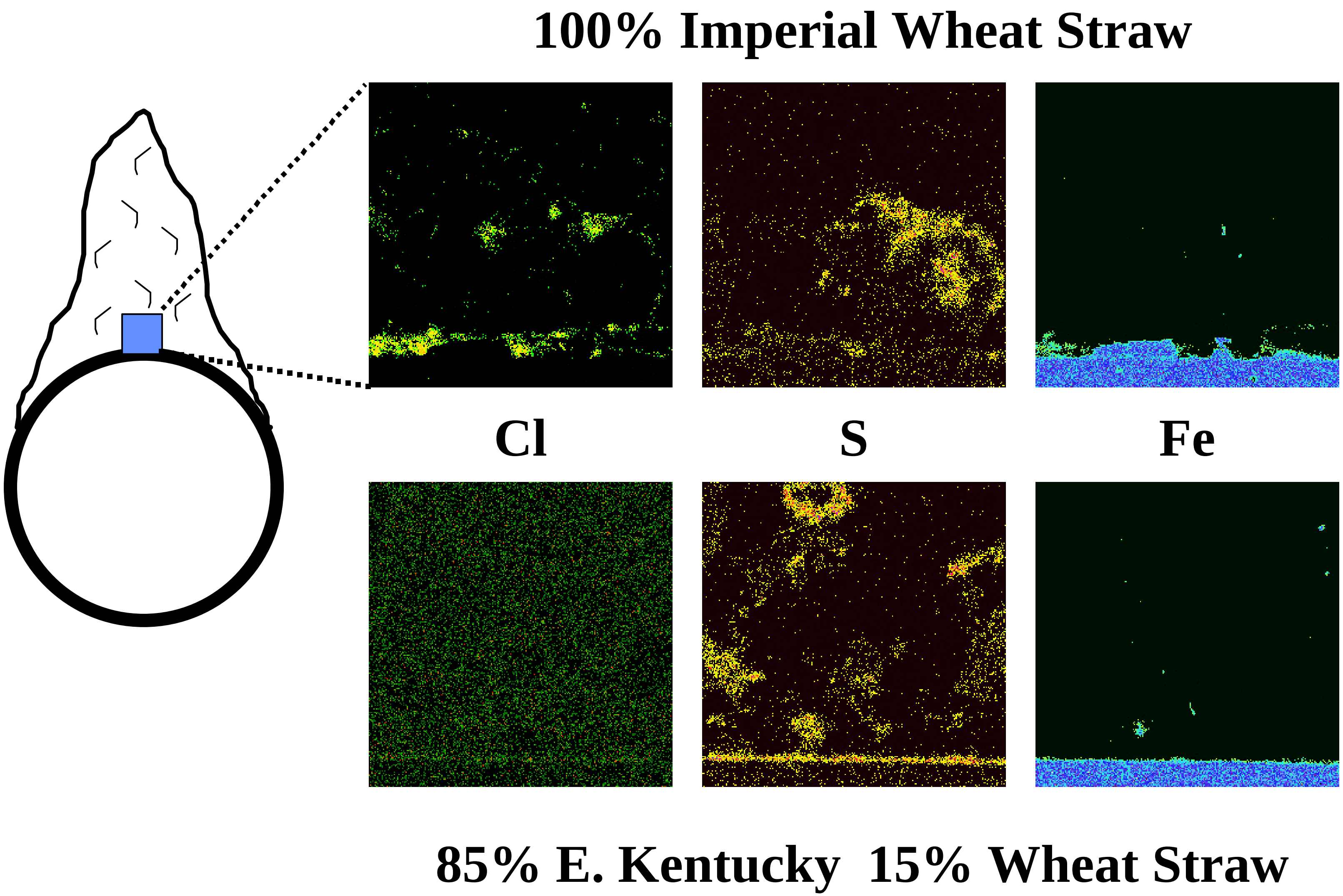
No Unanticipated NO_x Effects



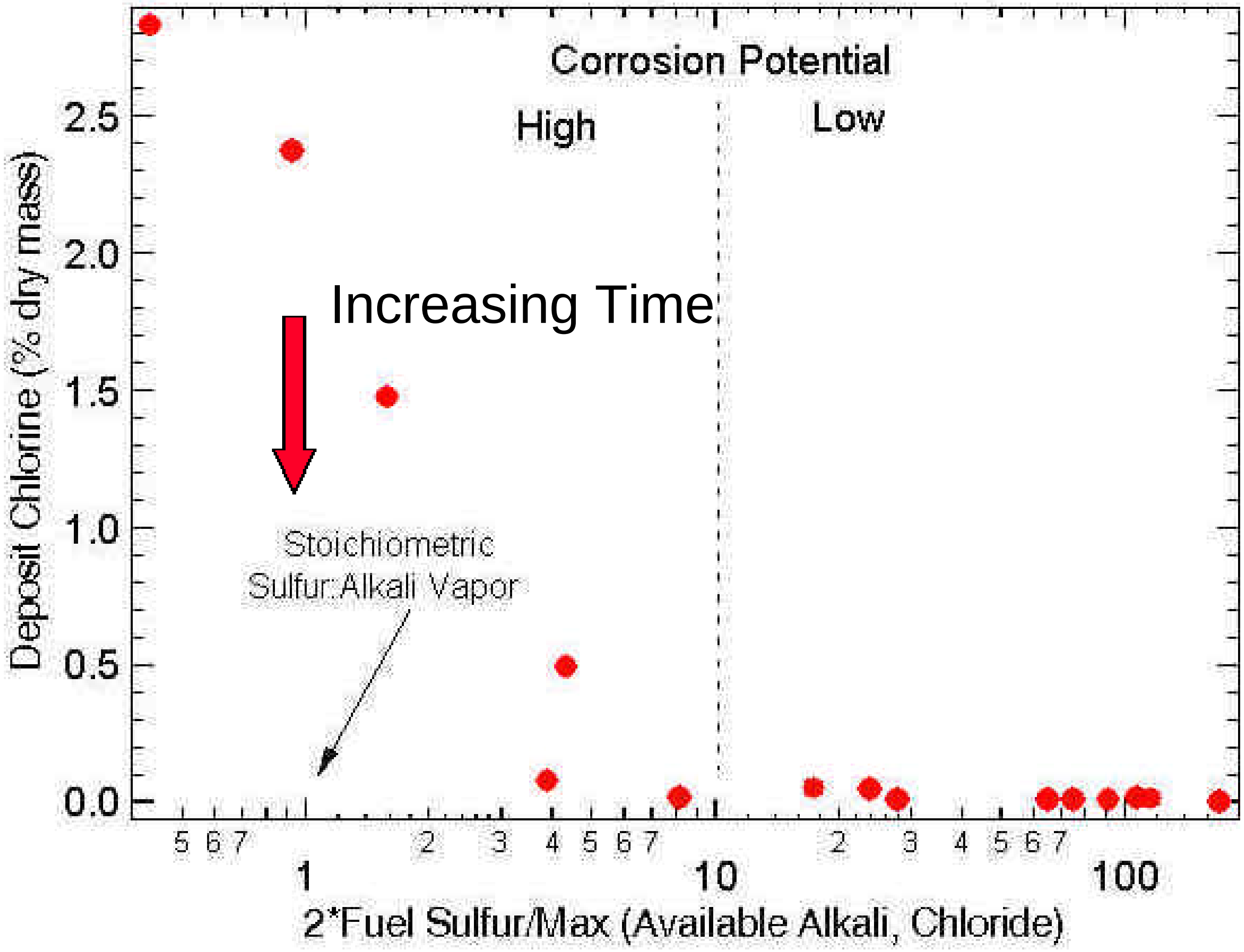
Stoichiometry and Temperature Impacts



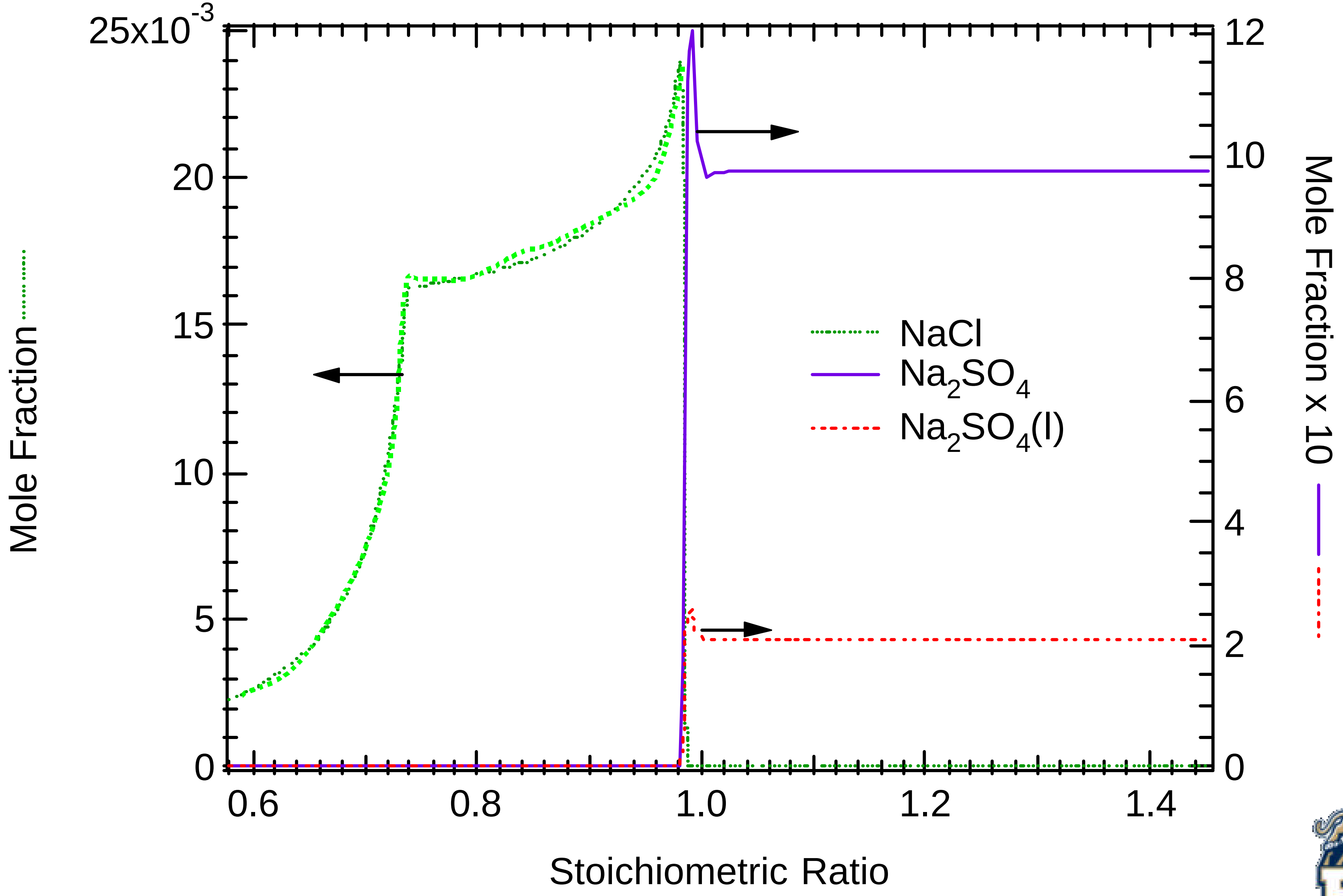
Composition Maps Support Corrosion Hypothesis



Fuel Properties Predict Corrosion



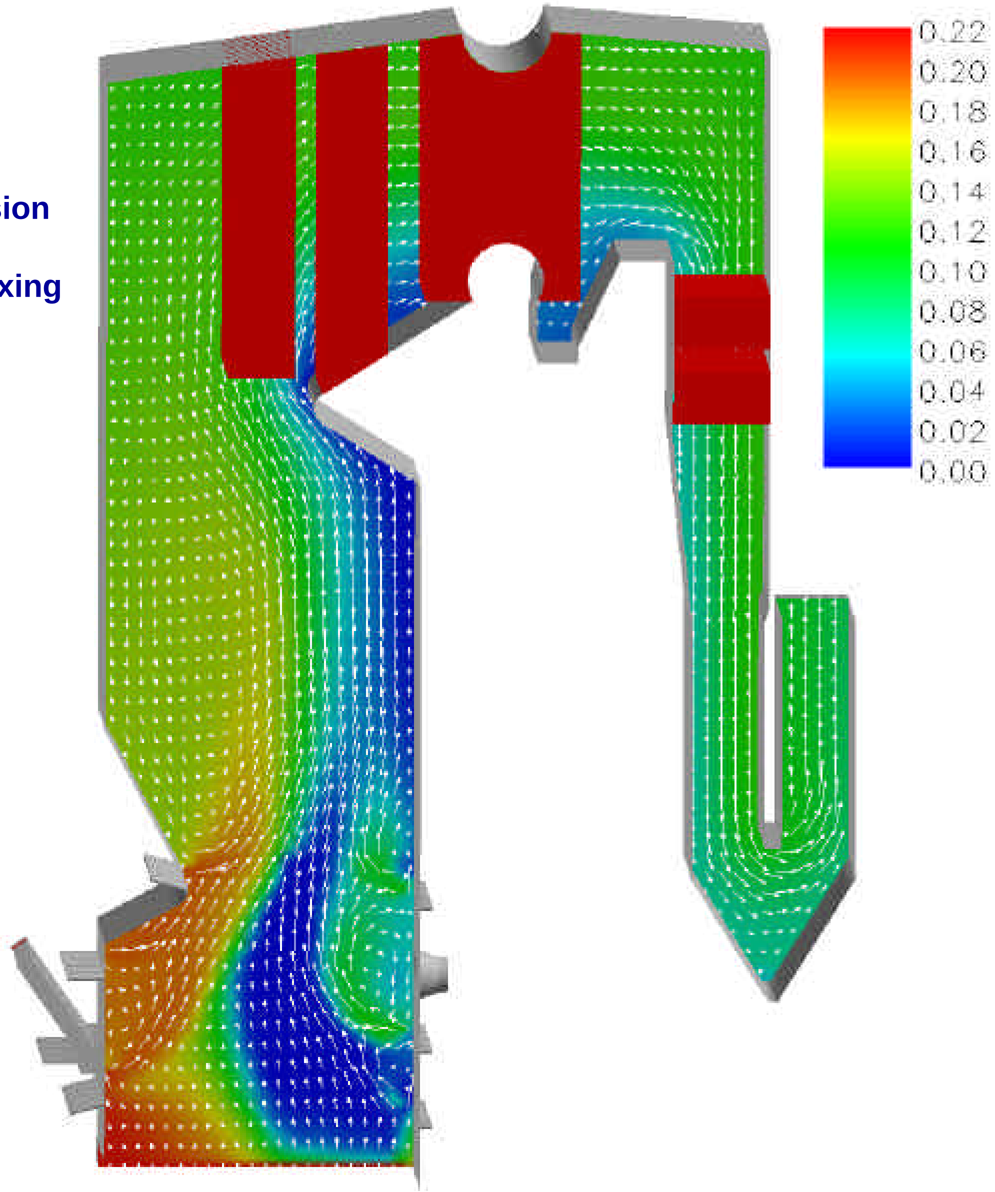
Oxidizing Conditions Favor Sulfates

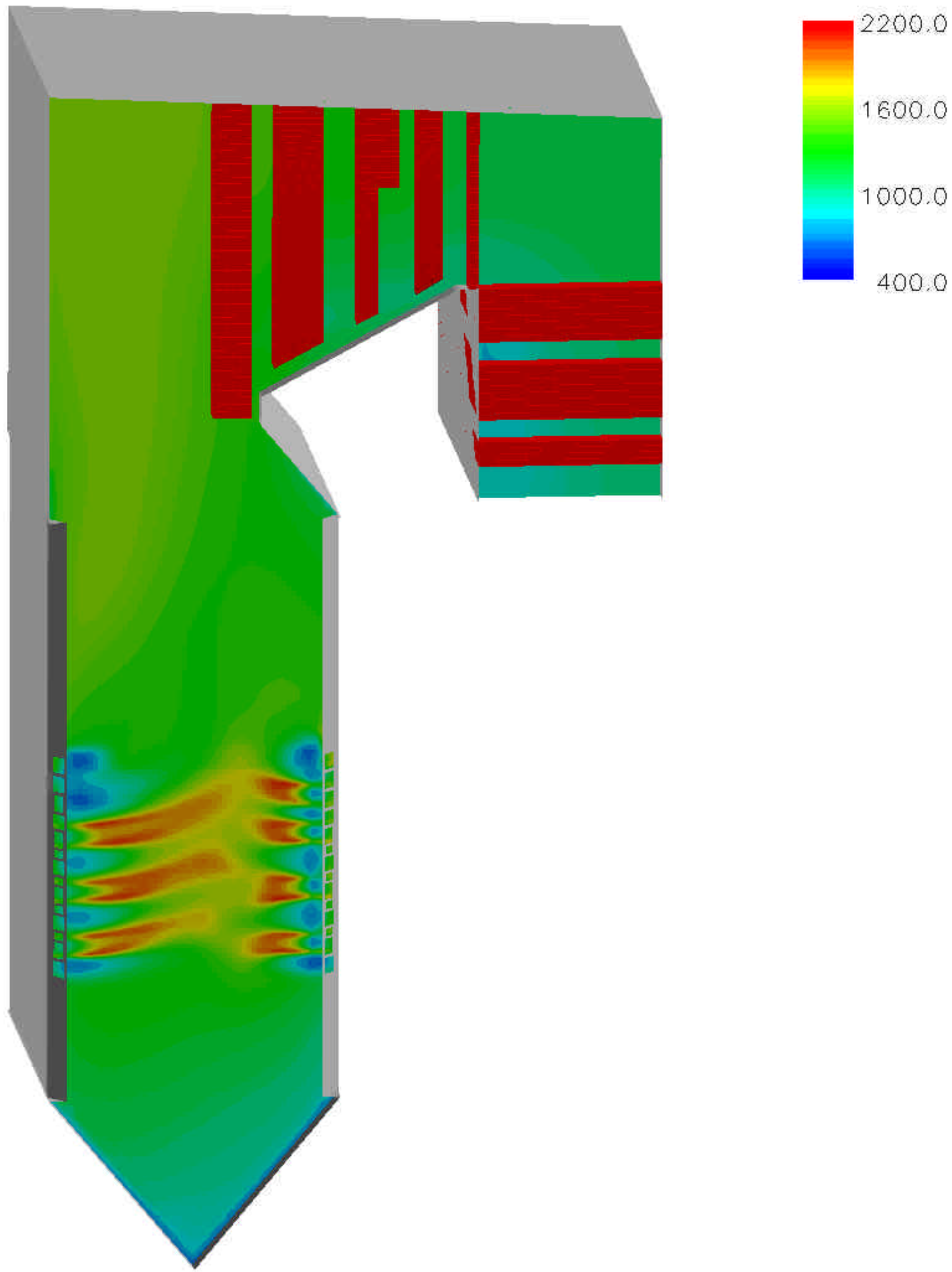


Low O2 alley along backwall

Impacts deposition rates and corrosion

Nozzle diameter (penetration) vs. mixing



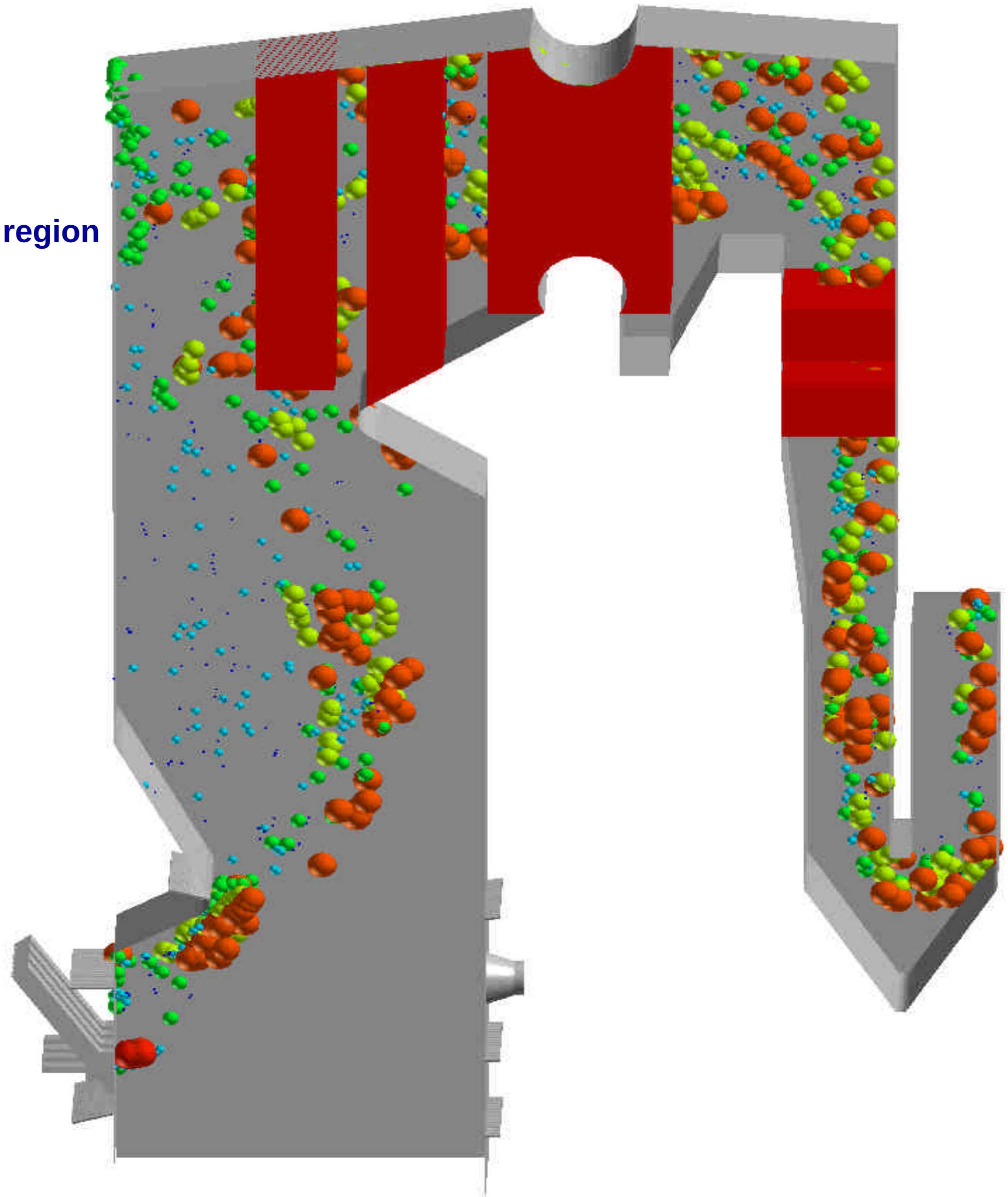


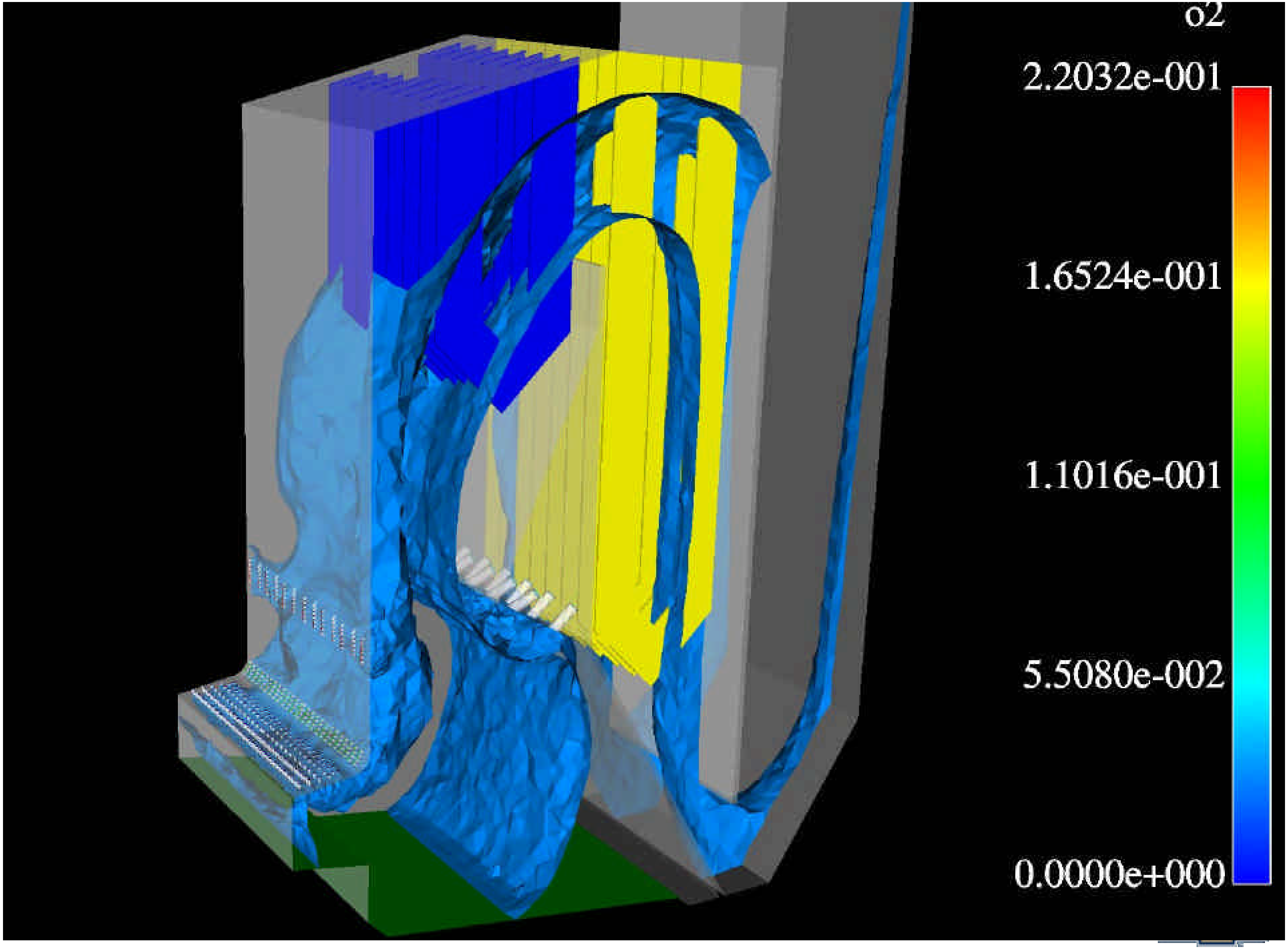
2200.0
1600.0
1000.0
400.0

Entrained particles

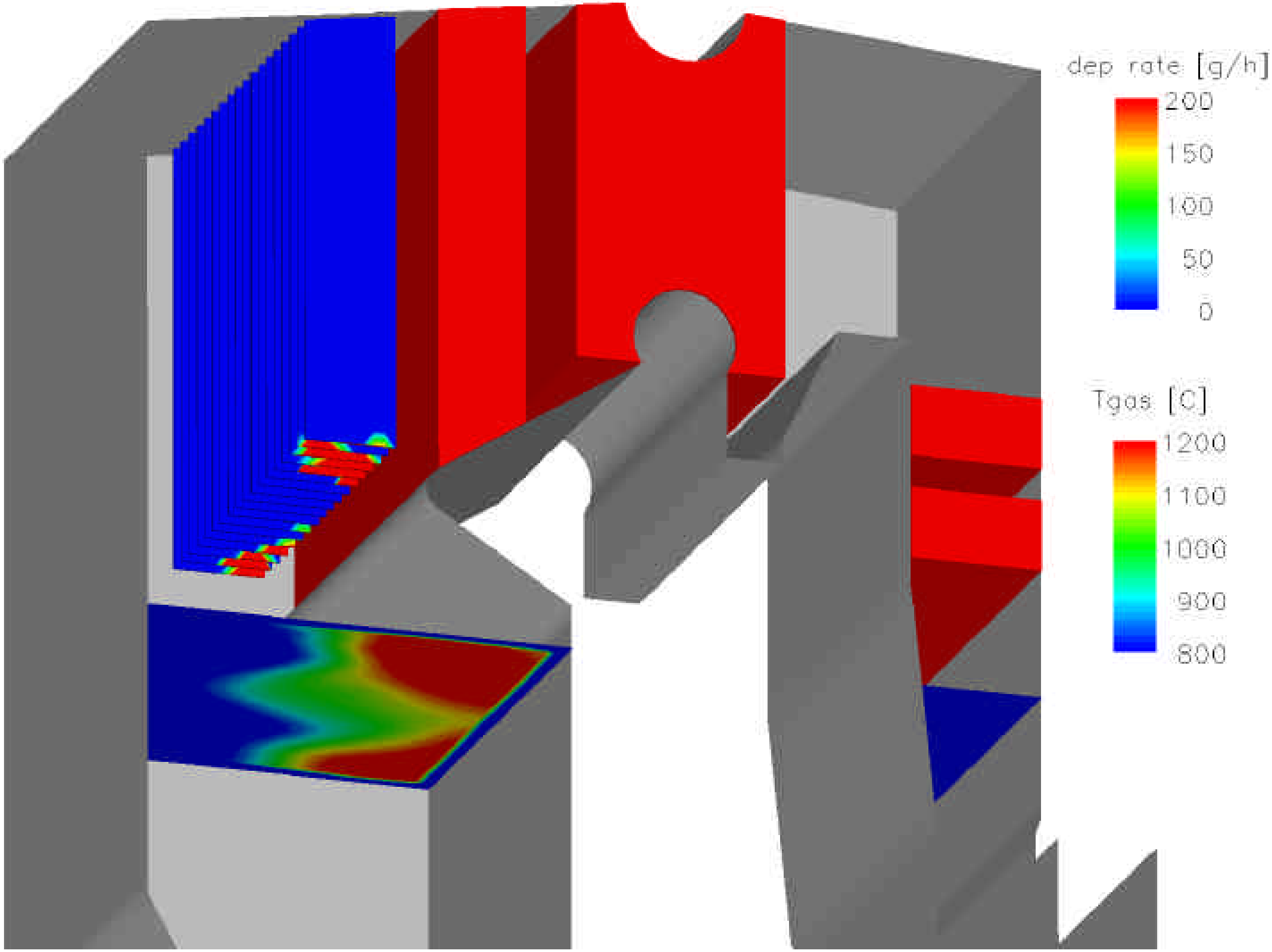
Small particles capture in recirc.

Most large particles impact lower region of SH2

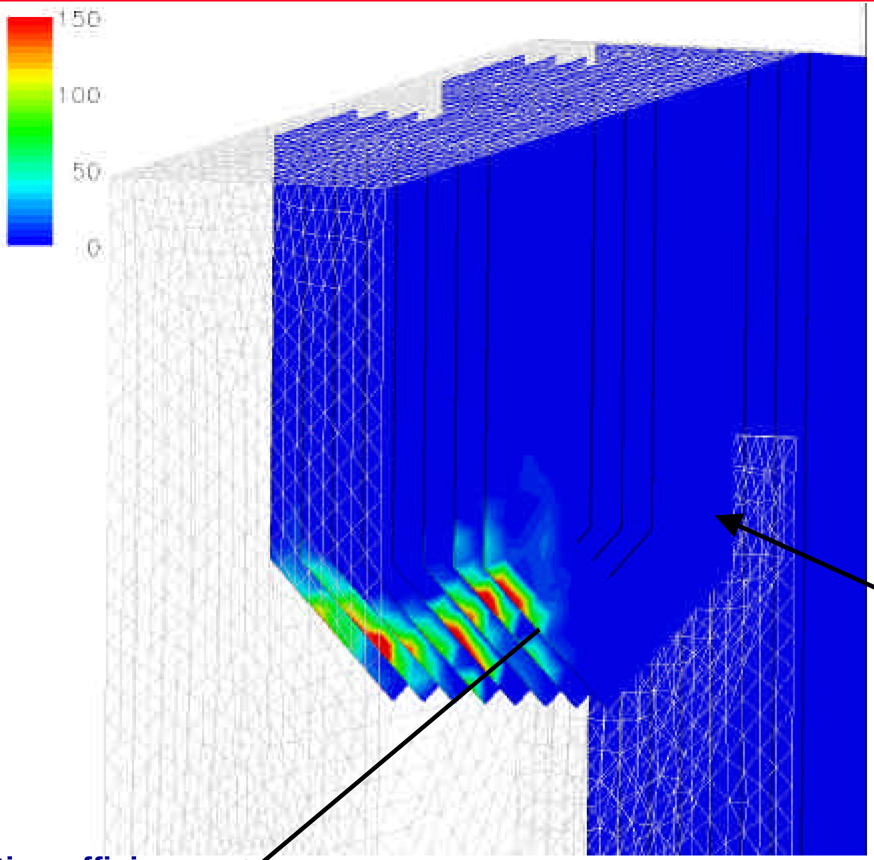


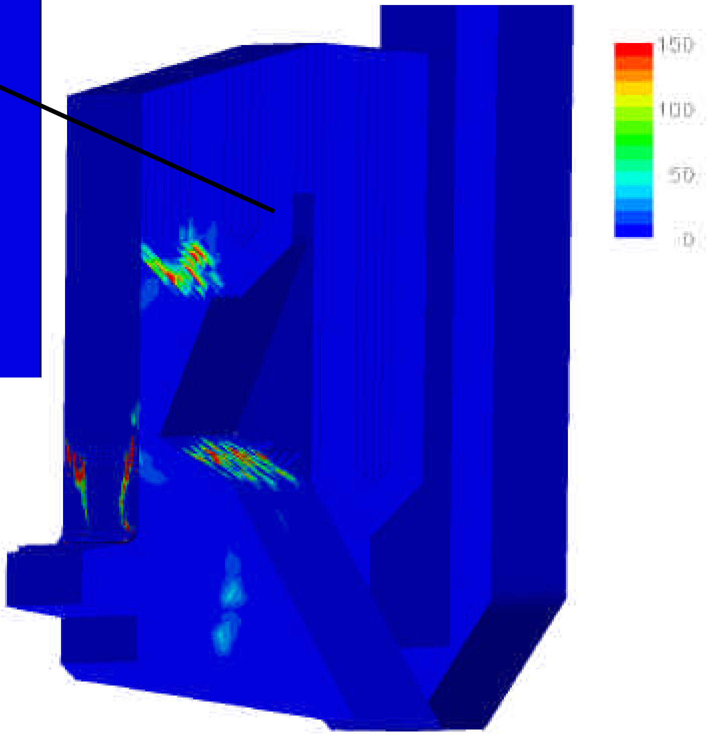

o2
2.2032e-001
1.6524e-001
1.1016e-001
5.5080e-002
0.0000e+000

Deposition rates cont'd

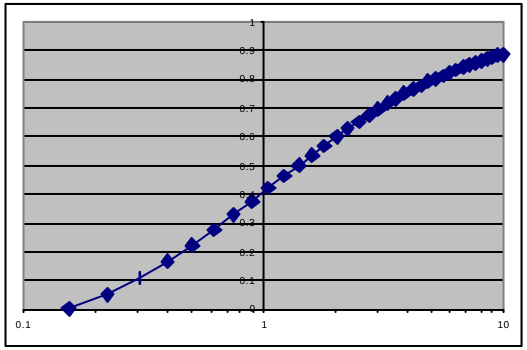


Inertial impaction (clean surface)



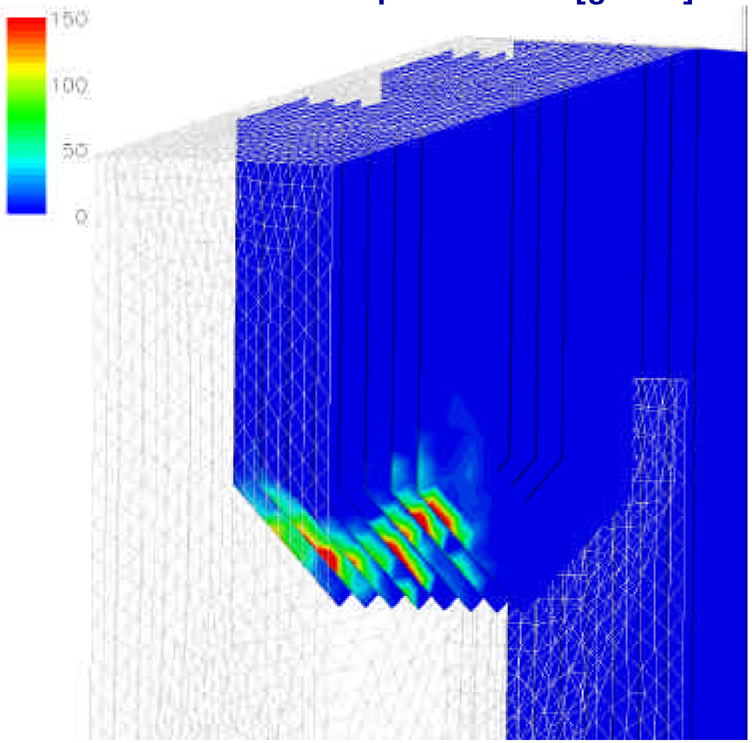


Impaction efficiency:

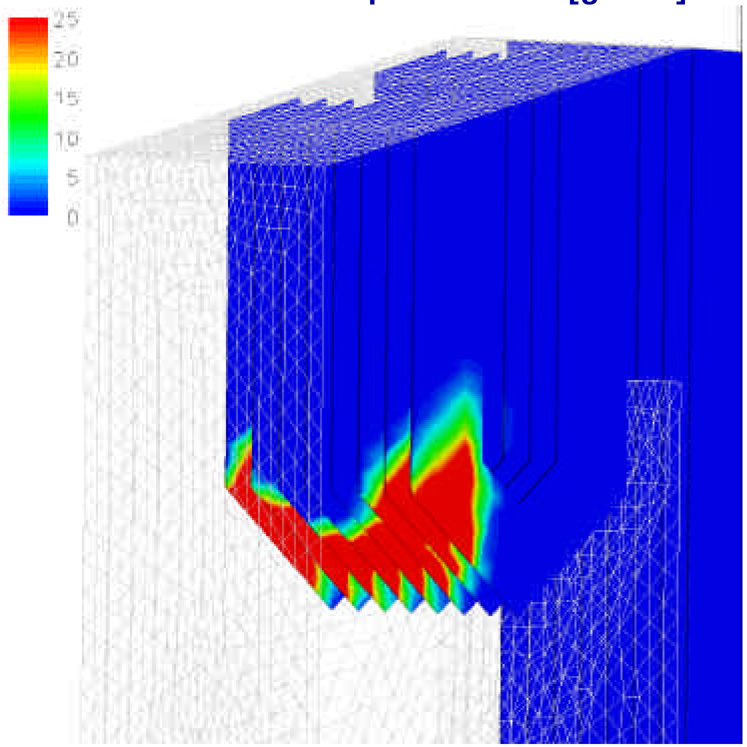


BL mechanisms

Inertial deposition flux [g/m²/h]

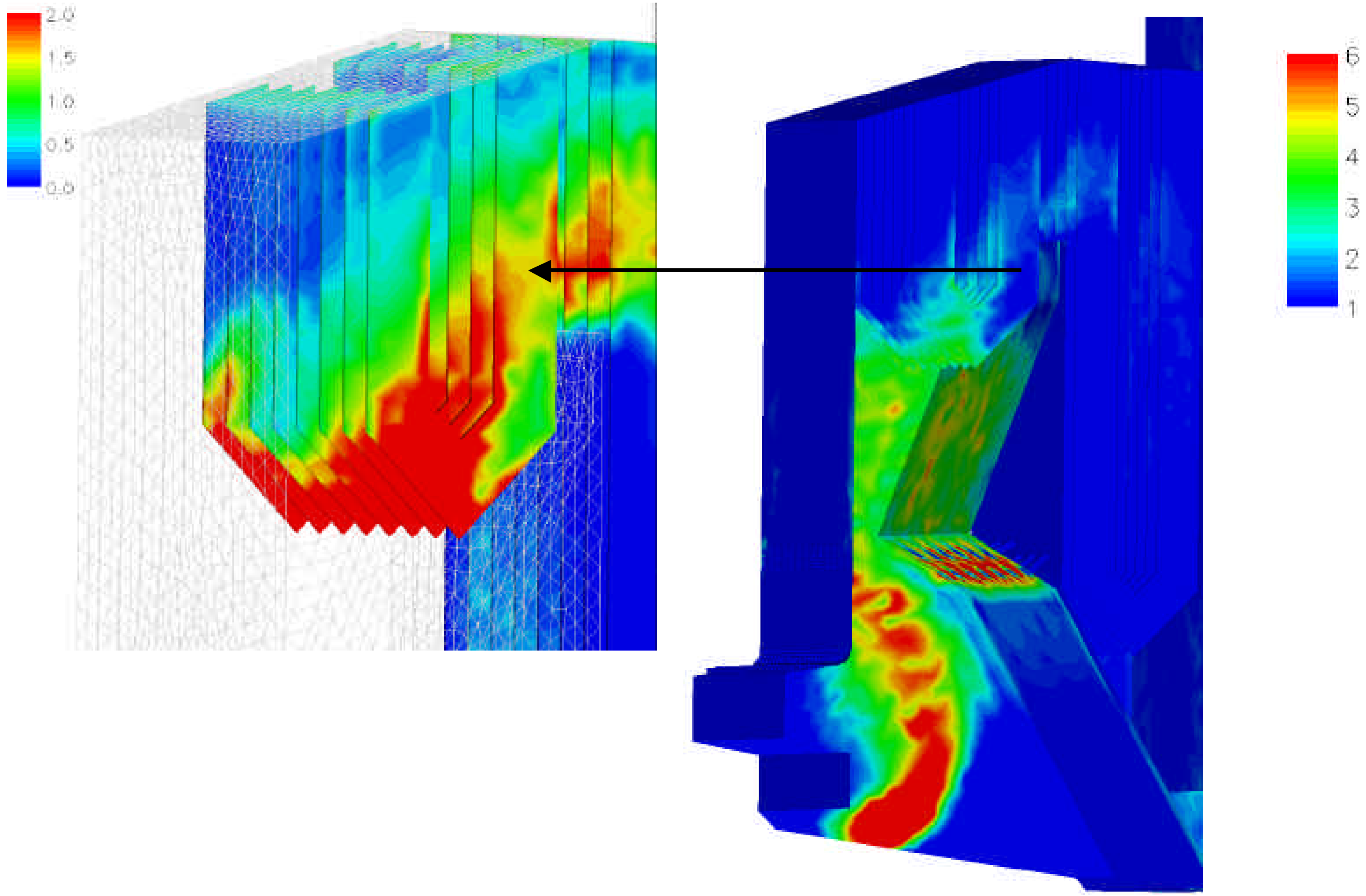


BL deposition flux [g/m²/h]

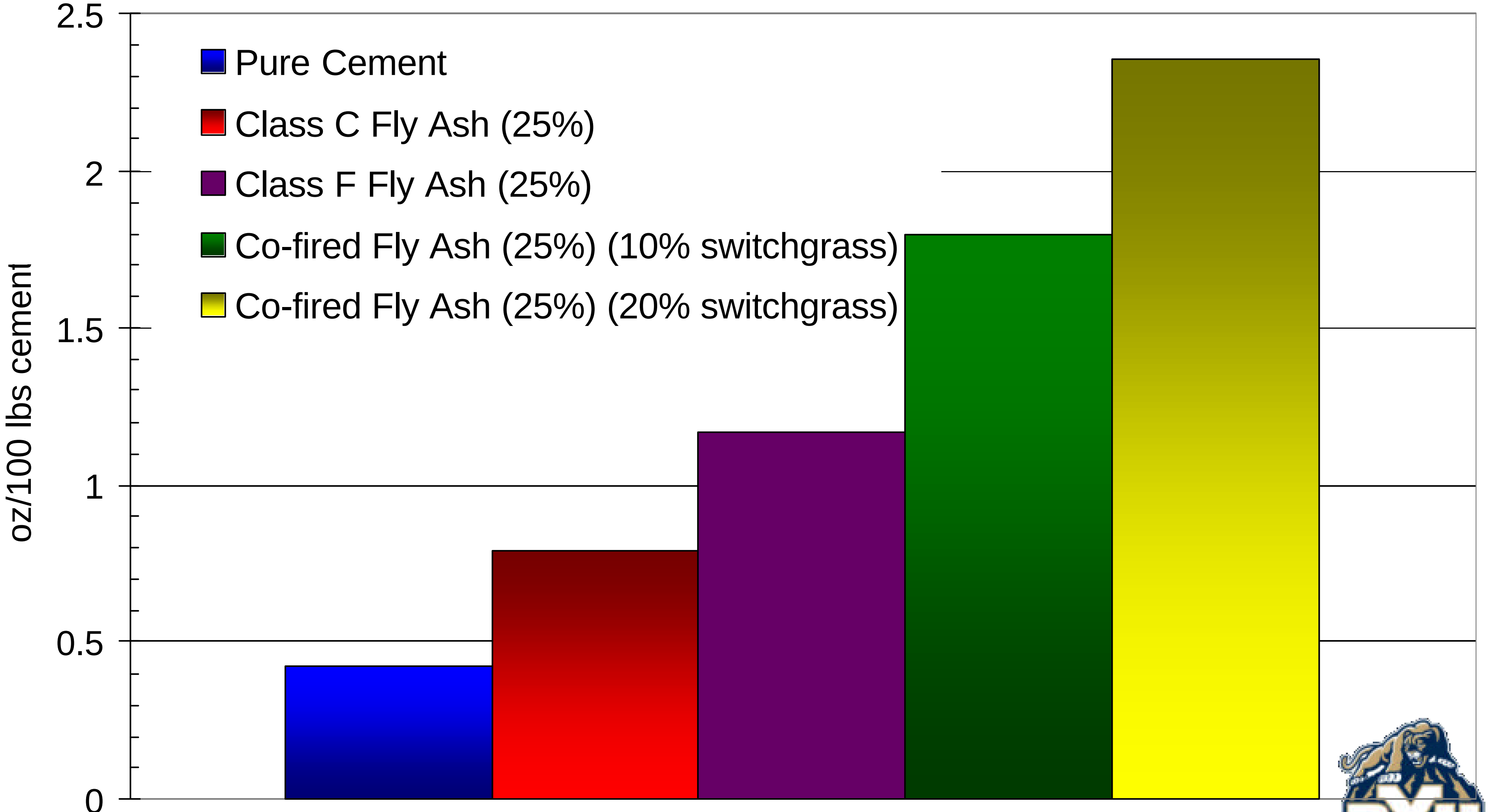


Vapor deposition

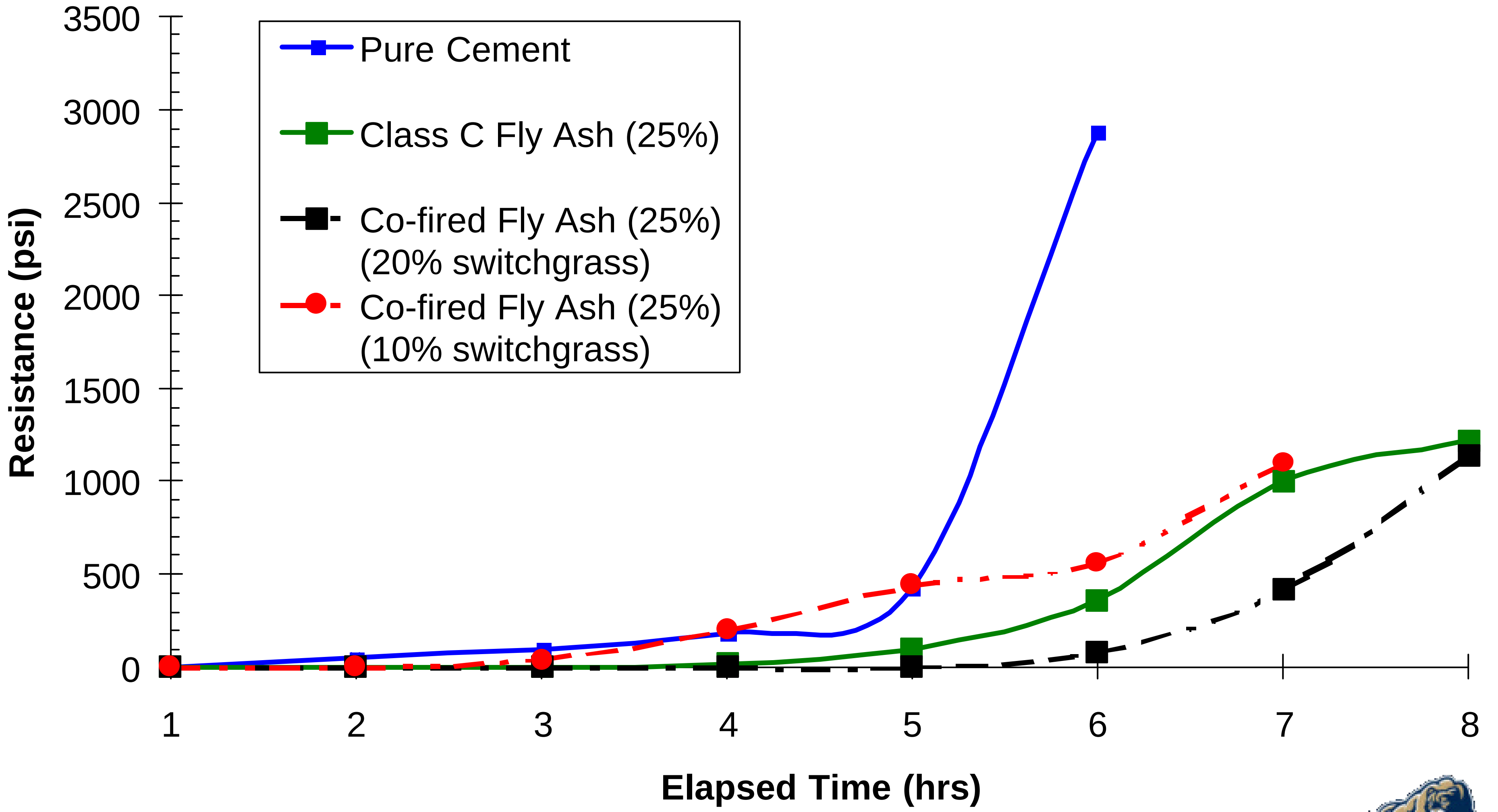
Vapor deposition flux [g/m^2/h]



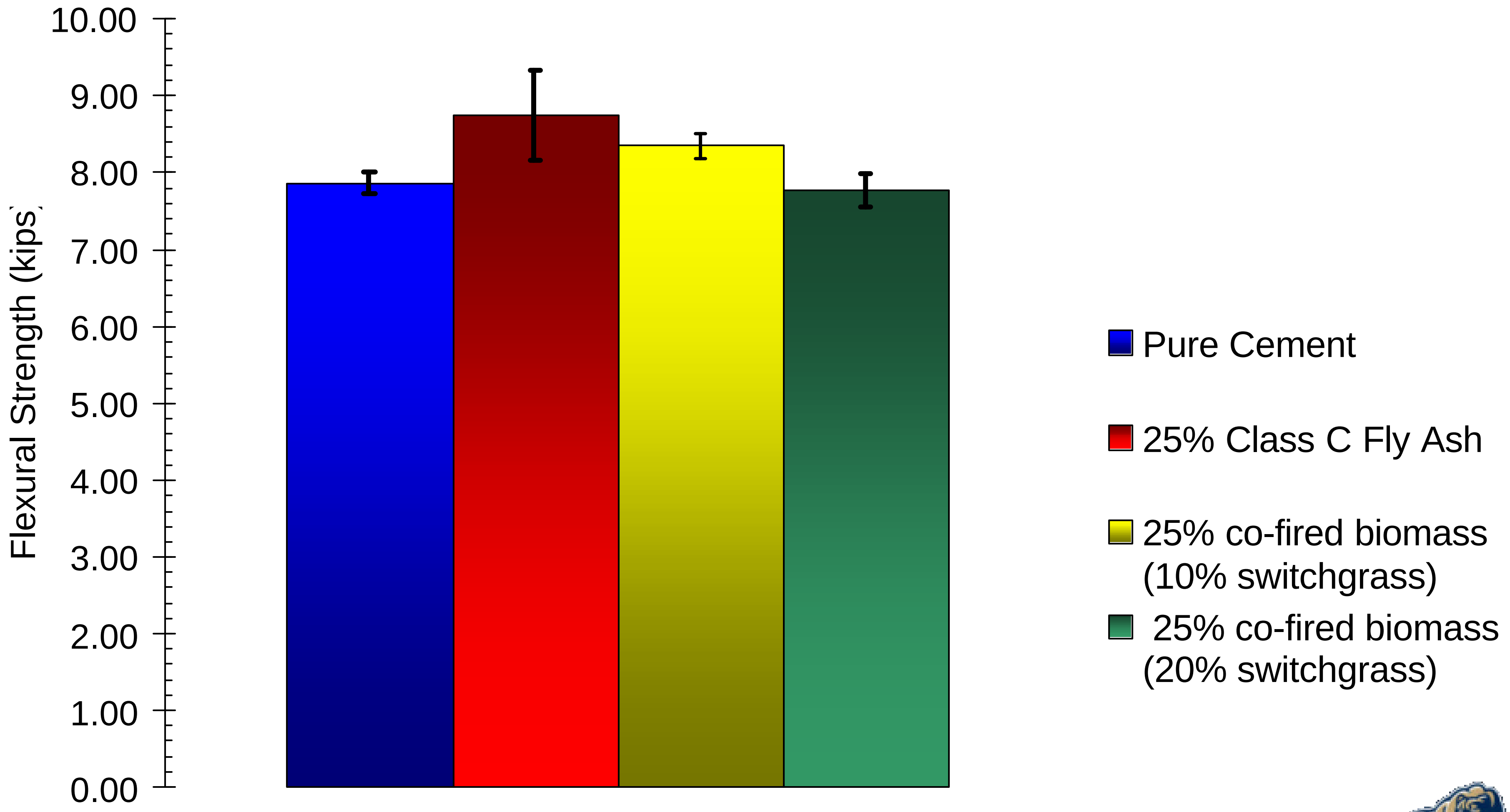
Required Aerating Agent



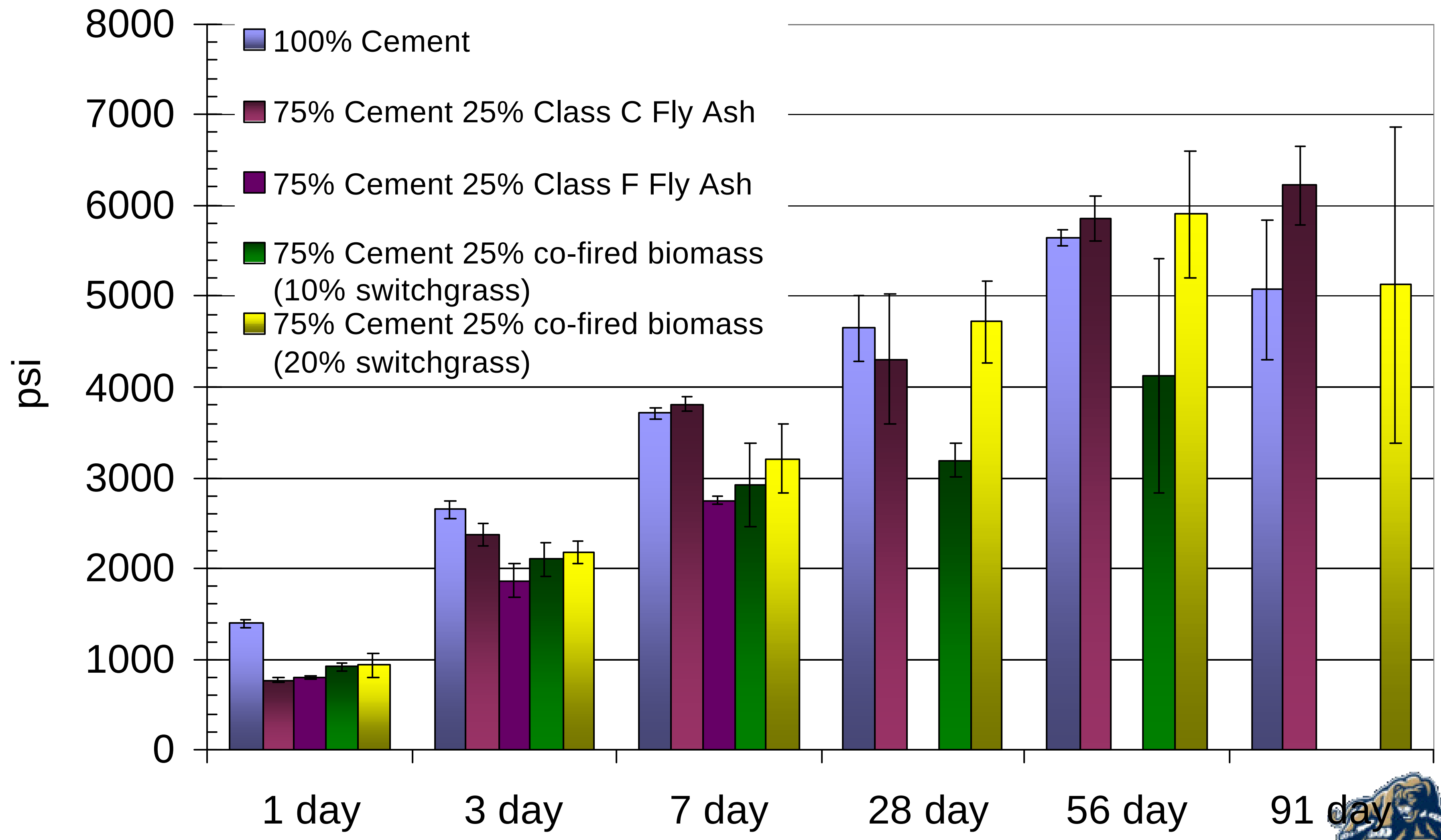
Set Time Delayed by Fly Ash



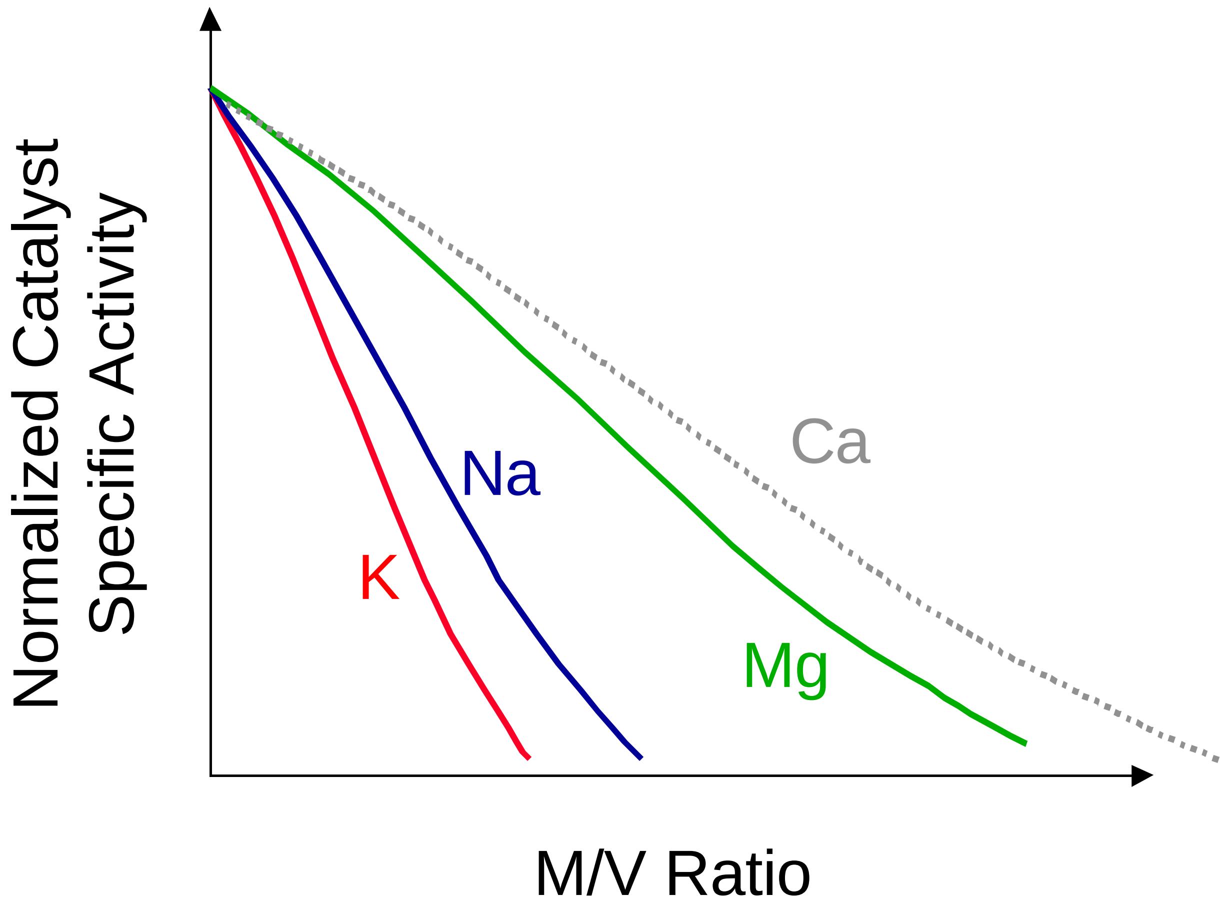
Fluxural Strength Unaffected



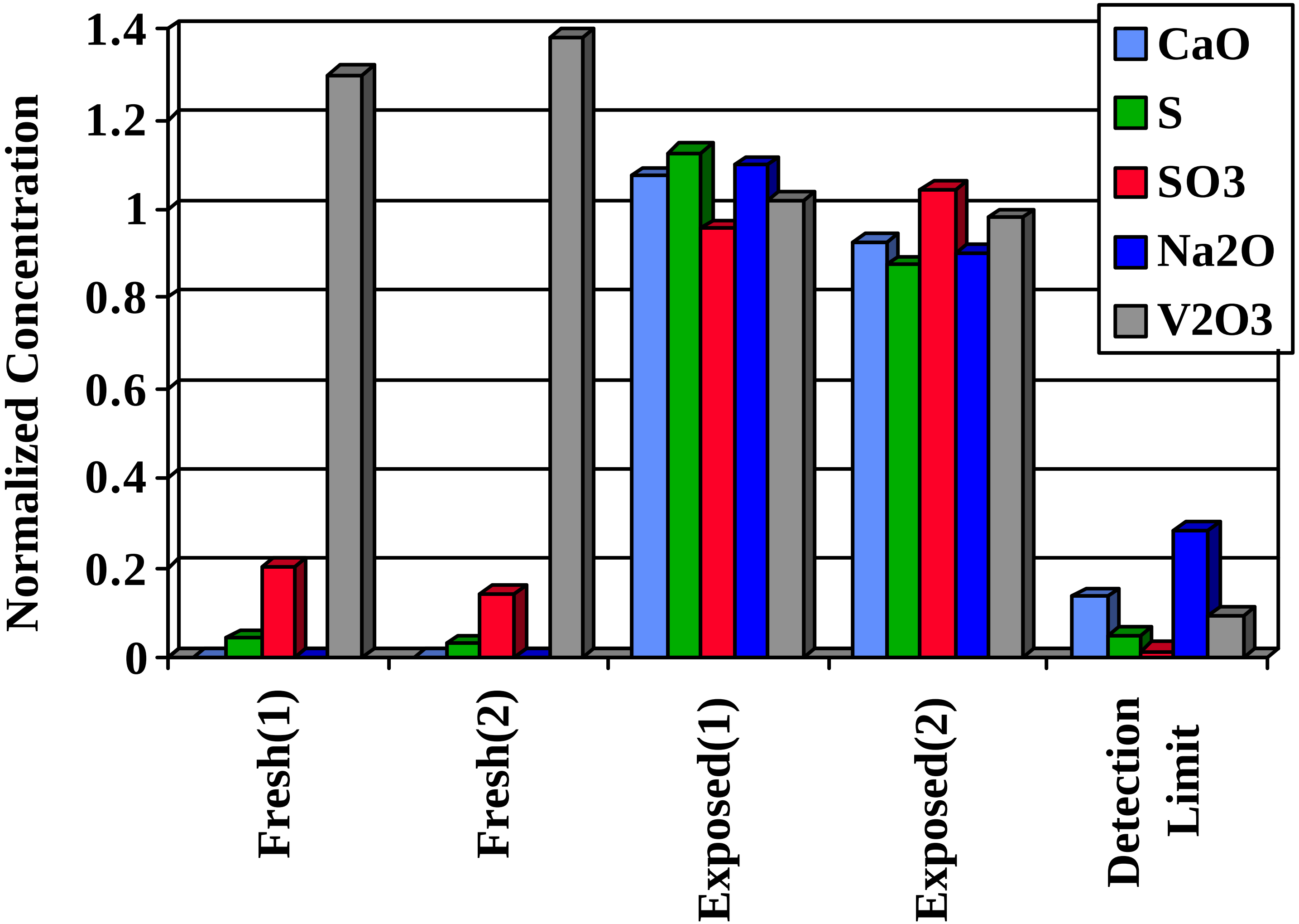
Compressive Strength Variations



SCR Catalyst Poisons



Surface Conditions of Catalyst



Conclusions

- **Major technical issues include fuel handling, storage, and preparation; NO_x formation; deposition; corrosion; carbon conversion; striated flows; effects on ash; impacts on SCR and other downstream processes.**
- **Importance of these issues depends strongly on fuel, operating conditions, and boiler design.**
- **Proper choices of fuels (coal *and* biomass) and operating conditions can minimize or eliminate most impacts for most fuels.**
- **Ample short-term demonstrations illustrate fuel handling feasibility. Dearth of fireside and long-term data.**

Acknowledgements

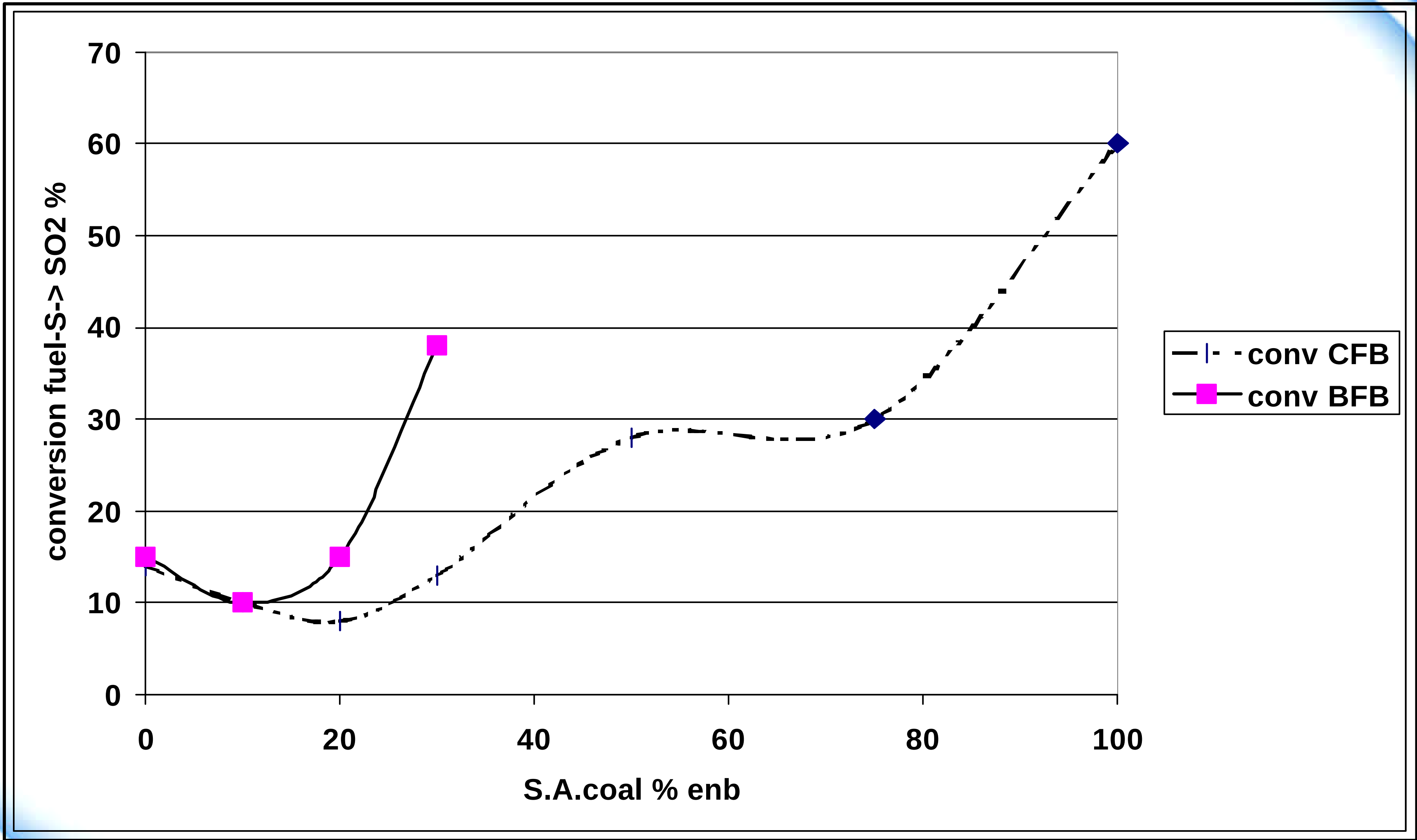
- Financial support provided by the DOE/EE Office of Biopower Technologies (now called the Biomass Program) through the National Renewable Energy Laboratory and the Electric Power Research Institute.
- Profs. Cal Bartholomew and William Hecker contributed to the SCR work with Xiaoyu Guo, Aaron Nackos, Ben Severson, Seth Herring, and Ken Crowther. Profs. Warren Lucas and Fernando Fonseca contributed to the ash and concrete work with Shuangzhen Wang, Amber Miller, Emilio (Mike) Llamozas, Joe Seidel, Aaron Olson, and John Hema. Drs. Søren Kær, Matt Hall and Hugh Hales contributed to the modeling with Steve Hardy, Mark Vickers, Tracy Denison, Eric Halpenny, Jennifer Marsh. Prof. Dale Tree contributed to the deposition and corrosion work with Shrinivas Lokare, Dave Dunaway, Doug Rogers, Mark Anderson, Steve Tuttle, and Justin Scott. Larry Felix and SRI supplied fly ash for concrete tests.

BIOMASS CO-COMBUSTION IN FLUIDISED BED BOILERS: PROBLEMS AND SOLUTIONS

by Martti Aho
VTT Processes P.O.Box 1603 40100 Jyväskylä, Finland
tel +358 14 672 545 fax +358 14 672 597 e-mail martti.aho@vtt.fi

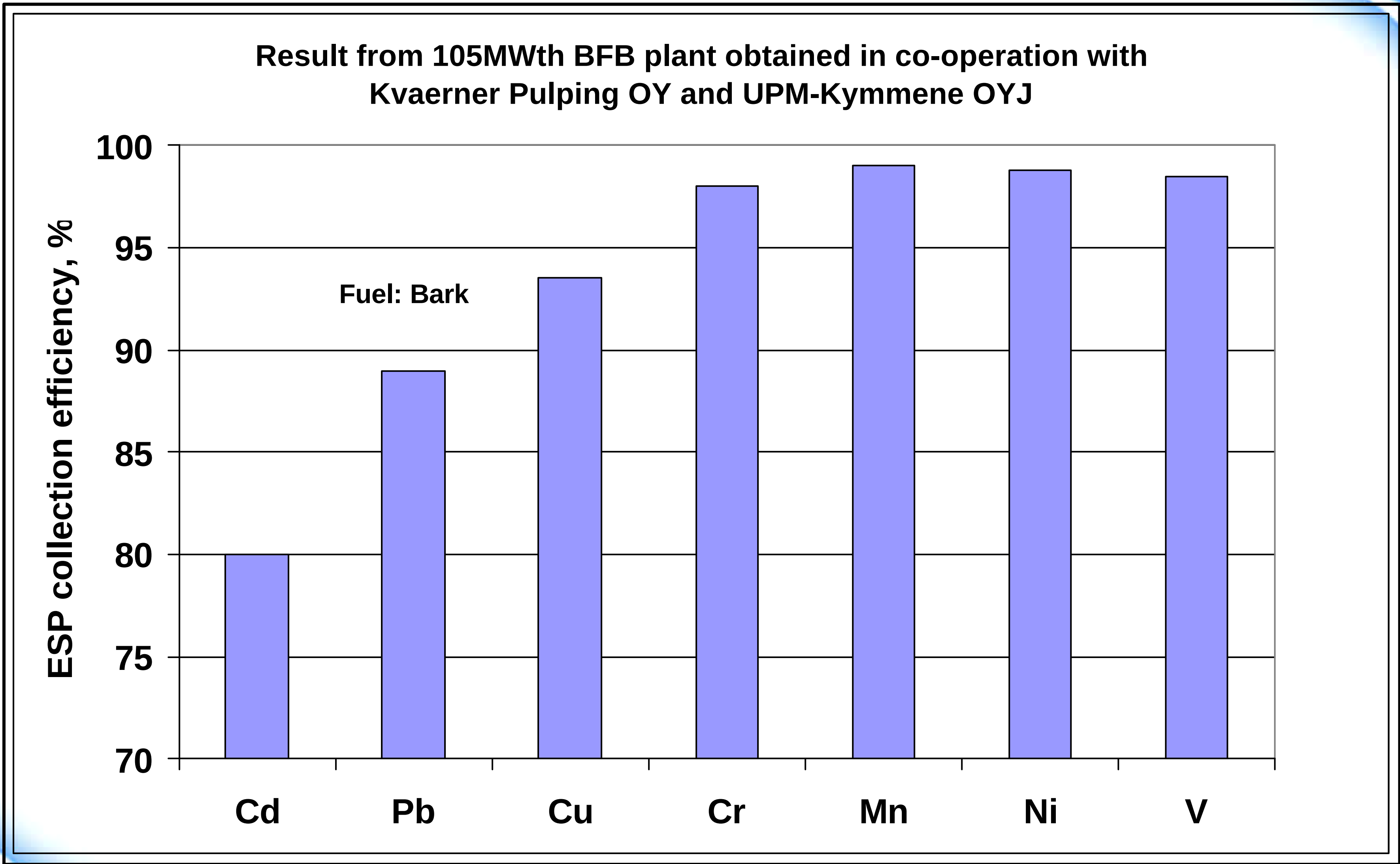
Emissions

Conversion of fuel sulphur to SO_2

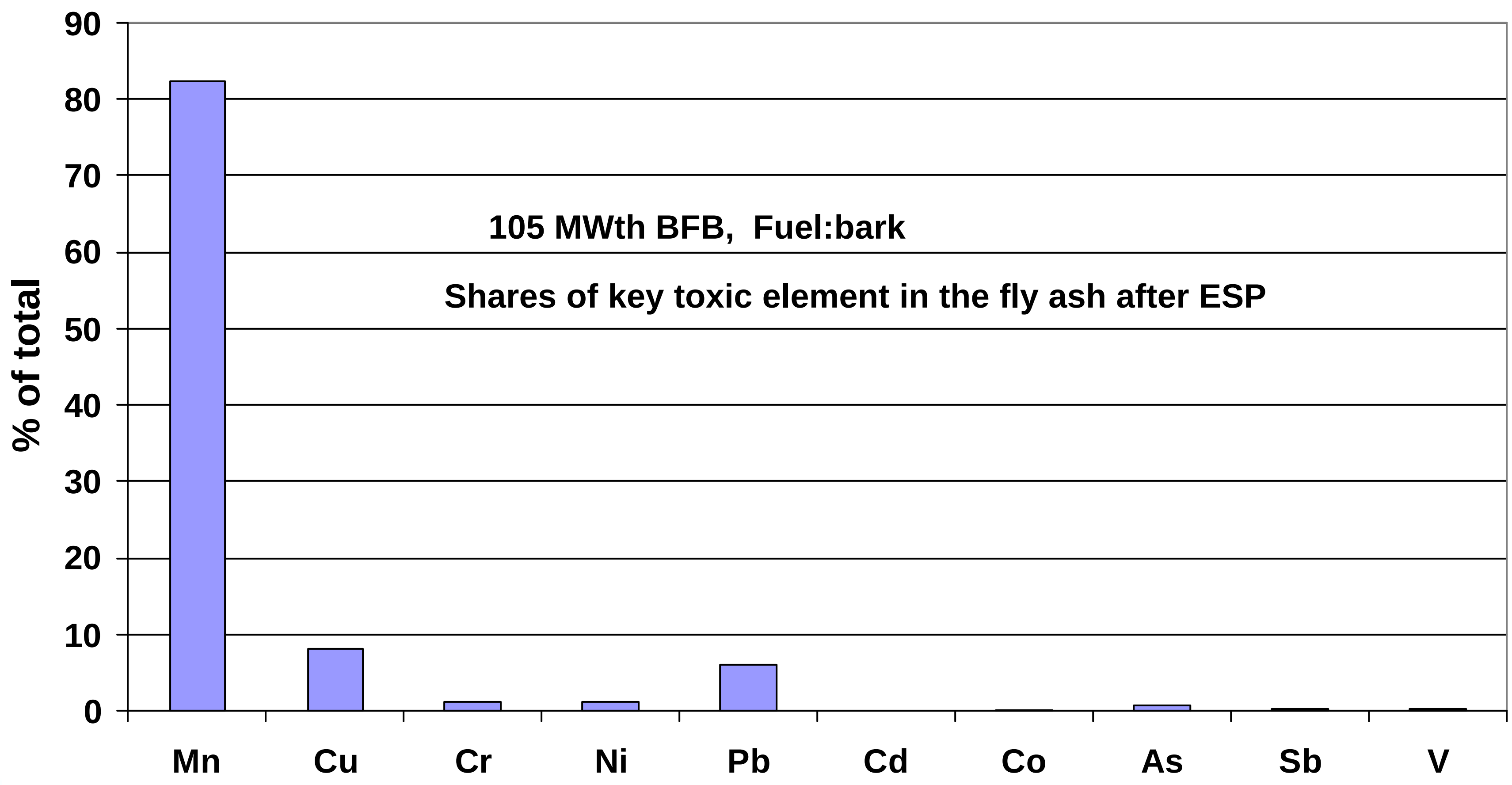


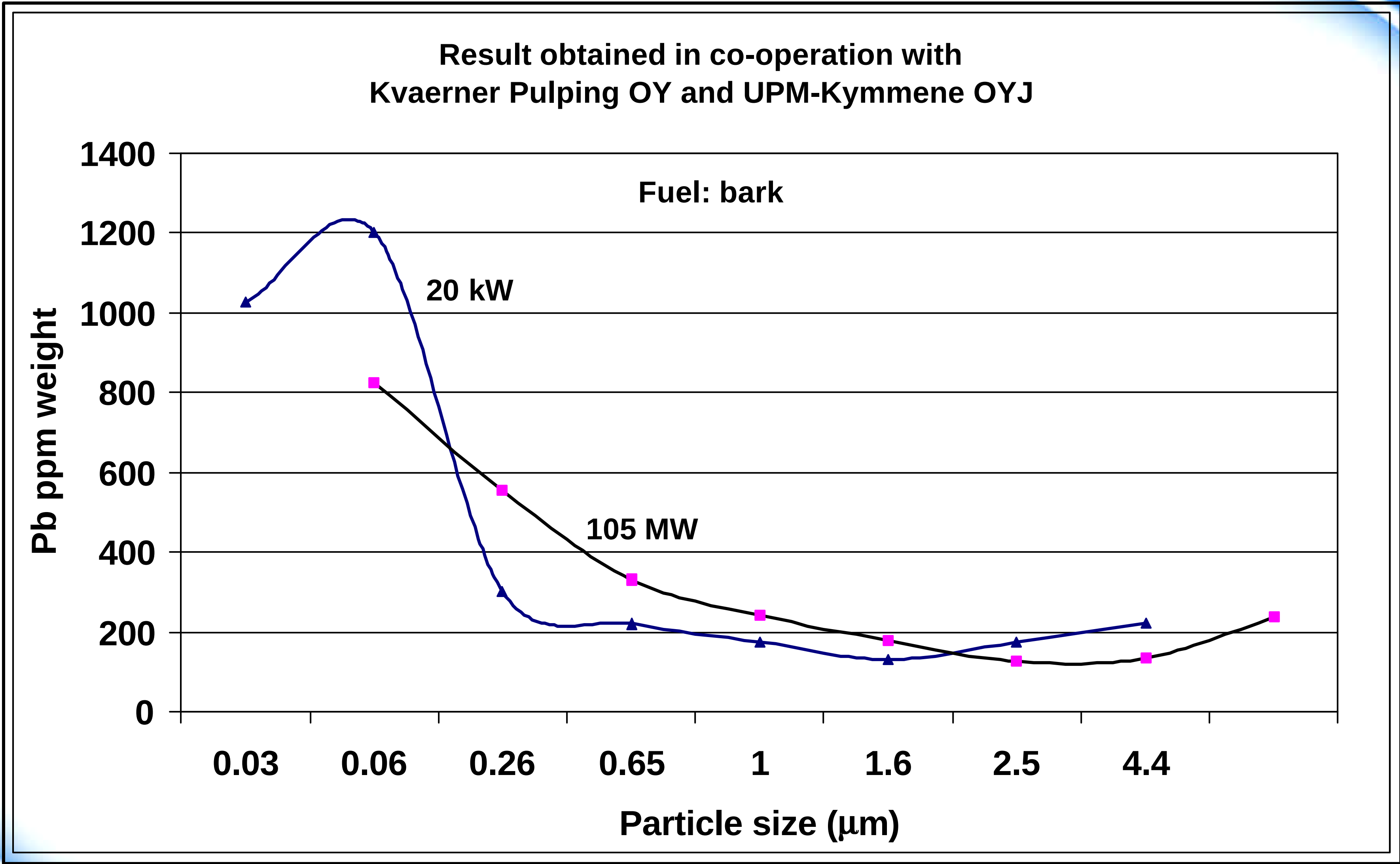
TOXIC ELEMENTS IN CO-COMBUSTION

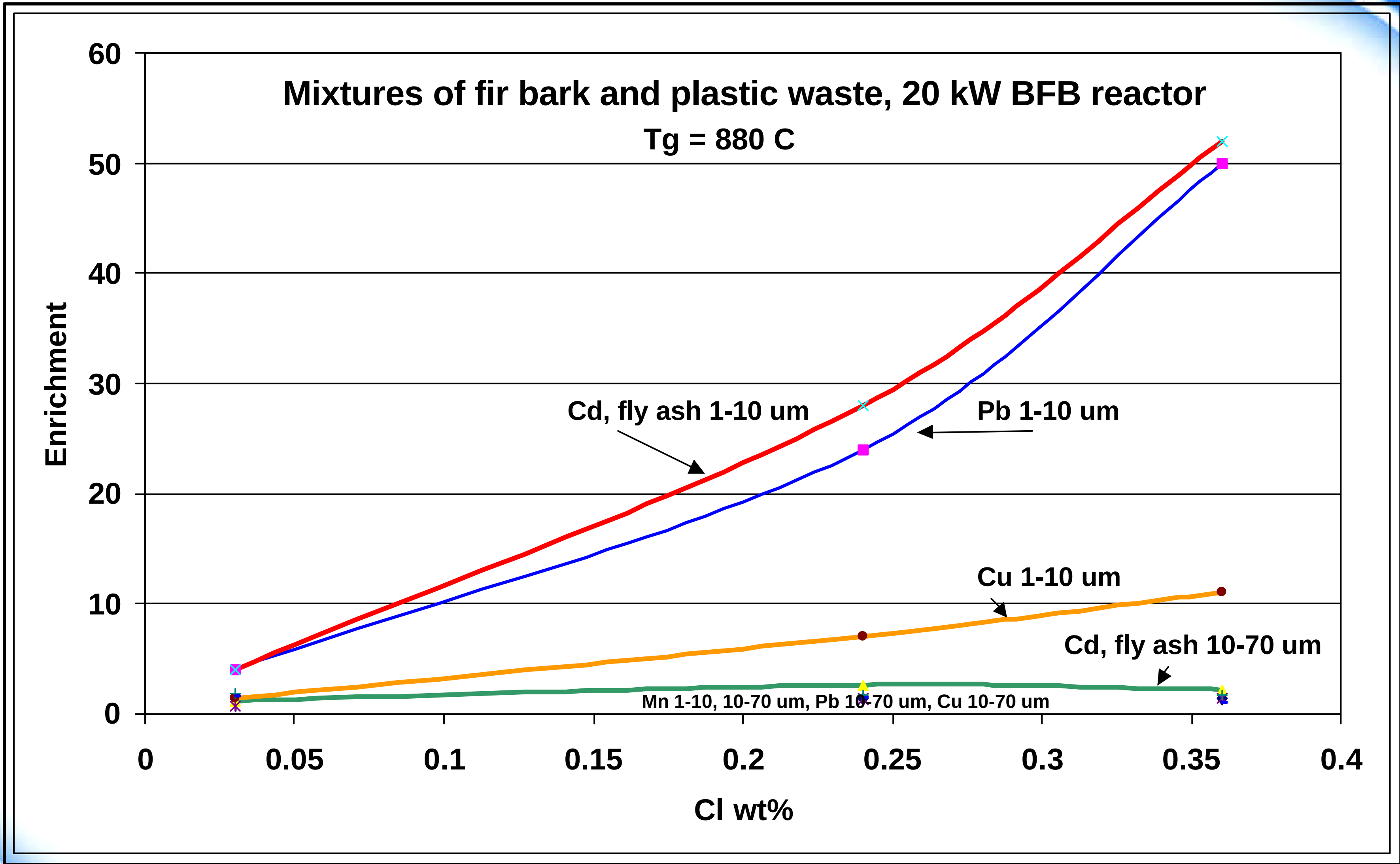
Coal and some biomass residues may contain significant concentrations of "toxic" elements included in the new co-incineration directive determining emission limit 0.5 mg/Nm^3 for the sum of (Mn+Pb+Cr+Ni+Cu+Co+As+Sb+V) and 0.05 mg/Nm^3 for (Cd + Tl) and Hg.


Result from 105MWth BFB plant obtained in co-operation with Kvaerner Pulping OY and UPM-Kymmene OYJ
ESP collection efficiency, %
100
95
90
85
80
75
70
Fuel: Bark
Cd
Pb
Cu
Cr
Mn
Ni
V

The result has been obtained in co-operation with Kvaerner Pulping and UPM-Kymmene OYJ

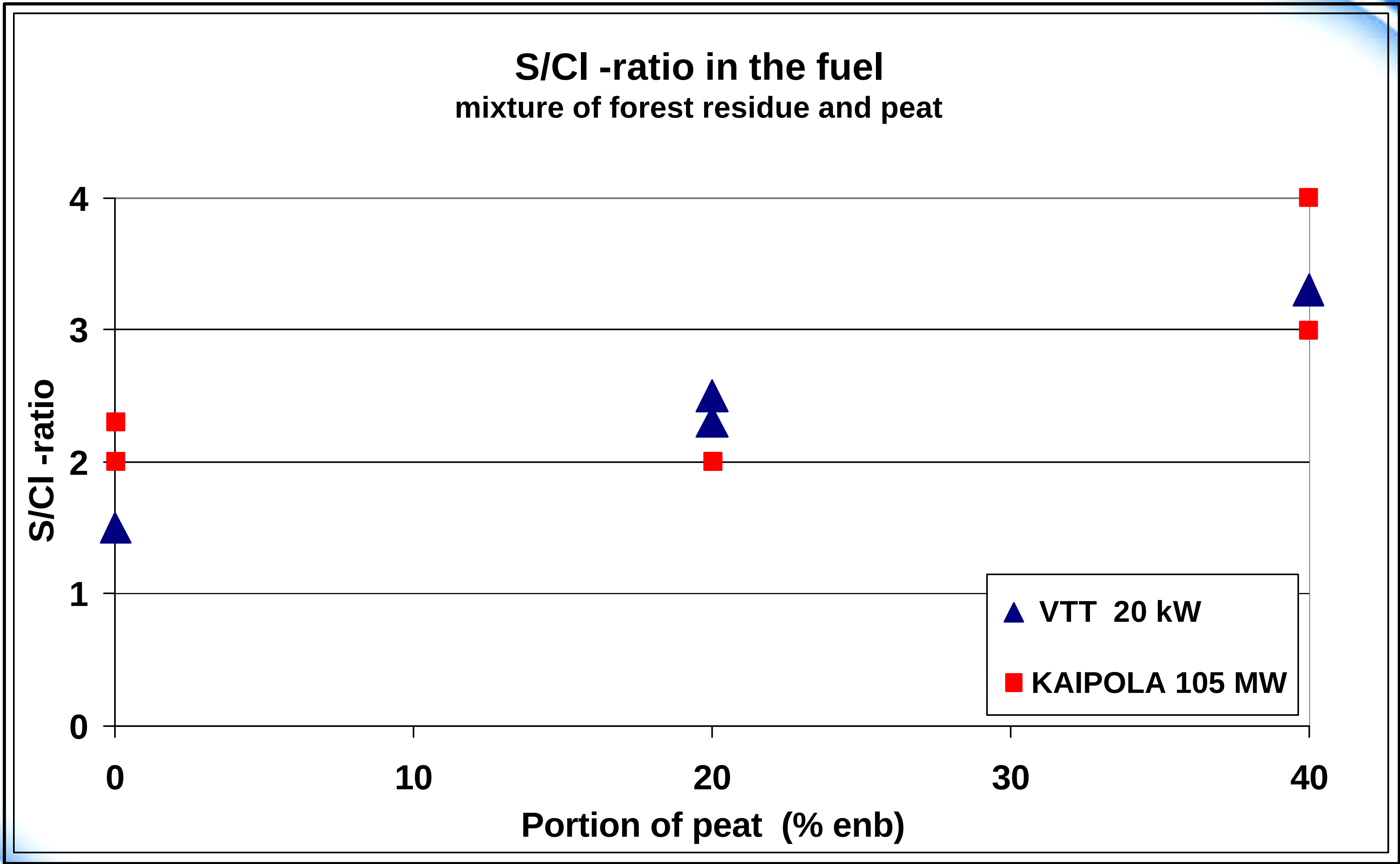



Result obtained in co-operation with
Kvaerner Pulping OY and UPM-Kymmene OYJ
Fuel: bark
20 kW
105 MW
Pb ppm weight
1400
1200
1000
800
600
400
200
0
0.03
0.06
0.26
0.65
1
1.6
2.5
4.4
Particle size (µm)

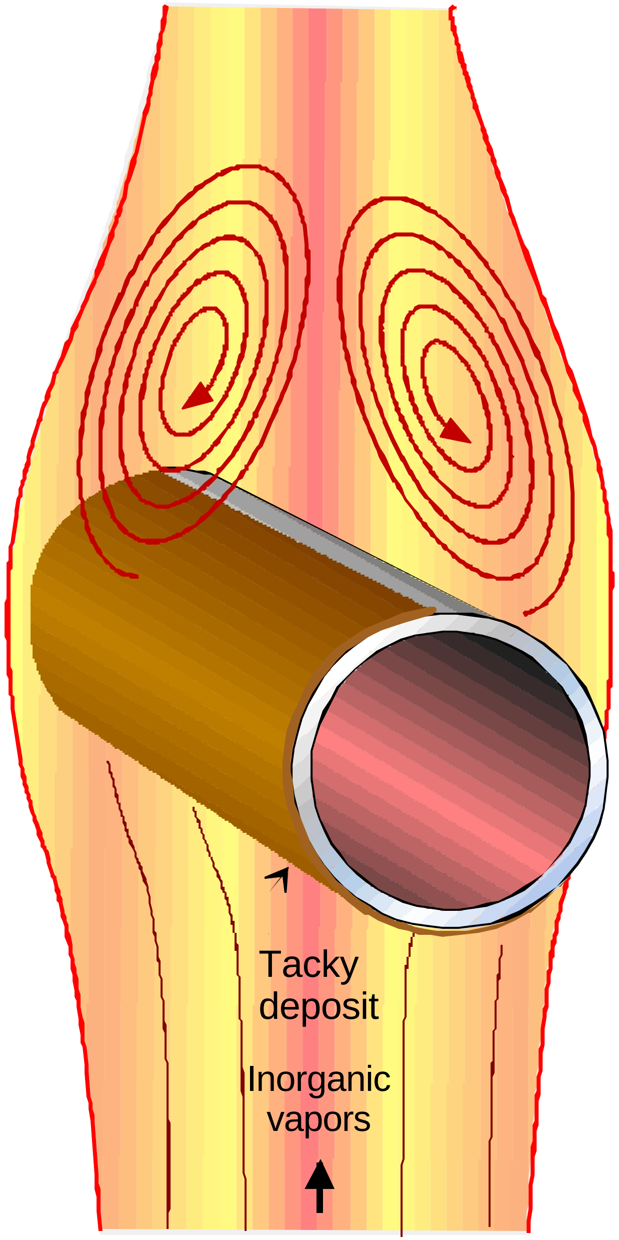


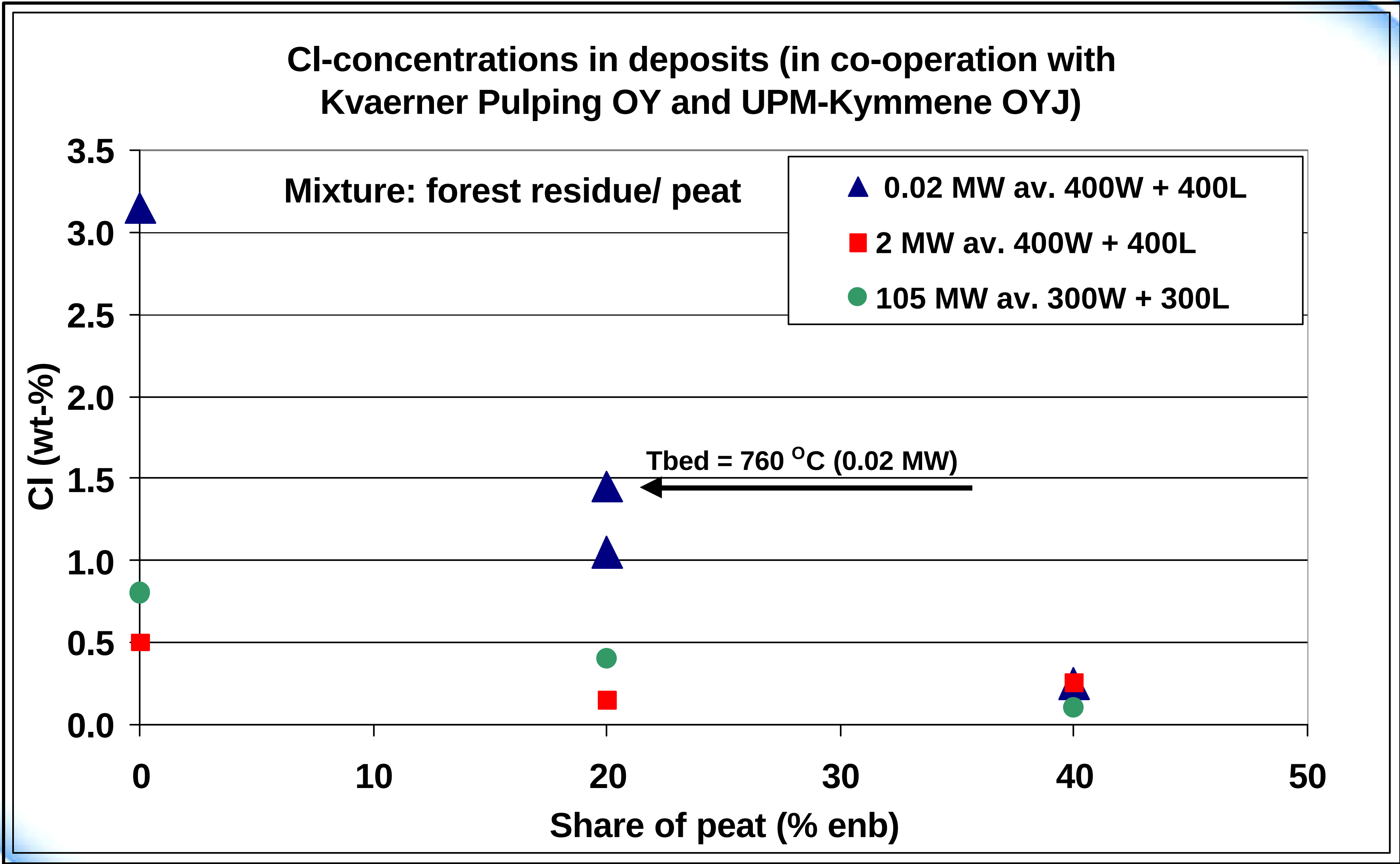
Mixtures of fir bark and plastic waste, 20 kW BFB reactor
Tg = 880 C
Enrichment
Cl wt%
0
10
20
30
40
50
60
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Cd, fly ash 1-10 um
Pb 1-10 um
Cu 1-10 um
Cd, fly ash 10-70 um
Mn 1-10, 10-70 um, Pb 10-70 um, Cu 10-70 um

C l - deposition


S/Cl -ratio in the fuel
mixture of forest residue and peat
S/Cl -ratio
4
3
2
1
0
0
10
20
30
40
Portion of peat (% enb)
VTT 20 kW
KAIPOLA 105 MW

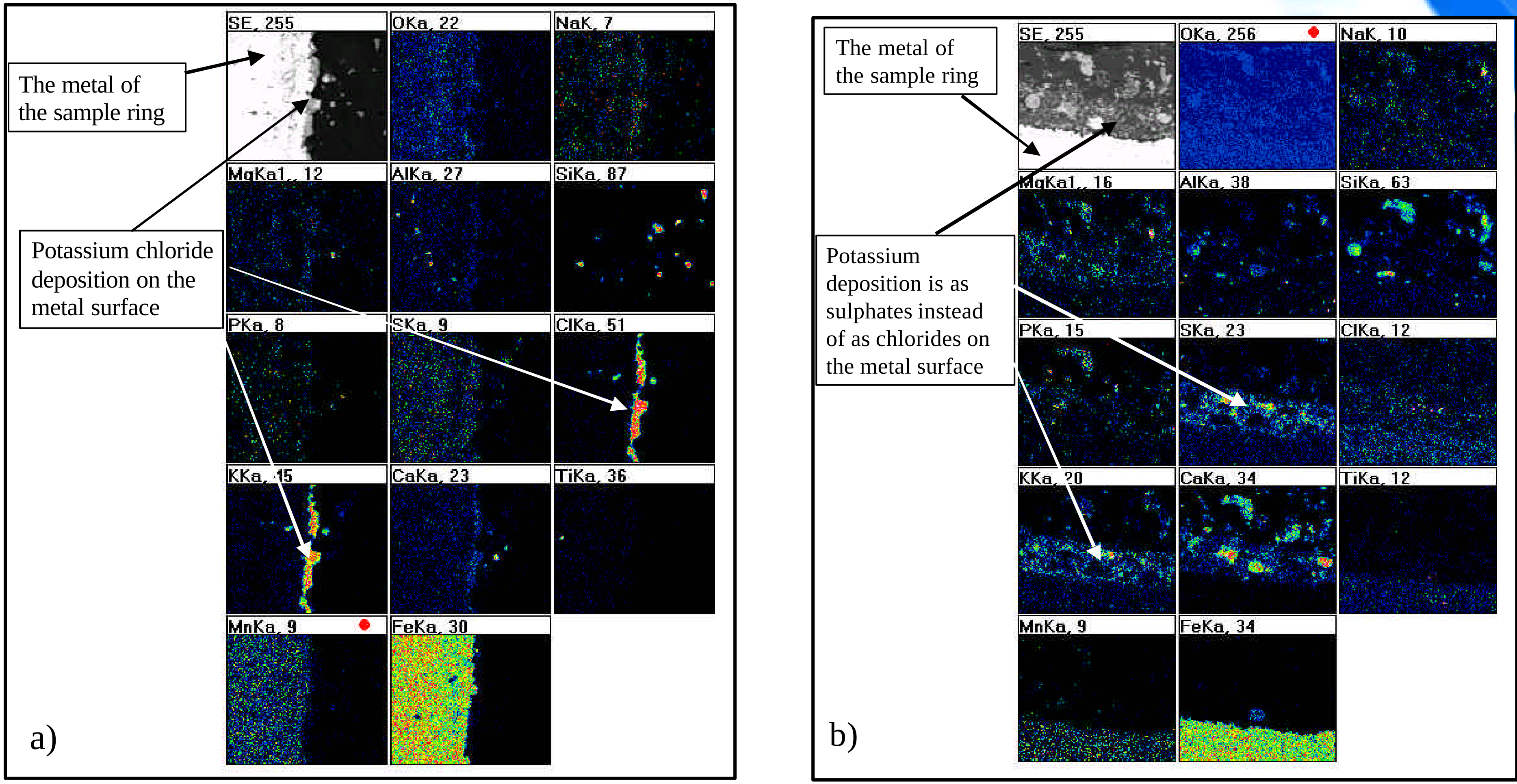
Schematic illustration of condensation on a tube in cross flow




Cl-concentrations in deposits (in co-operation with Kvaerner Pulping OY and UPM-Kymmene OYJ)
Mixture: forest residue/ peat
0.02 MW av. 400W + 400L
2 MW av. 400W + 400L
105 MW av. 300W + 300L
Tbed = 760 °C (0.02 MW)
Cl (wt-%)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
Share of peat (% enb)

How to control superheater tube corrosion in FB boilers which use wood and wood waste as fuel

Markku Orjala*), Riikka Ingalsuo*), Kari Paakkinen*), Jouni Hämäläinen*),
Martti Mäkipää**), Maria Oksa**), Thomas Malkow***), Richard Fordham***), David Baxter***)
*) VTT Energy, Jyväskylä, Finland
**) VTT Manufacturing Technology, Espoo, Finland
***) European Commission, Institute of Advanced Materials, JRC Petten, The Netherlands



X-ray maps from the probe (cross-section) in the BFB reactor. The average temperature of the probe was 480 ºC.

a) Flue gas: O_2 = 4,4%, CO = 98 ppm, NO = 63 ppm, SO_2 = 1 ppm, Temperature of the reactor was 827 ºC.
Fuel: logging residue chips (stored 0 years). Clear potassium cloride deposit

b) Flue gas: O_2 = 5,1%, CO = 208 ppm, NO = 93 ppm, SO_2 = 24 ppm. Temperature of the reactor was 873 ºC.
Fuel: 50% logging residue chips (stored 0 years) + 50% peat (sulphur content 0,16%). No potassium chloride deposit.

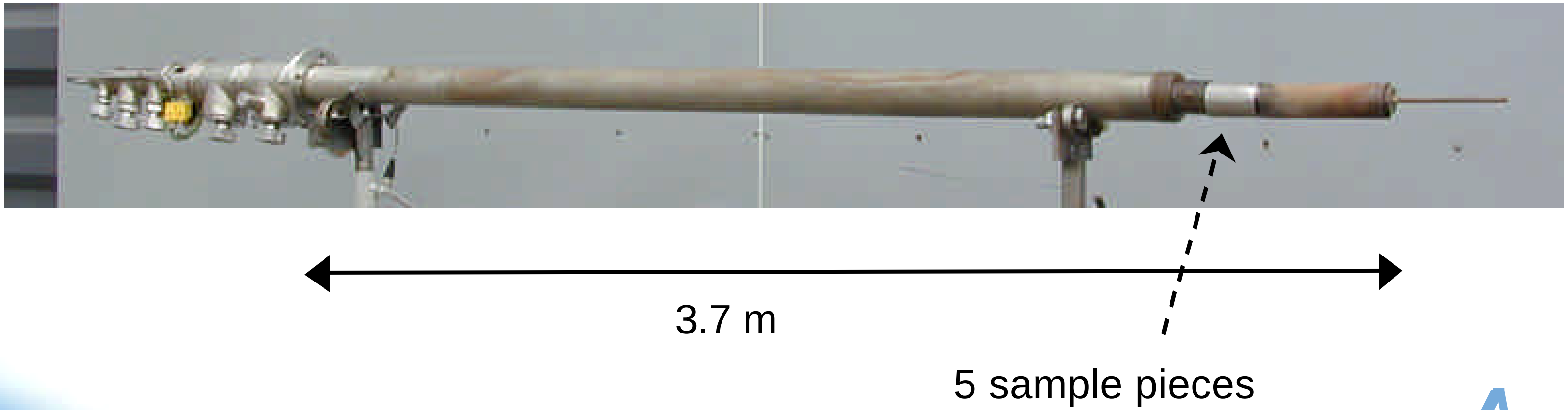
Cooled probes for fouling and corrosion monitoring at superheater area

Recent experiences from CFB-plants using mixed wood-based fuels

Markku Orjala, Jouni Hämäläinen, Janne Kärki (VTT Processes)
Martti Mäkipää (VTT Processes

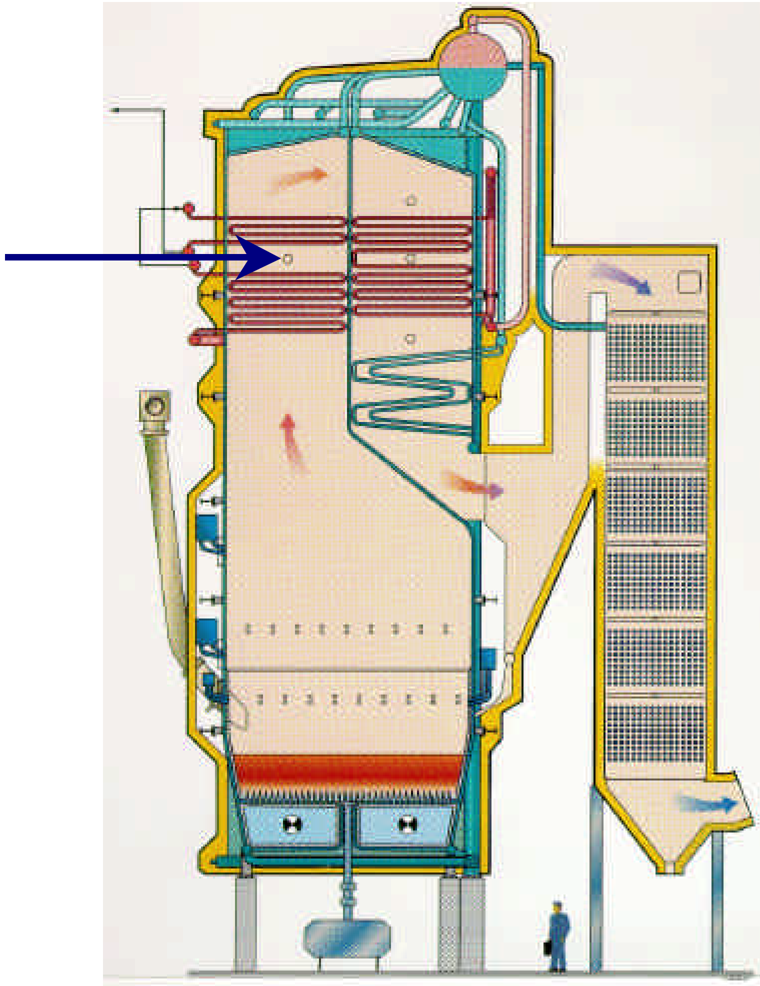
Details of the probe

- length 3.7 m
- five sample pieces; 15 mm long, 48 mm outer diameter
- temperature controlled at upstream side at 540^{o}C
- temperature measured at three sides of the probe, and flue gas T at the probe tip
- samples embedded in epoxy at the plant



Cocombustion of recovered fuels (REF) with peat and wood based fuels

- 66 MW bubbling fluidized bed
- 10 -15 % REF, 50 % peat and 40 % wood
- bed temperature 800-850^{o}C
- SO_2 16 ppm, HCl 50 mg/Nm^3
- probe between superheaters at T = 780-880^{o}C, close to soot-blowers



Cocombustion of recovered fuels (REF) with peat and wood based fuels. The share of REF 10 to 15 % as energy basis

Test period I: Combustion of REF III with peat and wood based fuels: One week probing

Test period II: Combustion of REF I with peat and wood based fuels: One and half week probing

BENEFITS OF BIOMASS AND COAL CO-COMBUSTION IN FLUIDISED BED BOILERS

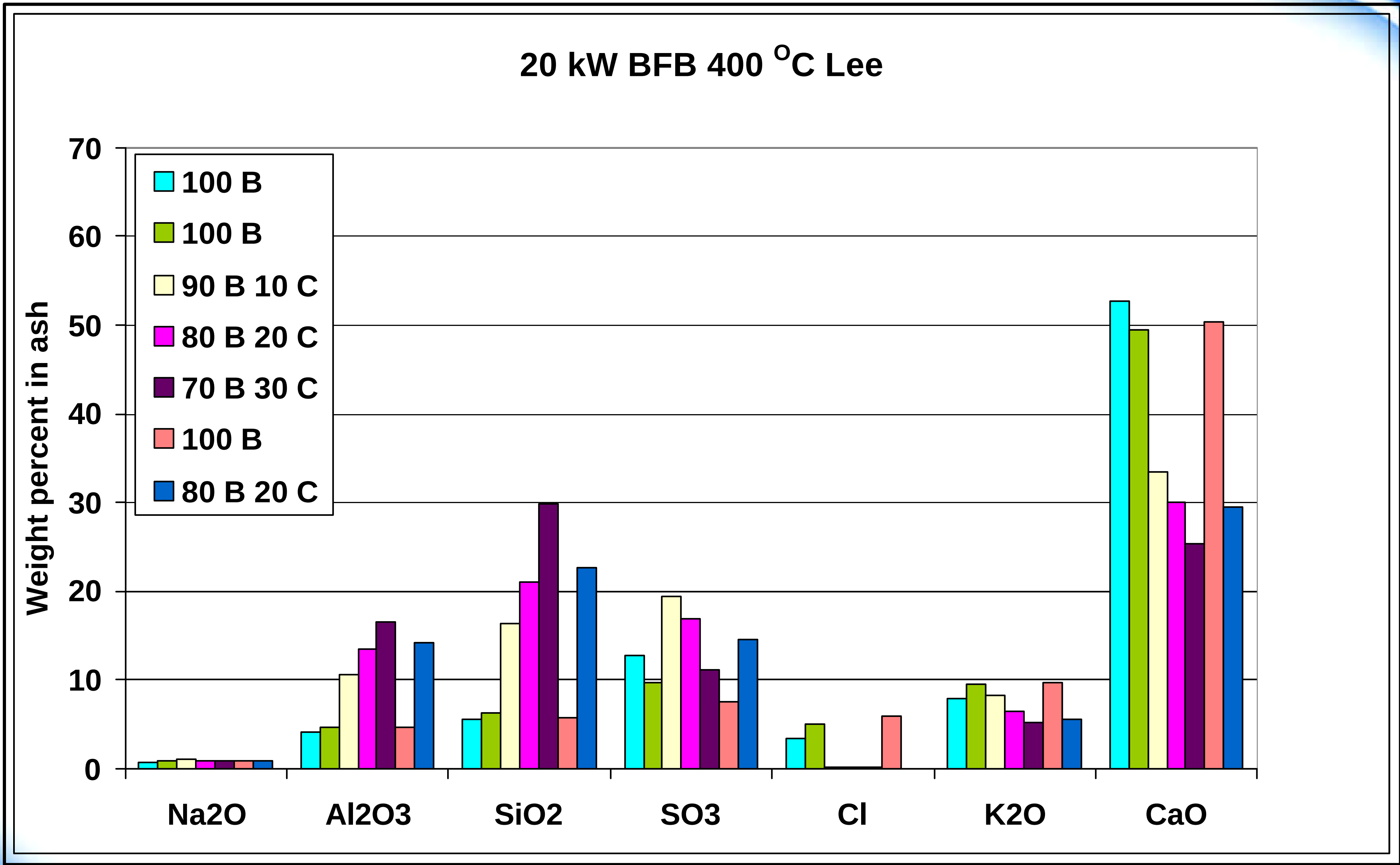
Martti Aho

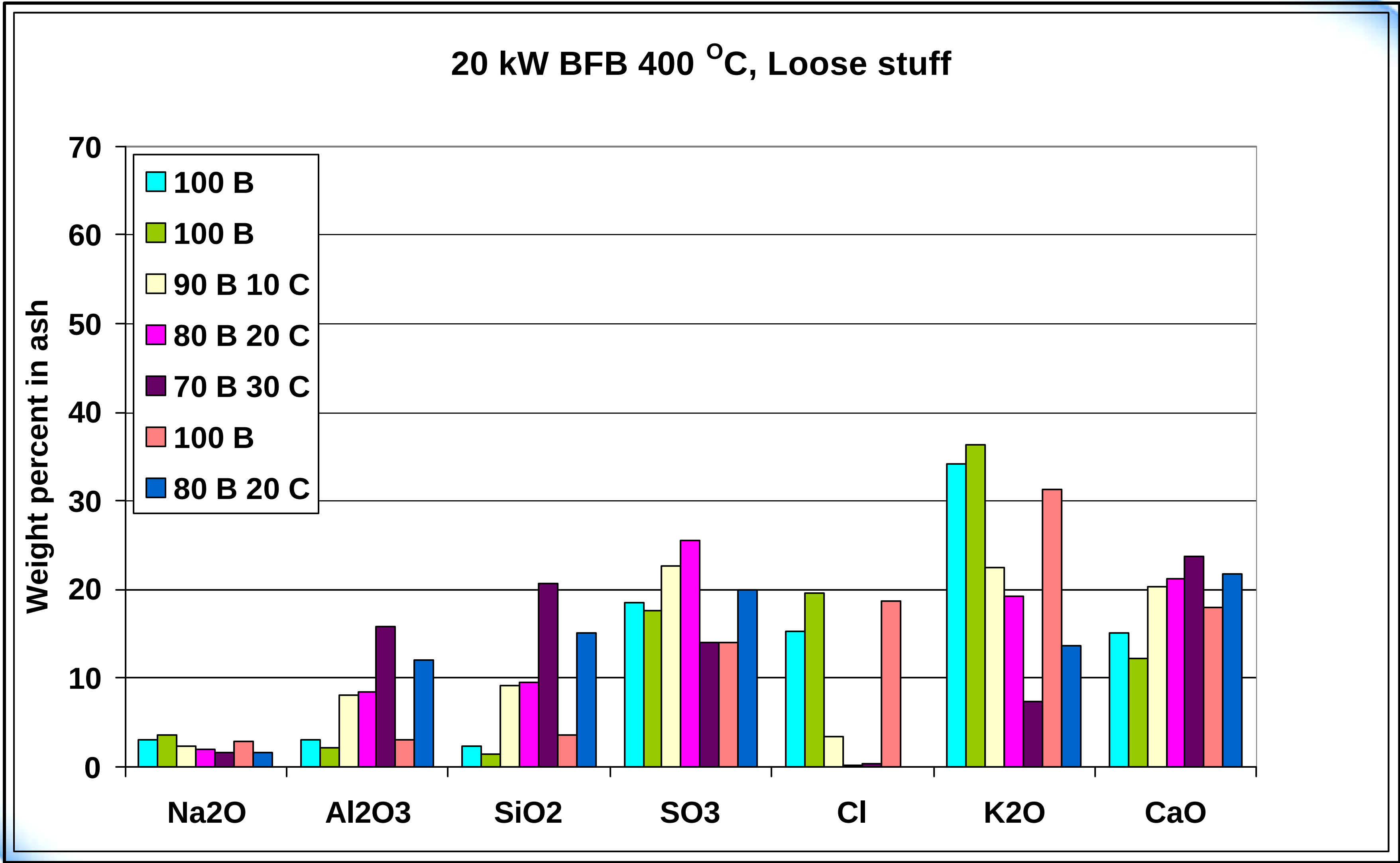
VTT Processes, P.O.Box 1603, 40100 Jyväskylä, Finland

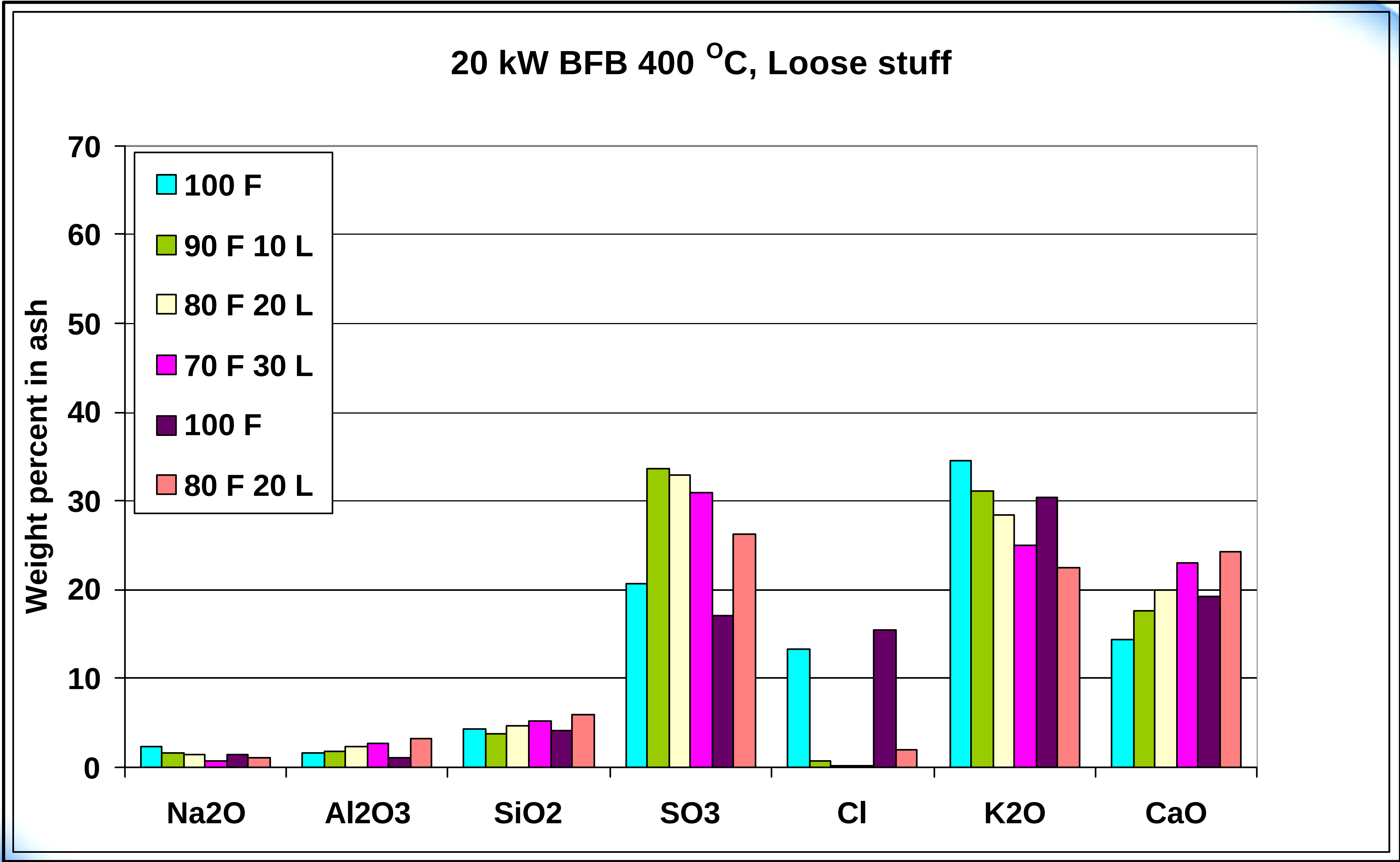
tel +358 14 672 545 fax +358 14 672 597 e-mail martti.aho@vtt.fi

Co-authors: Bengt-Johan Skrifvars[2], Patrik Yrjas[2], Kati Veijonen[1], Raili Taipale[1], Eila Lybeck[1], Tor Lauren[2] and Mikko Hupa[2]

1) VTT Processes, 2) Process Chemistry Group, Åbo Akademi University, Finland


20 kW BFB 400 °C Lee
Weight percent in ash
0
10
20
30
40
50
60
70
100 B
100 B
90 B 10 C
80 B 20 C
70 B 30 C
100 B
80 B 20 C
Na2O
Al2O3
SiO2
SO3
Cl
K2O
CaO


20 kW BFB 400 °C, Loose stuff
Weight percent in ash
70
60
50
40
30
20
10
0
100 B
100 B
90 B 10 C
80 B 20 C
70 B 30 C
100 B
80 B 20 C
Na2O
Al2O3
SiO2
SO3
Cl
K2O
CaO


20 kW BFB 400 °C, Loose stuff
Weight percent in ash
70
60
50
40
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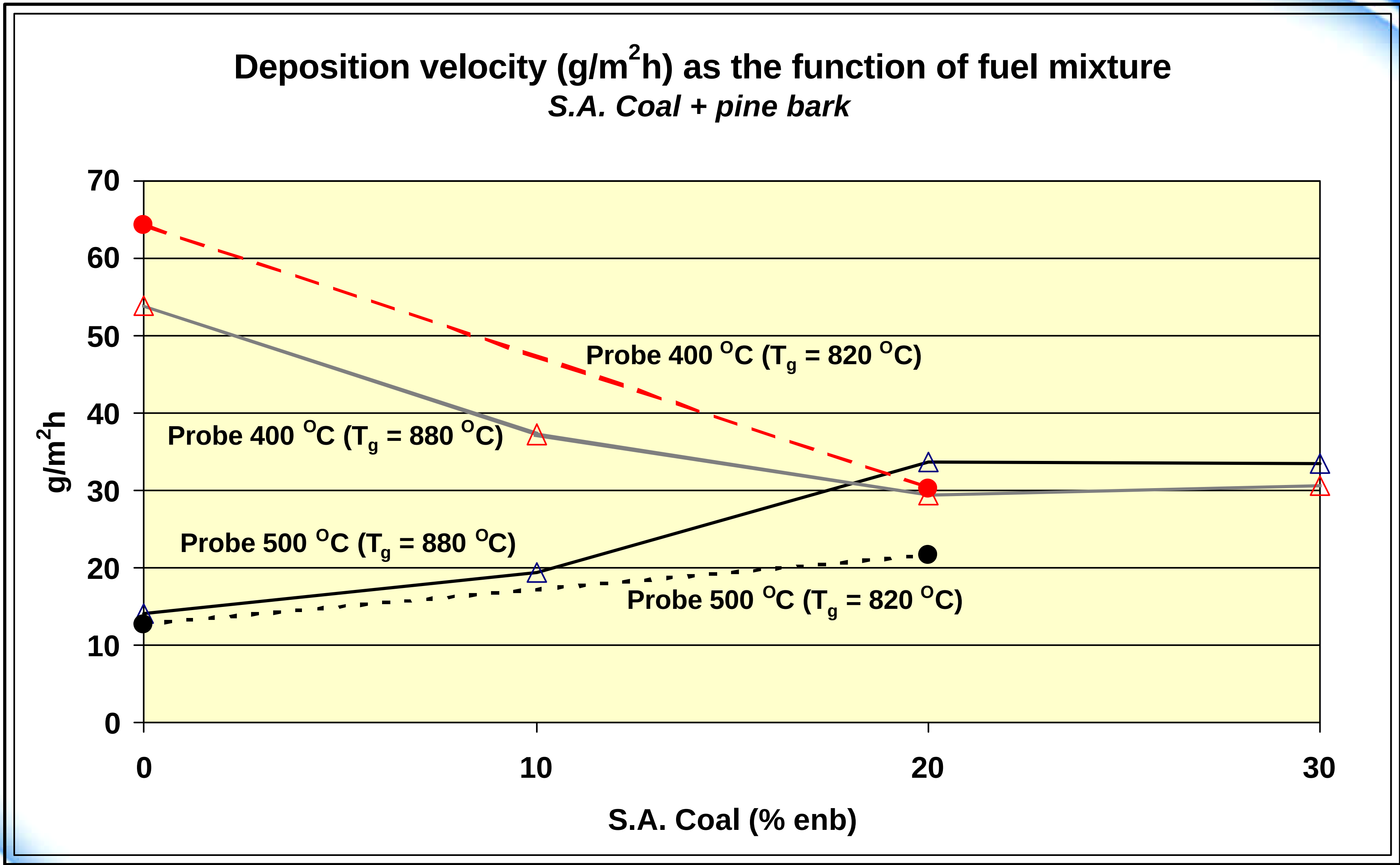
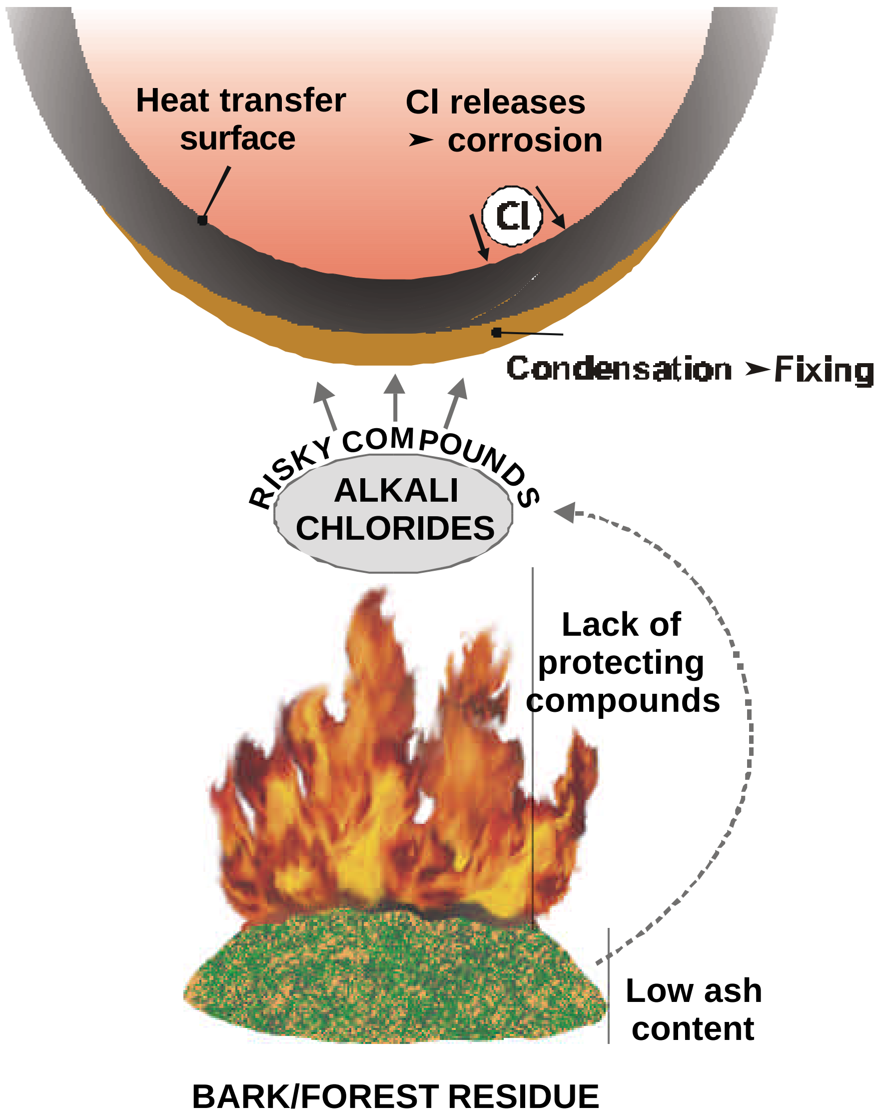
20
10
0
100 F
90 F 10 L
80 F 20 L
70 F 30 L
100 F
80 F 20 L
Na2O
Al2O3
SiO2
SO3
Cl
K2O
CaO

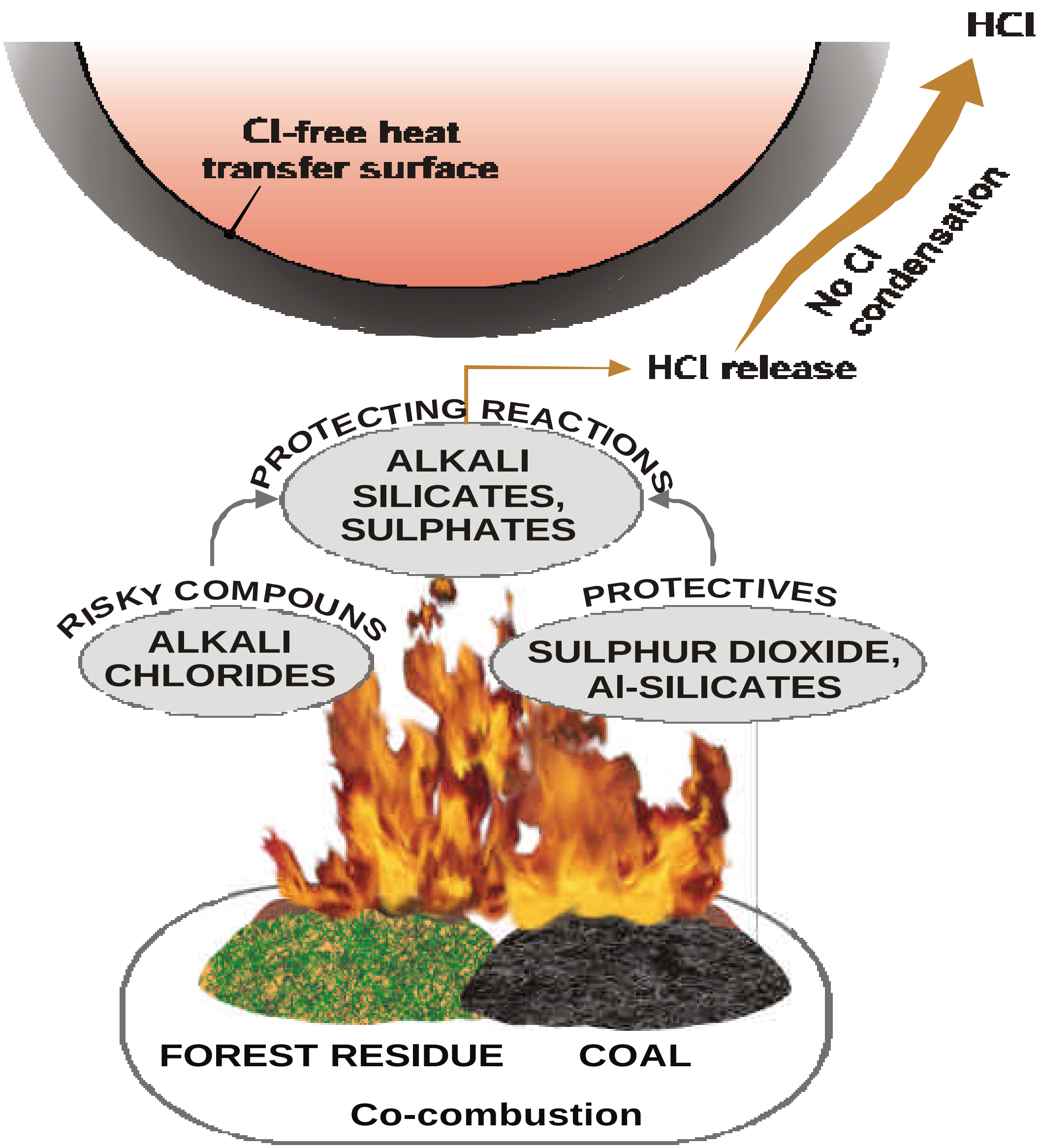


Deposition velocity (g/m2h) as the function of fuel mixture
S.A. Coal + pine bark
g/m2h
70
60
50
40
30
20
10
0
Probe 400 OC (Tg = 820 OC)
Probe 400 OC (Tg = 880 OC)
Probe 500 OC (Tg = 880 OC)
Probe 500 OC (Tg = 820 OC)
0
10
20
30
S.A. Coal (% enb)

CASE 1. BARK/FOREST RESIDUE



CASE 2. PROTECTING POWER OF COAL



CONCLUSIONS

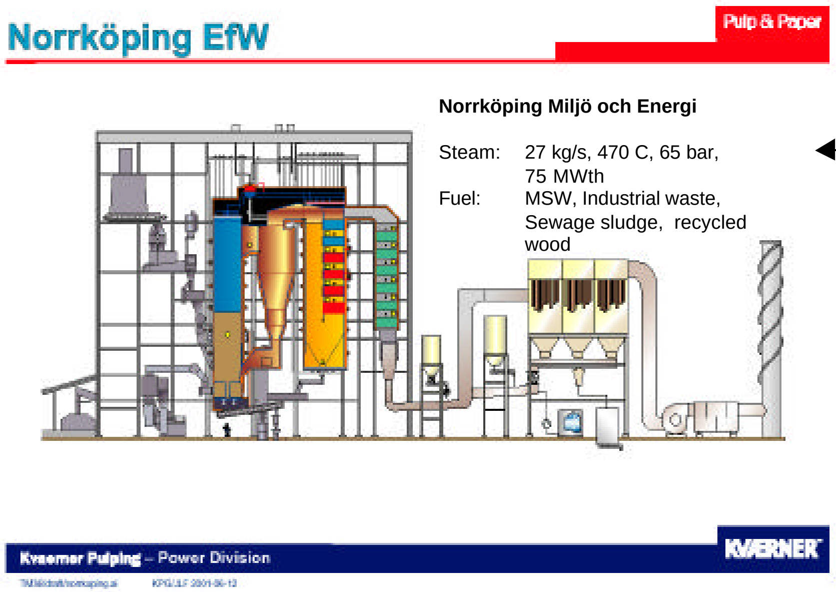
- **Co-combustion of coal, peat and lignite with biomass leads to many significant benefits in fluidised bed boilers**
- **These benefits originate both from fossil fuel and biomass components**
- **Wood ash significantly strengthened sulphur binding from coal, and peat reducing SO_2 emissions**
- **Aluminium, silicon and sulphur of coal, lignite and peat removed effectively chlorine from deposits and fine fly ash**
- **Mixing coal, lignite and peat with wood residues may lower toxicity of the fine fly ash (due to Mn) in view of the new co-incineration directive, but mixing Cl-rich waste to the feedstock makes toxic metal removal more difficult.**

Gasification-based Co-firing of Biomass and Recovered Fuels in Coal-fired boilers

- Lahti CFB gasifier demonstration (EU/Thermie)
- Corenso gasifier for plastic waste
- R&D on advanced gas cleaning

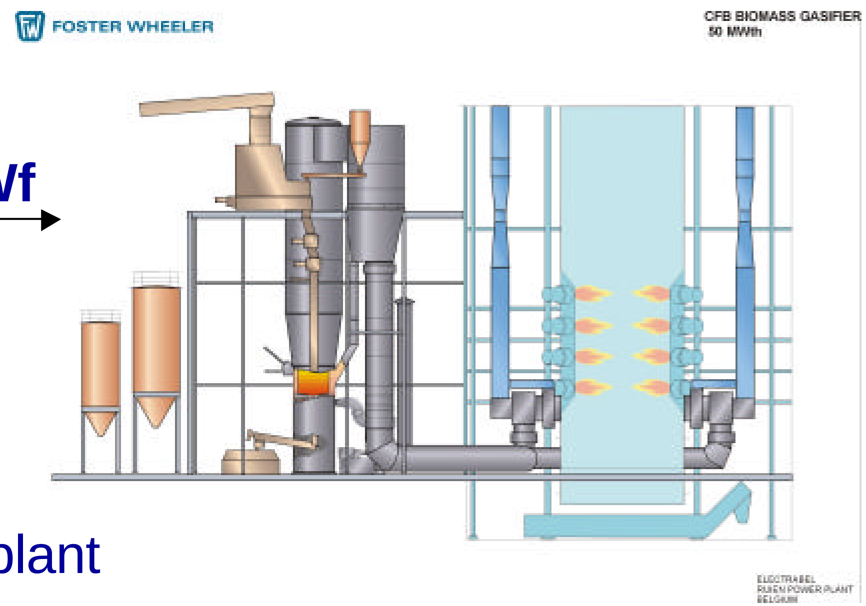
Esa Kurkela, VTT Processes, Finland

Amsterdam Biomass Conference, June 2002
Workshop on Co-firing, 20.6.2002



Fluid Bed Combustion 20 - 300 MWf

- multi fuel BFB and CFB technology
- co-firing biomass and coal, lignite
- high efficiency, low emissions
- proven technology
- typical investment ca. 2000 €/kWe



Fluid Bed Gasification 15 - 120 MWf

- multi fuel BFB and CFB technology
- co-firing the clean gas in coal boiler
- high efficiency, low investment
- typical investment ca. 600 €/kWe
  in co-firing large coal/oil/gas power plant

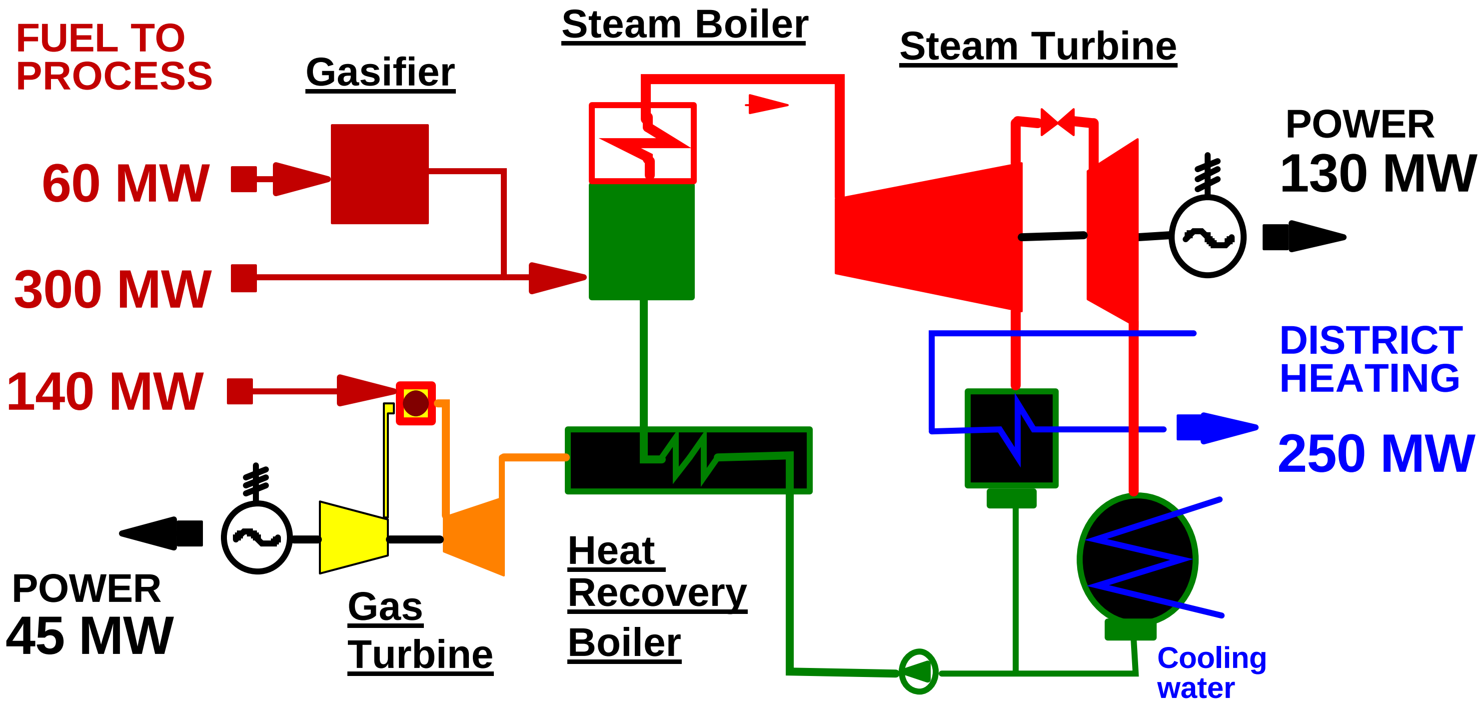
Power Station Kymijärvi, town of Lahti Finland

Lahti Energia Oy is municipal-owned energy company:

- **Power 1100 GWh**
- **District Heat 1200 GWh**
- **Turnover 84 M€**
- **Personnel 340**

Source: Kivelä M, Lahti Energia, 2002

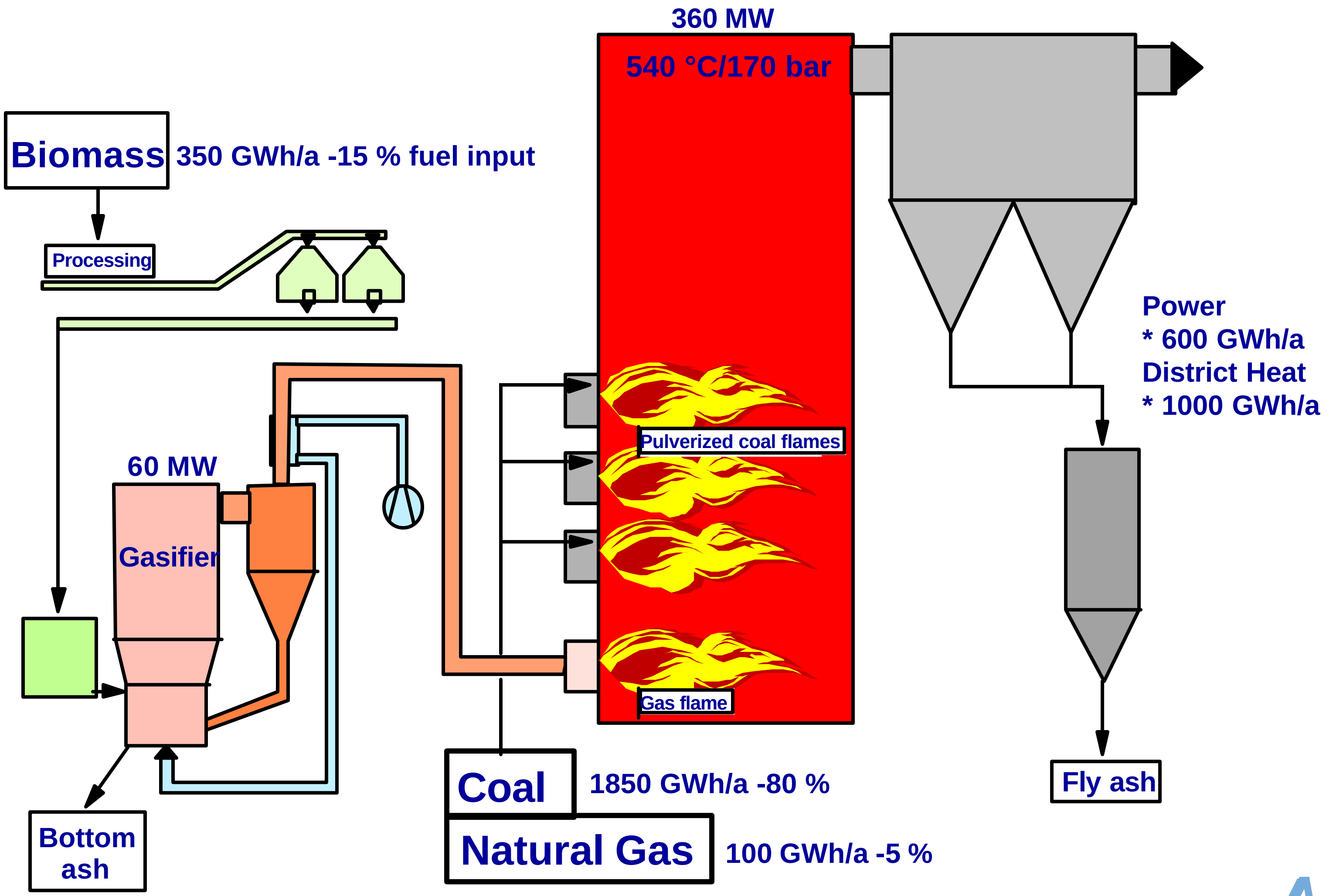
FLOW DIAGRAM OF THE KYMIJÄRVI POWER STATION, LAHTI FINLAND

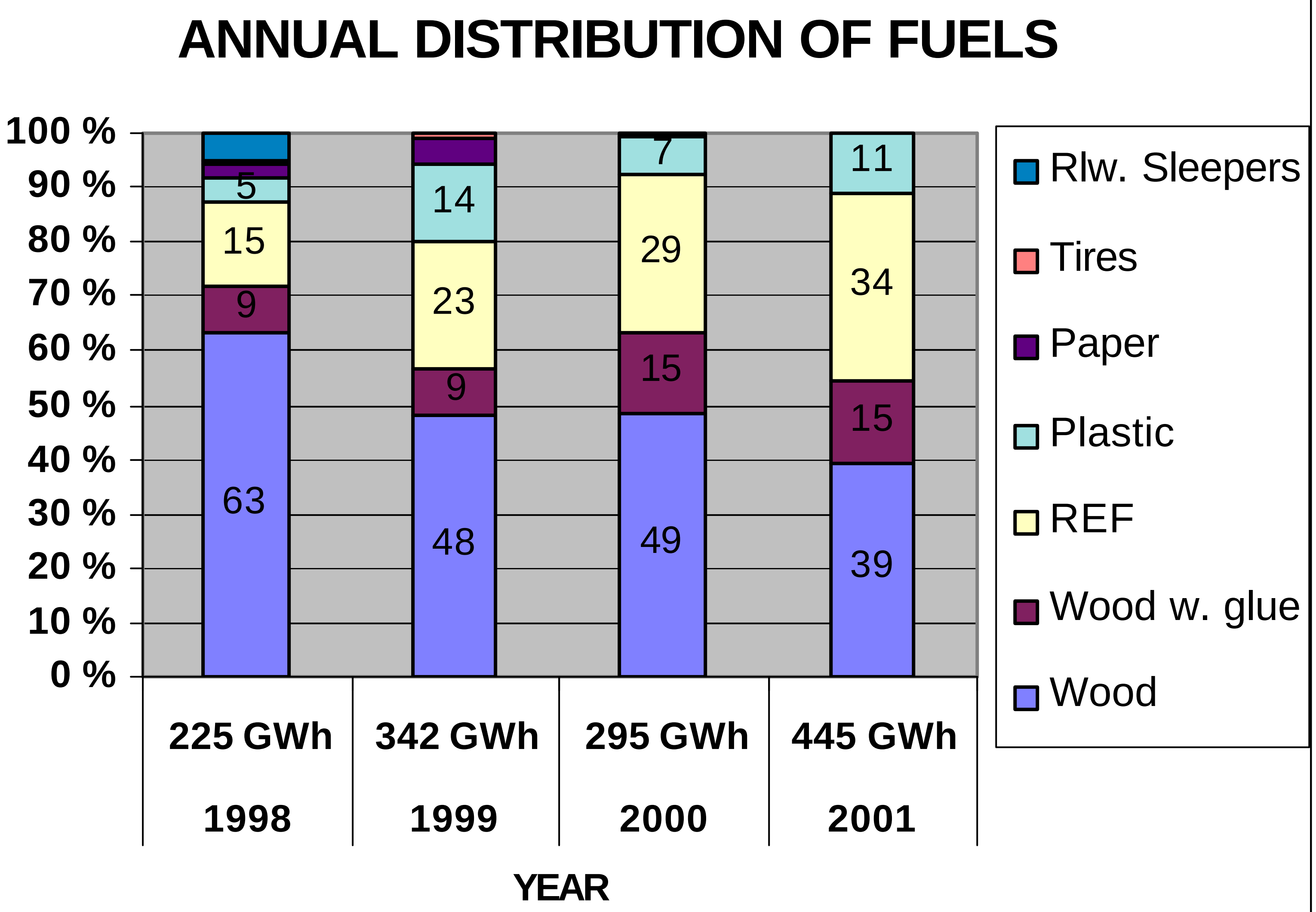


POWER IN CONDENSING MODE 200 MW

Source: Kivelä M, Lahti Energia, 2002

BIOMASS GASIFICATION - COAL BOILER
Lahti, Finland



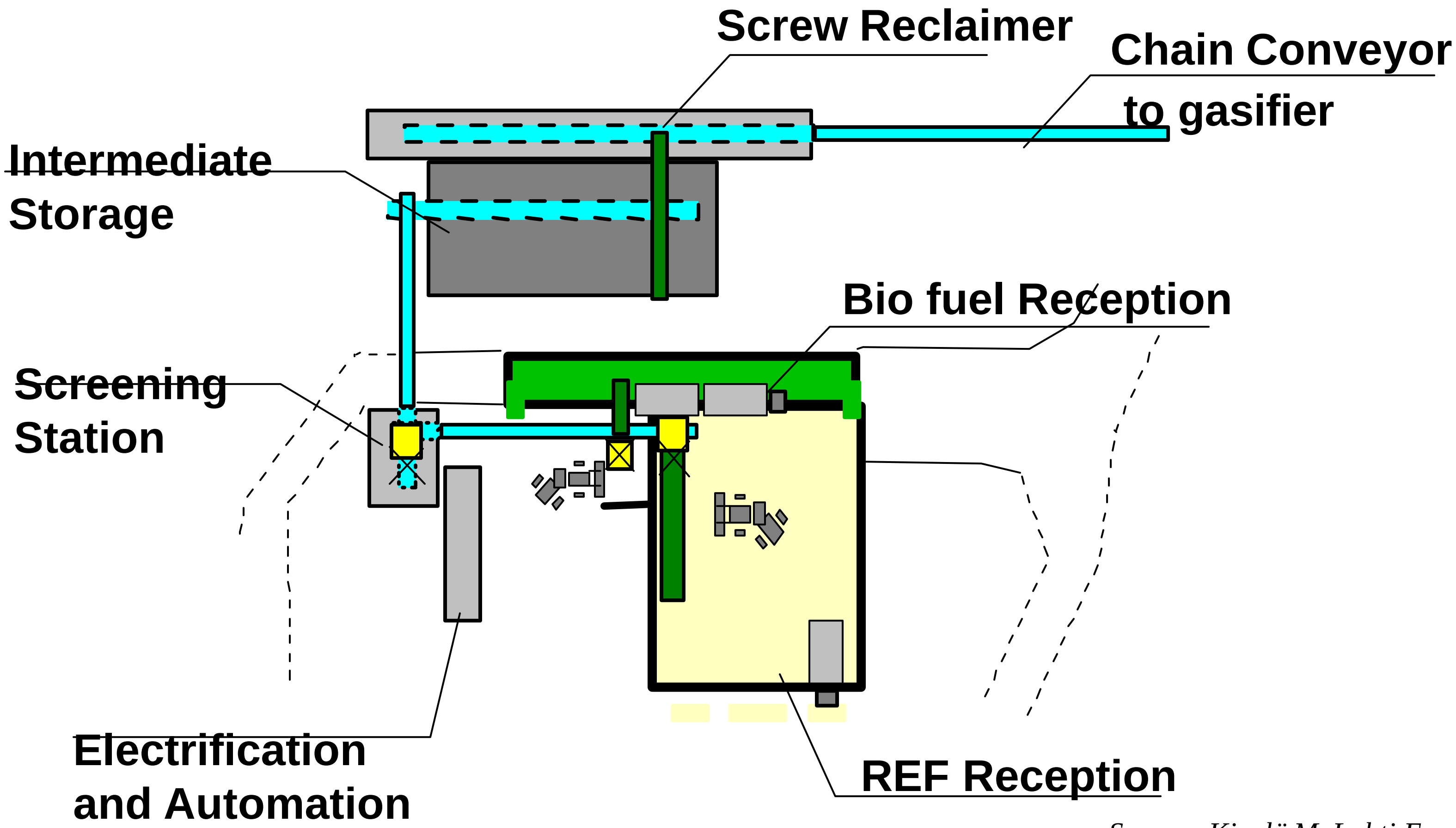


Source: Kivelä M, Lahti Energia, 2002

Source: Palonen J, Foster Wheeler, 2002

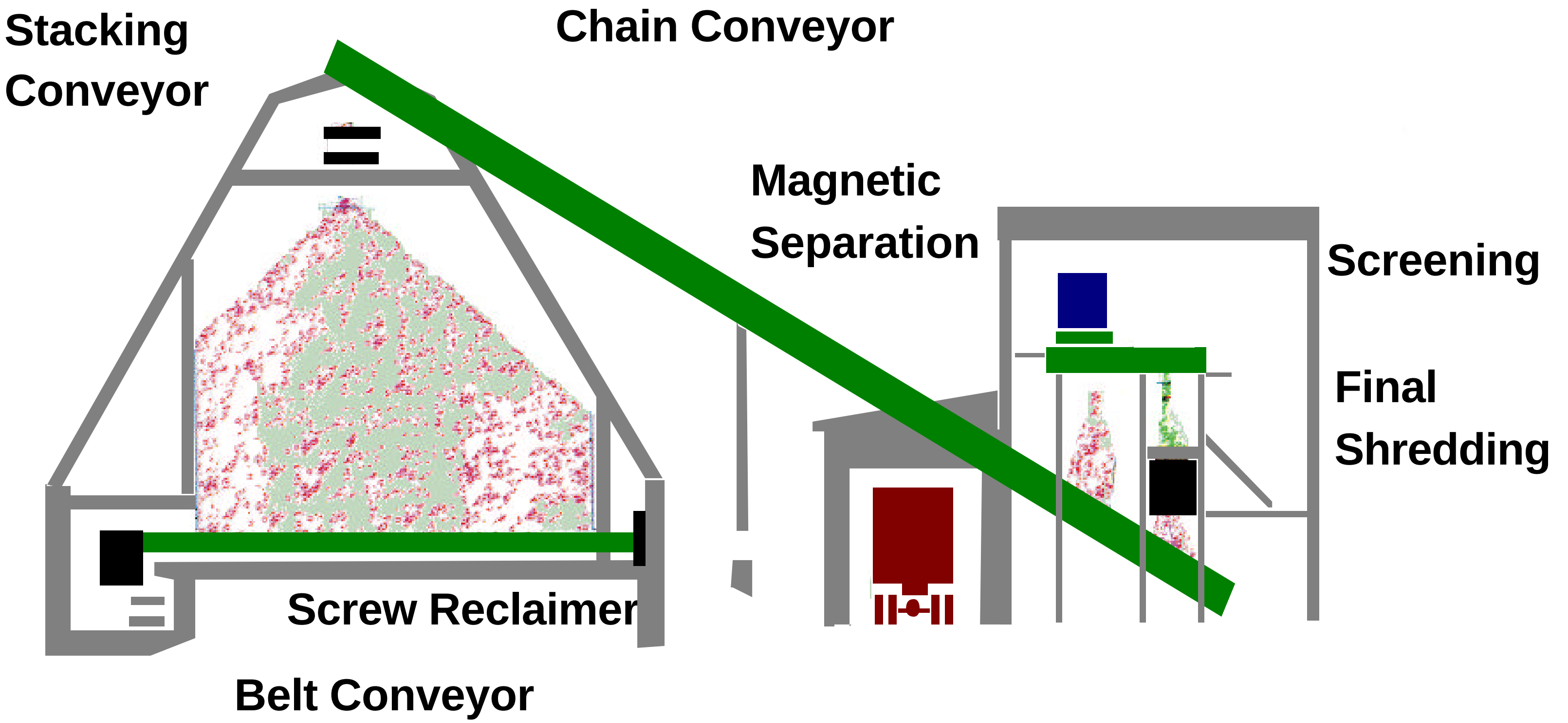
Lahti Fuels

FUEL HANDLING LAY OUT



Source: Kivelä M, Lahti Energia, 2002

FUEL HANDLING CROSS-SECTION



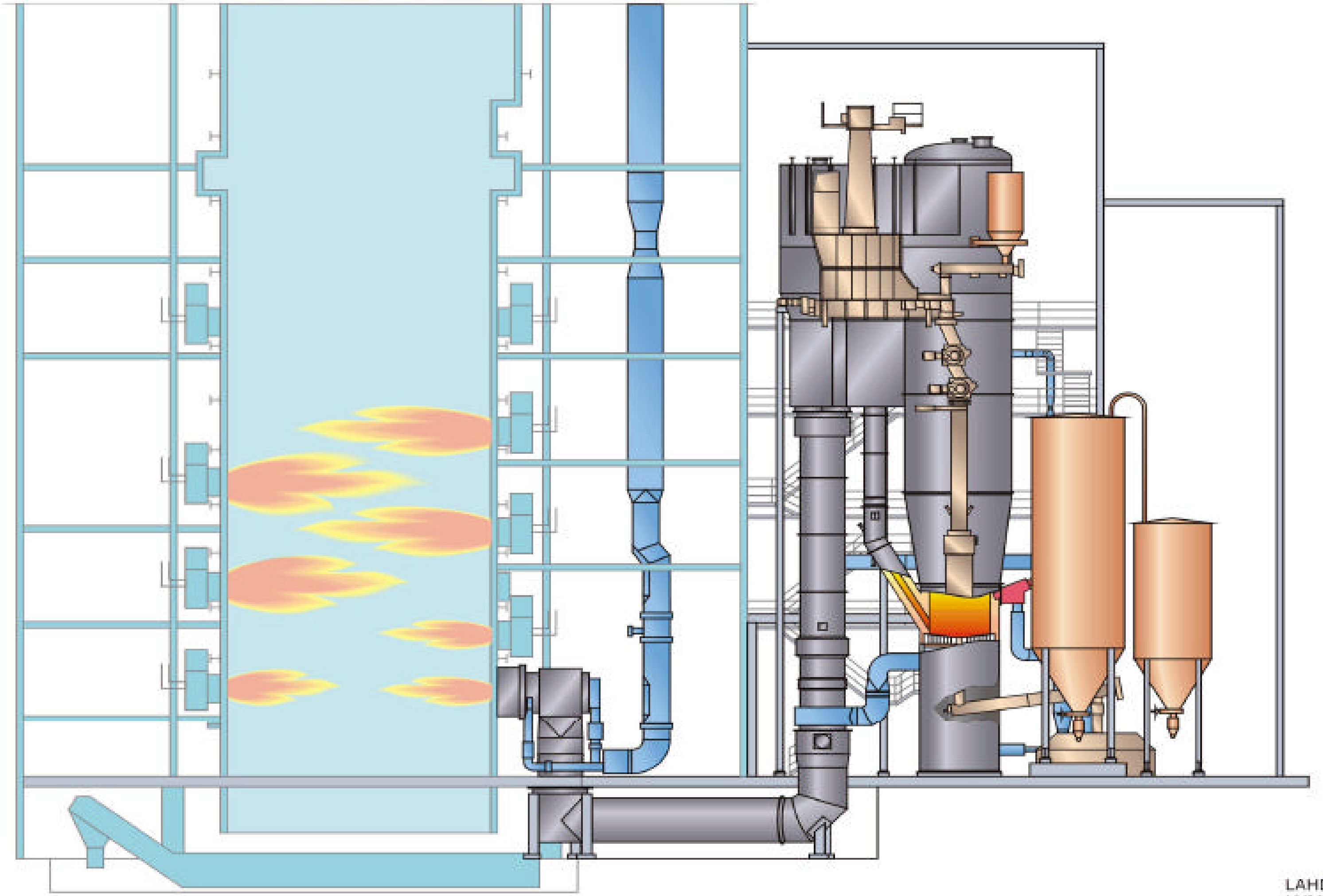
Source: Kivelä M, Lahti Energia, 2002

Source: Palonen J, Foster Wheeler, 2002

Lahti Plant

FOSTER WHEELER

CFB BIOMASS GASIFIER
40 - 70 MWth



LAHDEN LÄMPÖVOIMA
KYMIJÄRVI POWER PLANT
KYMIJÄRVI, FINLAND

Lahti Operating Experiences

- Commercial operation since March 1998
- Operating data 1998 - 2001
  - Operating time 21 000 hours
  - Energy produced 1270 GWh
  - Fuel gasified 394 000 ton
  - Availability (whole plant) 86.6 %

Source: Palonen J, Foster Wheeler, 2002

Availability and Energy Produced

Gasifier in gasification mode

		1998	1999	2000	2001
Operating hours	**h**	**4730**	**5460**	**4727**	**7089**
Availability *	**%**	**99.3****	**98.9**	**97.1**	**96.1**
Energy produced	**GWh**	**223**	**343**	**295**	**449**

Plant designed to produce energy 300 GWh/a

* Heat up periods excluded. Consists only of the operation in gasification mode.

** The second half of the year.

Source: Palonen J, Foster Wheeler, 2002

Product Gas Main Components

	Range (%-dry)	Average (%-wet)
CO_2	17 … 19.8	12.9
CO	4.5 … 9	4.6
H_2	7 … 10.5	5.9
C_xH_y	3.4 … 6	3.4
N_2	-	40.2
H_2O	-	33.0

Source: Palonen J, Foster Wheeler, 2002

Product Gas Special Measurements

NH_3	mg/m3n (dry)	800 - 1000
HCN	mg/m3n (dry)	25 - 45
HCl	ppmv (dry)	30 - 90
H_2S	ppmv (dry)	50 - 80
Tars	g/m3n (dry)	7 - 12
Alkalies	ppmw (dry)	< 0.1
Particulates	g/m3n (wet)	6 - 10

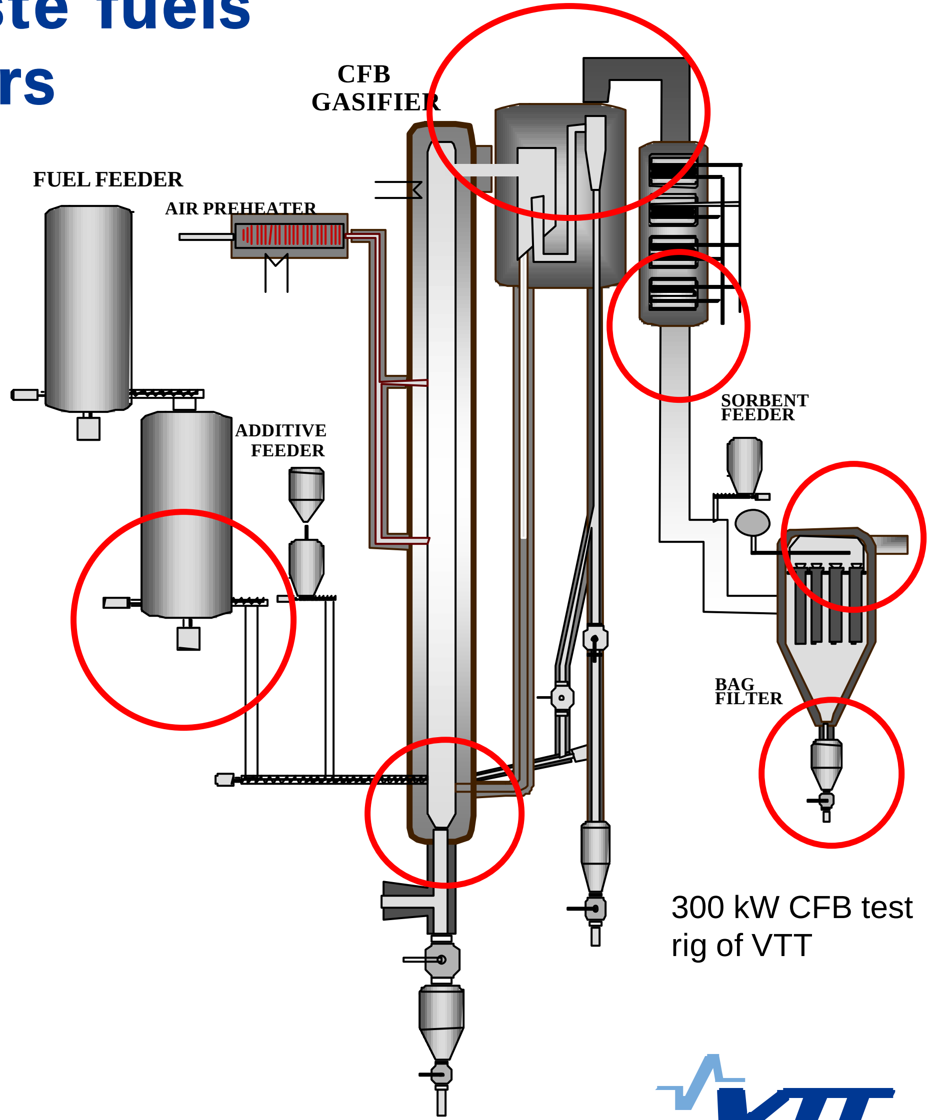
Source: Palonen J, Foster Wheeler, 2002

Gasifier Effect to Main Boiler Emissions

NOx	Decrease by 10 mg/MJ (= 5 to 10 %)
SOx	Decrease by 20 - 25 mg/MJ
CO	No change
HCl	Increase by 5 mg/MJ , base level low
Particulates	Decrease by 15 mg/m3n
Heavy metals	Increase in some elements, base level low
Dioxins, etc.	No change

Source: Palonen J, Foster Wheeler, 2002

Low-pressure CFB/BFB-gasification for utilising biomass and waste fuels in existing coal/oil-fired boilers



300 kW CFB test rig of VTT

Industrial projects

- **Lahti 50 MW*** plant since 1998
- **Corenso 40 MW*** gasifier since 2001
- **Ruien plant 50 MW*** 2002
- Straw pilot tests by FWE and E2
- SRF gasification pilot by VTT/Vapo/PVO

* by Foster Wheeler

VTT R&D in 1997-2002

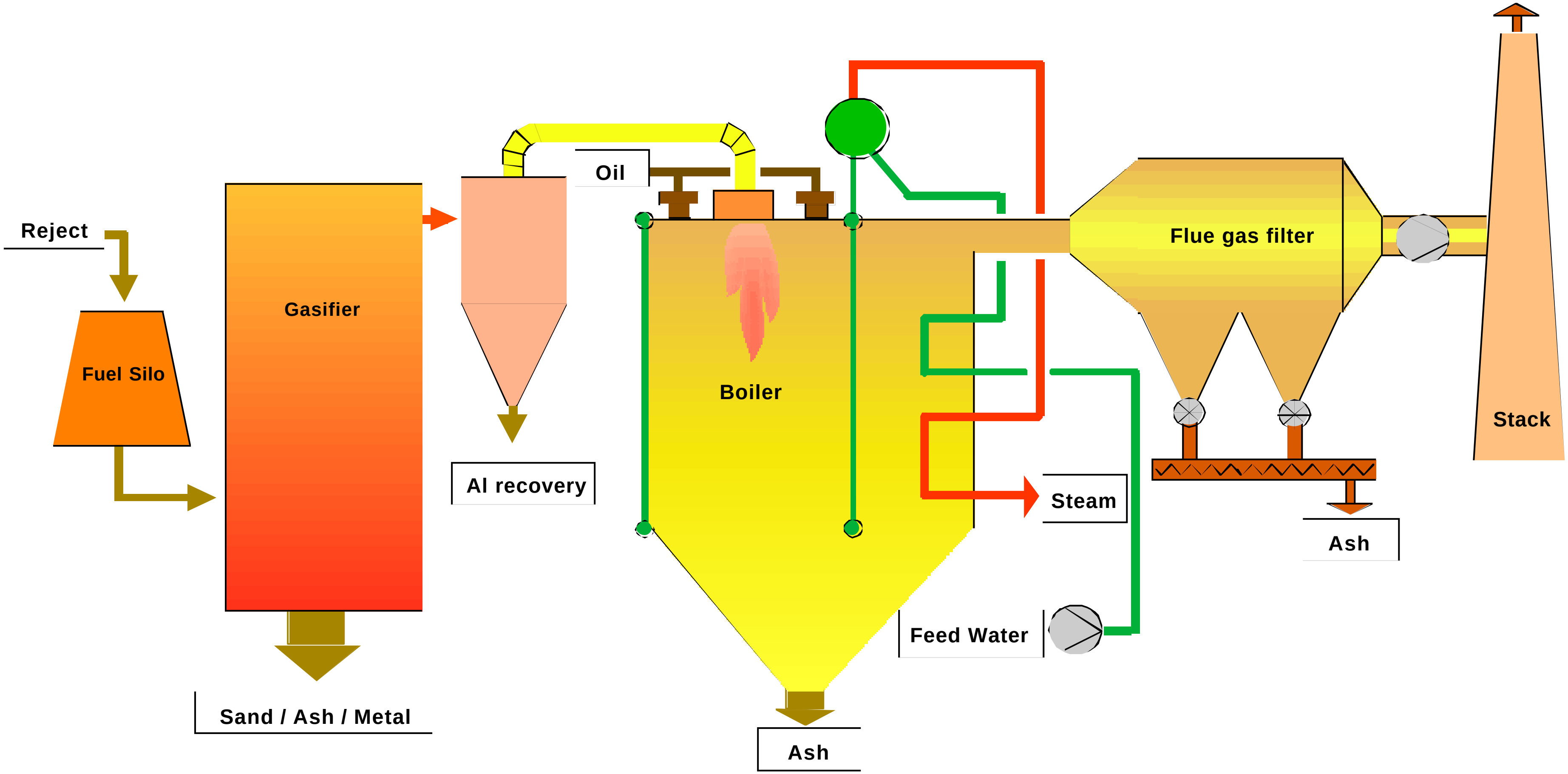
- CFB-gasification of straw and demolition wood
- Gasification of plastic wastes
- Gasification of MSW-derived SRF
- Gas filtration with bag filters
- Removal of HCl and heavy metals

Corenso Gasification Plant
Varkaus, Finland

- Problems in PE-Al reject co-combustion in a CFB boiler in 1996
- VTT test runs at bench and PDU-scale in 1997
  - Gasification process selection and development
- FWE-SE tests at 15 MW pilot/demonstration plant
  - Operational experiences / optimization, fuel feeding
  - Design basis for commercial scale unit
- **Commercial 40 MW unit**
  - Commercial operation started in autumn 2001
  - Operating hours 6200 h (until June 10, 2002)
  - Energy produced 165 GWh/a substituting 16 500 ton HFO/a
  - Aluminium recovered 2 100 ton/a

FOSTER WHEELER

Corenso Gasifier



Lahti - gasification demonstration project

Conclusions:

- succesfull large-scale 60 MW demonstration plant
- reliable operation and high availability since1998
- no change in coal-boiler emissions, 15 % CO_2 reduction
- low cost investment, about 600 eur/kWe in co-firing
- promising dissemination potential in Europe: 150 plants
- straw and MSW based recovered fuels offers additional large business opportunities on top of wood fuels
- successful R&D on advanced gas cleaning

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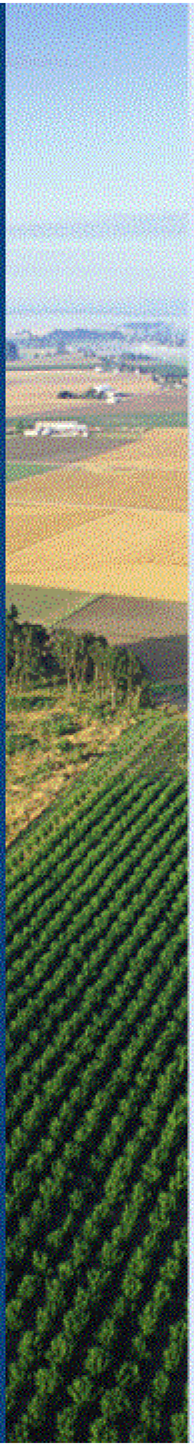

Gasification

The Enabling Co-Firing Option

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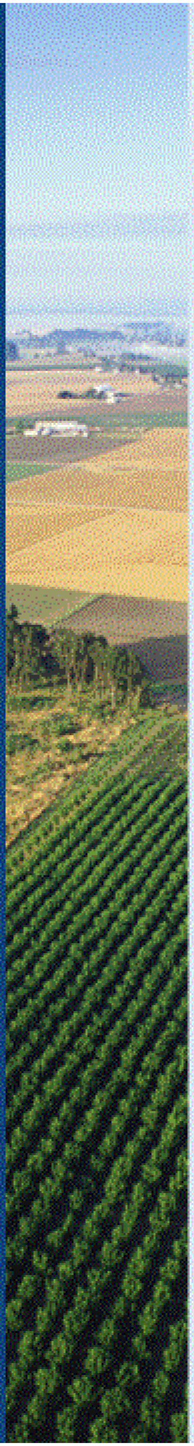

Gasification The Enabling Co-firing option

- Avoids ash issues in boiler
- Cleanup of MCV gas simpler than flue gas cleanup
- Allows phased implementation of IGCC
- Provides means to use biomass in larger scale projects

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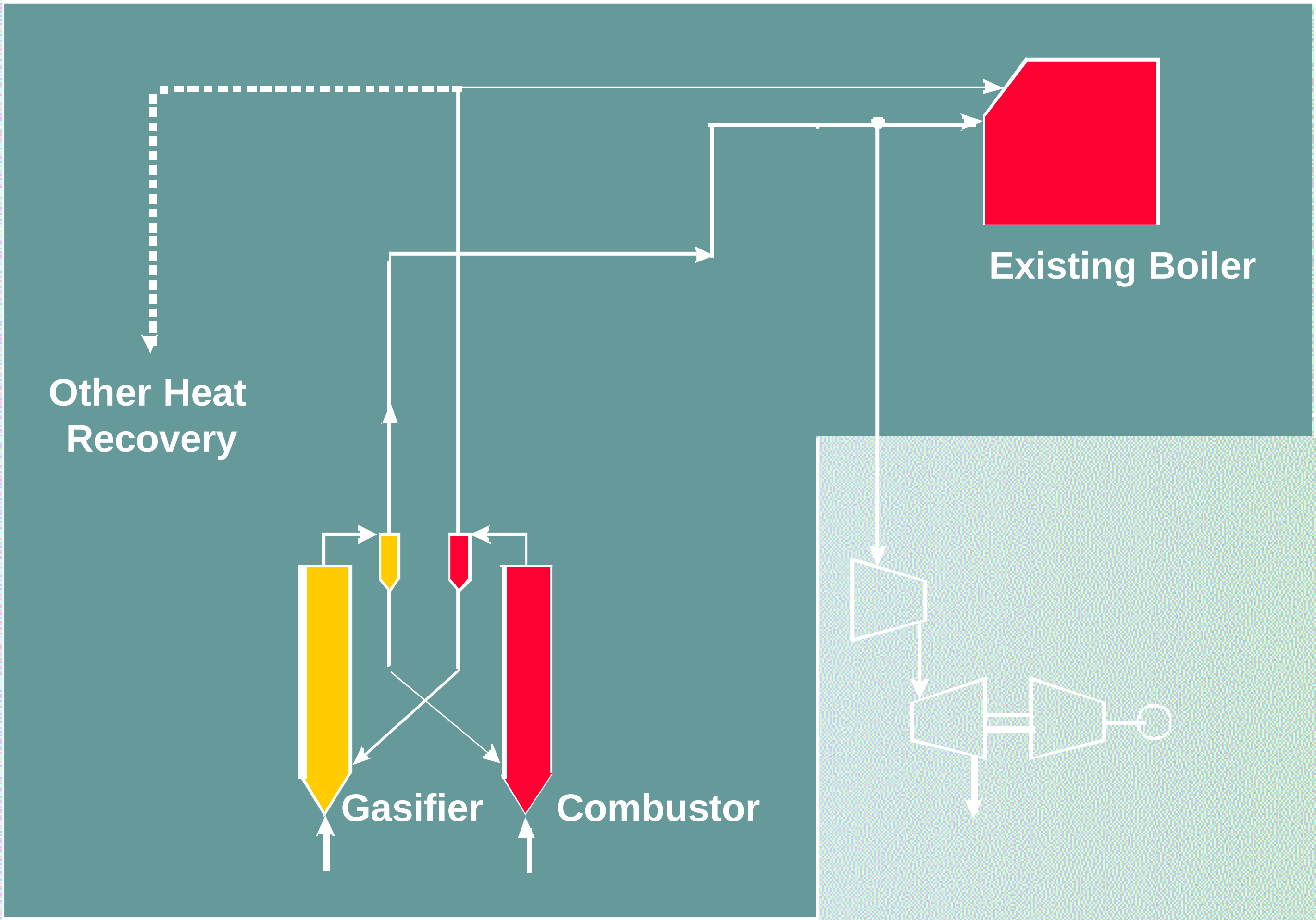
Gasification   A Simpler Route



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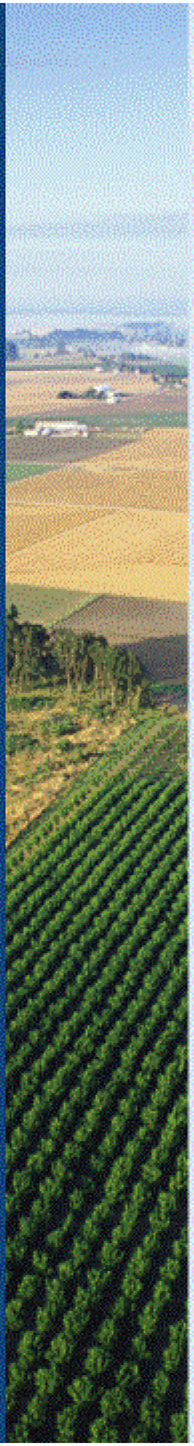
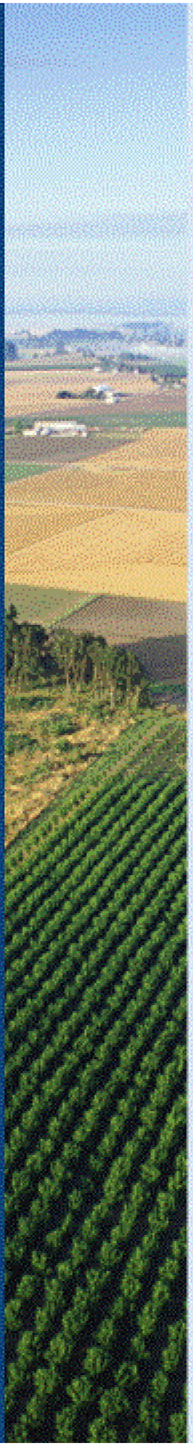


Co-firing MCV Gas - Advantages

- Enhanced greenhouse gas performance for fossil boilers
- Natural gas burners no modification
- Provides a green component to natural gas fired equipment
- Eliminates natural gas price uncertainties



Co-firing MCV Gas Environmental Advantages

Conventional thinking

- **Reduced particulate emissions**
- **Reduced SO_x emissions**
- **Reduced NO_x emissions**

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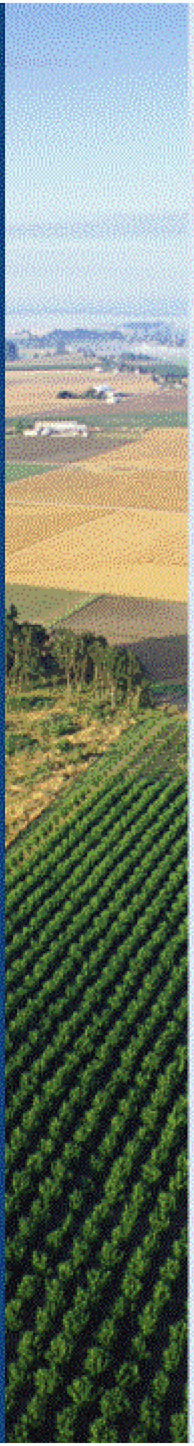

Co-firing MCV Gas Environmental Advantages

Enhanced opportunity

- Replace natural gas as a reburn fuel
  - NO_x reductions of 60+%
  - Adds green credits to reburn application

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Co-firing MCV Gas Issues

- Increased confidence in MCV gas combustion characteristics
- Desire to retain multifuel capability
- Additional piping in boiler house
- Recognition by permitting agencies as emissions reduction option

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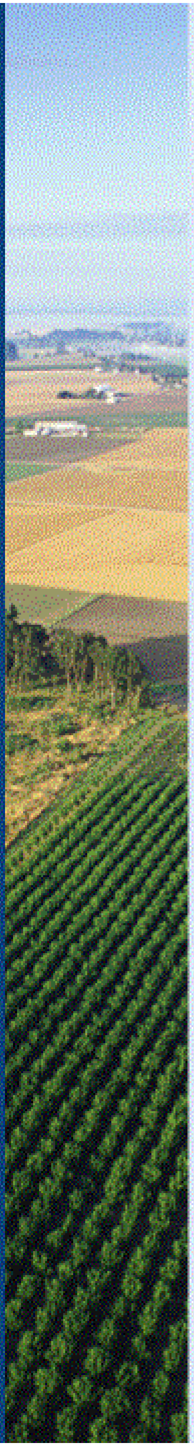
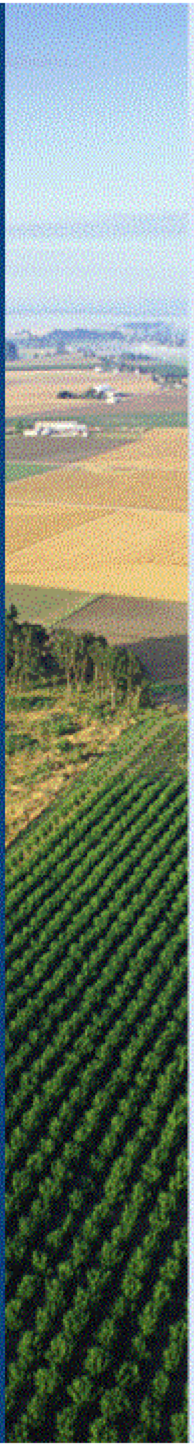


The Vermont Experience

- Boiler modifications minimal
- Reduction in NO_x emissions
- Boiler operation affects gasifier operation
- Boiler operators becoming more familiar with gasifier contribution



Future Options for Co-firing

- Gasifier / coal boiler
- Gasifier / biomass boiler
  - Option for pulp & paper
  - Extends useful life of existing equiment
- Gasifier / large scale gas turbine
  - Provides green component to larger plants
  - Lower risk IGCC option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