Biomass co-firing in high percentages

opportunities in conventional and advanced coal-fired plants

J.H.A. Kiel

IEA Bioenergy Task 32
workshop Increasing co-firing percentages in existing coal-fired power plants
Geertruidenberg, the Netherlands, 21 October 2008

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Biomass co-firing in high percentages – opportunities in conventional and advanced coal-fired plants

Jaap Kiel

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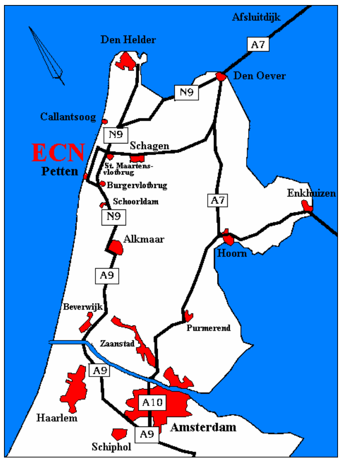
Energy research Centre of the Netherlands

In the dunes of N-Holland - Petten



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

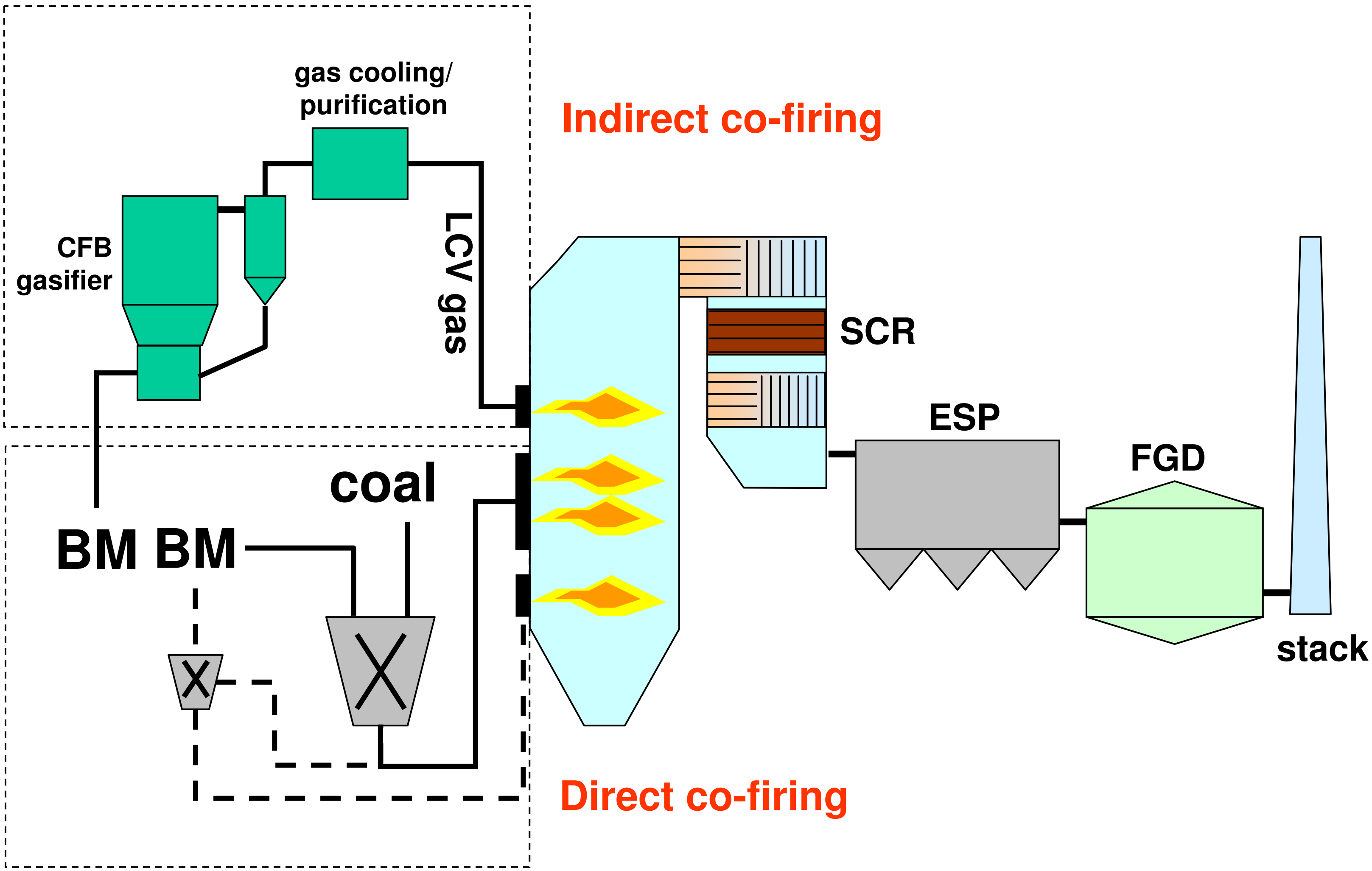
- Independent research institute
- 650 employees
- Annual turn-over: 80 million Euro
- Activities:
  - *Biomass, Solar, Wind*
  - *Clean fossil fuels (CCS, fuel cells)*
  - *Energy efficiency*
  - *Policy studies*

Presentation overview

- Biomass co-firing options
- State-of-the-art
- R&D needs
- Examples ECN R&D
- Co-firing in advanced coal conversion
- New challenges
- Concluding remarks

Essent Amer power station

Biomass co-firing technology options



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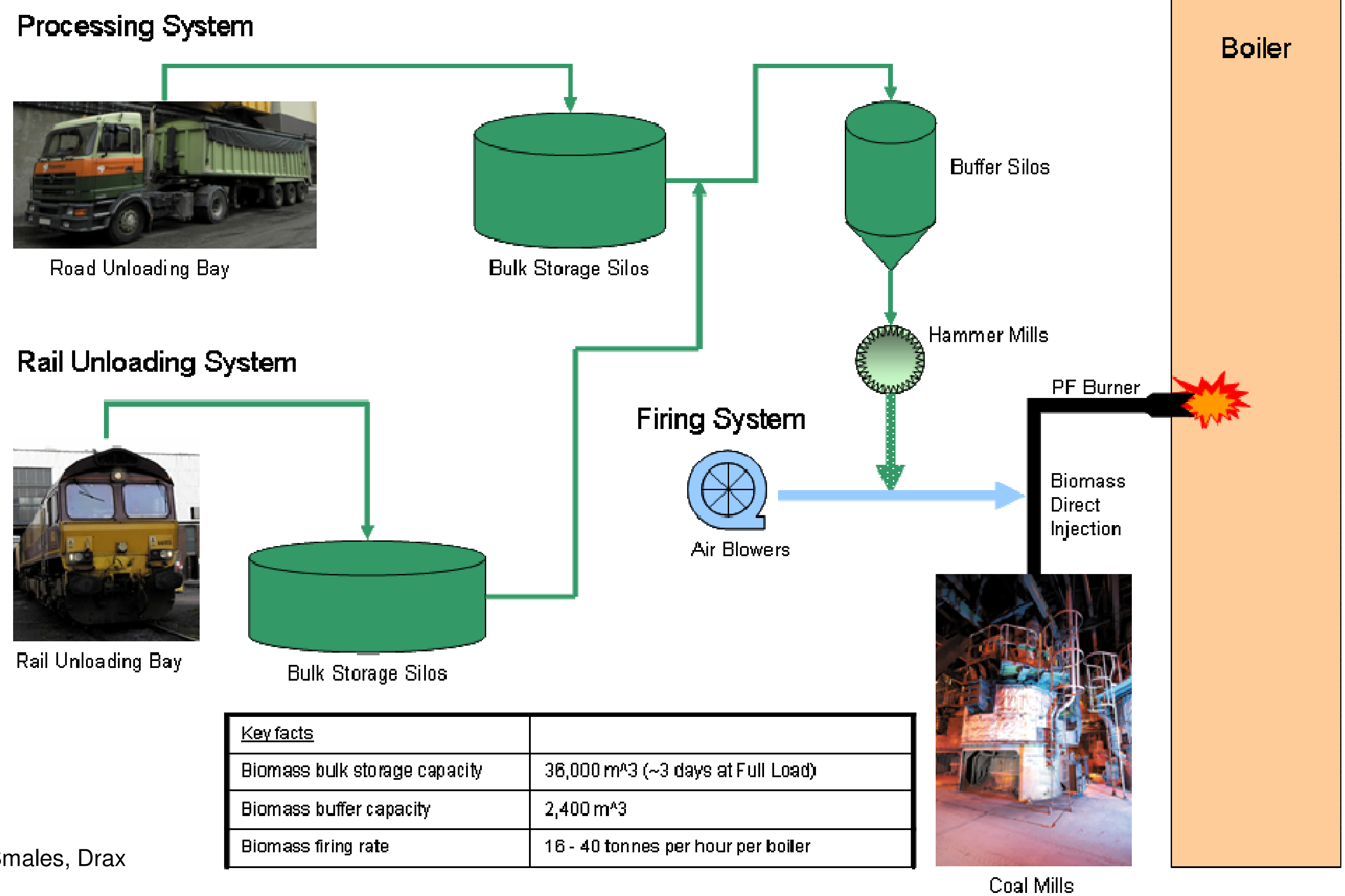
Co-firing at Drax power station (UK)

- Coal-fired power station
- Capacity 6 x 660 MWe
- ≅ 6.5% el. needs

- 10% biomass co-firing
- = 400 MWe
- = 1.5 Mtonne/a biomass

Source: Davis Smales, Drax

10% co-firing at Drax power station (UK)



Key facts	
Biomass bulk storage capacity	36,000 m^3 (~3 days at Full Load)
Biomass buffer capacity	2,400 m^3
Biomass firing rate	16 - 40 tonnes per hour per boiler

Source: Davis Smales, Drax

Biomass co-firing in high percentages – R&D needs

- Biomass upgrading technology to reduce the cost of biomass logistics and improve the compatibility of biomass as a fuel
- Better mechanistic understanding of combustion/gasification-related technical bottlenecks and translation into fuel mixing recipes, design specifications and operating guidelines
- Predictive tools for assessing the co-firing potential of biomass streams and optimising boiler design and operation for co-firing (low-cost screening, modelling)
- Advanced techniques for (on-line) process monitoring and control
- (Ash recycling strategies and) utilisation options

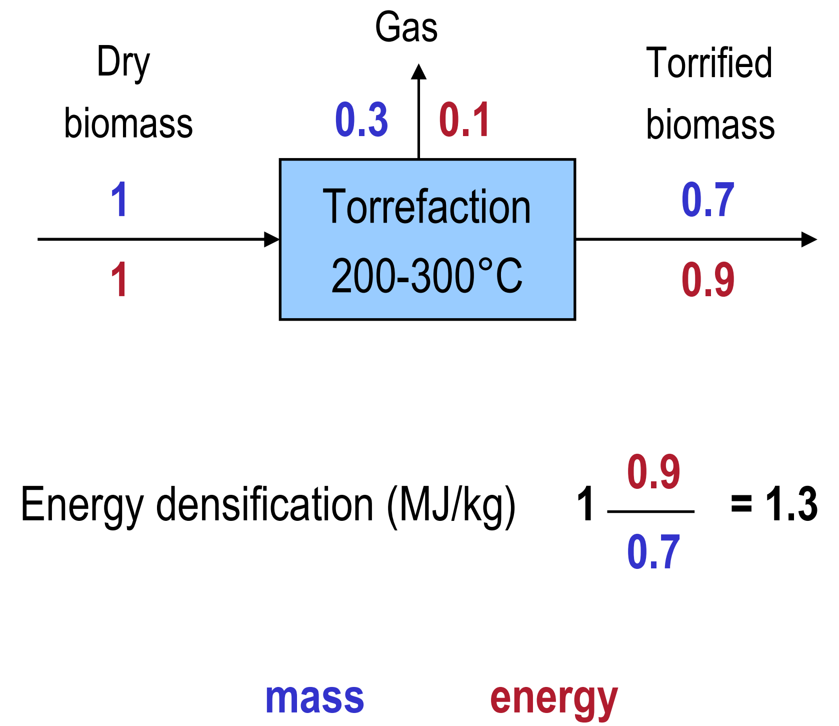
Biomass – a difficult energy source

- Tenacious and fibrous (grinding difficult)
- Low energy density (LHV_{ar} = 10-17 MJ/kg)
- Hydrophilic
- Vulnerable to biodegradation
- Heterogeneous

Biomass upgrading – technology options

- Adapt the biomass fuel to requirements of logistic systems and conversion processes (commodity fuel or “designer fuel”)
- Technology options (a.o.):
  - Pyrolysis
  - Briqueting
  - Pelletisation
  - Torrefaction

Torrefaction for upgrading biomass



Process parameters

- Temperature: 200-300°C
- Residence time: 10-30 minutes
- Particle size: < 4 cm
- Absence of oxygen
- Pressure: near atmospheric

Why torrefaction: from biomass/waste to commodity fuel

Woody biomass

Agricultural residues

Mixed waste

Tenacious and fibrous
10 - 17 MJ/kg (LHV, ar)
Hydrophilic
Vulnerable to biodegradation
Heterogeneous

Torrefaction and pulverisation

Friable and less fibrous
19 - 22 MJ/kg (LHV, ar)
Hydrophobic
Preserved
Homogeneous

Fuel powder

Pelletisation

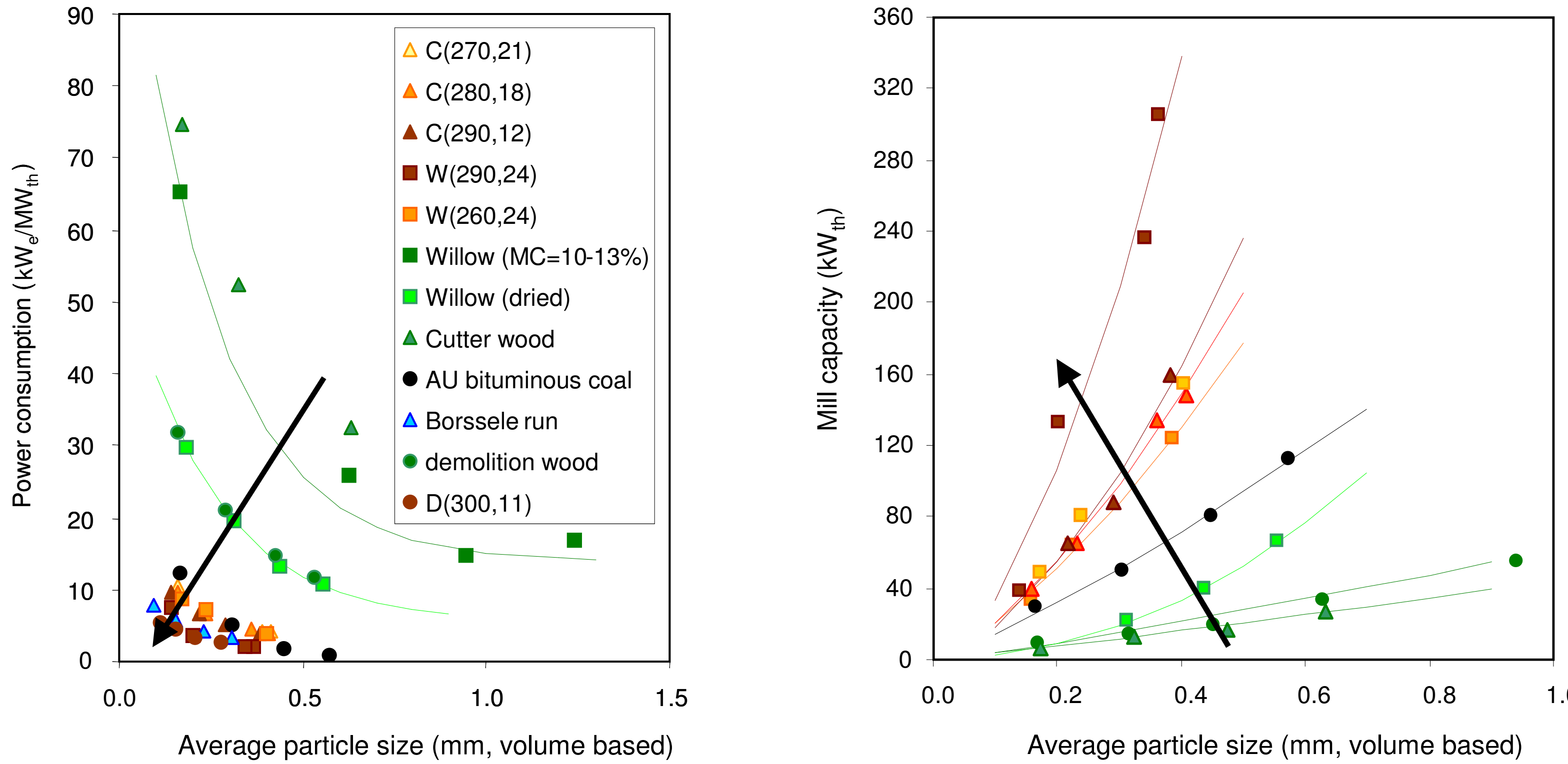
Fuel pellets

Bulk density 700-800 kg/m^3
Bulk energy density 13-17 GJ/m^3

Superior fuel properties:

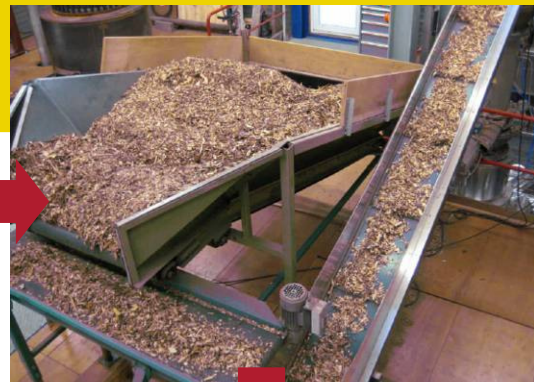
- Transport, handling, storage
- Milling, feeding
- Gasification, combustion
- Feedstock range
- Standardisation

Grindability of (torrefied) woody biomass

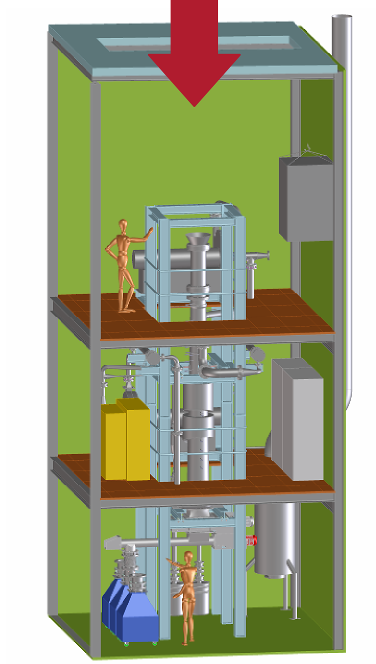


Torrefaction leads to a dramatic decrease in required milling power and increase in milling capacity

Pre-drying

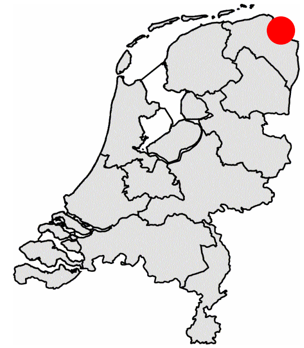


Feeding



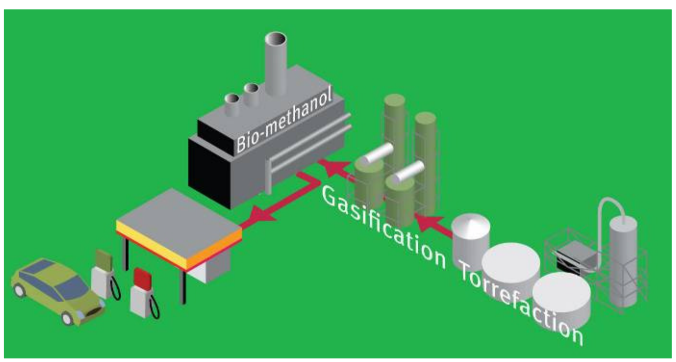
Torrefaction pilot-plant testing (50-100 kg/h)

BO_2GO demonstration plant



- Location: Delfzijl, the Netherlands
- Capacity:
  - Input: 130,000 tonne – 170,000 tonne/a
  - Output: 70,000 tonne/a
- Start-up: 2010

BioMCN
methanol production



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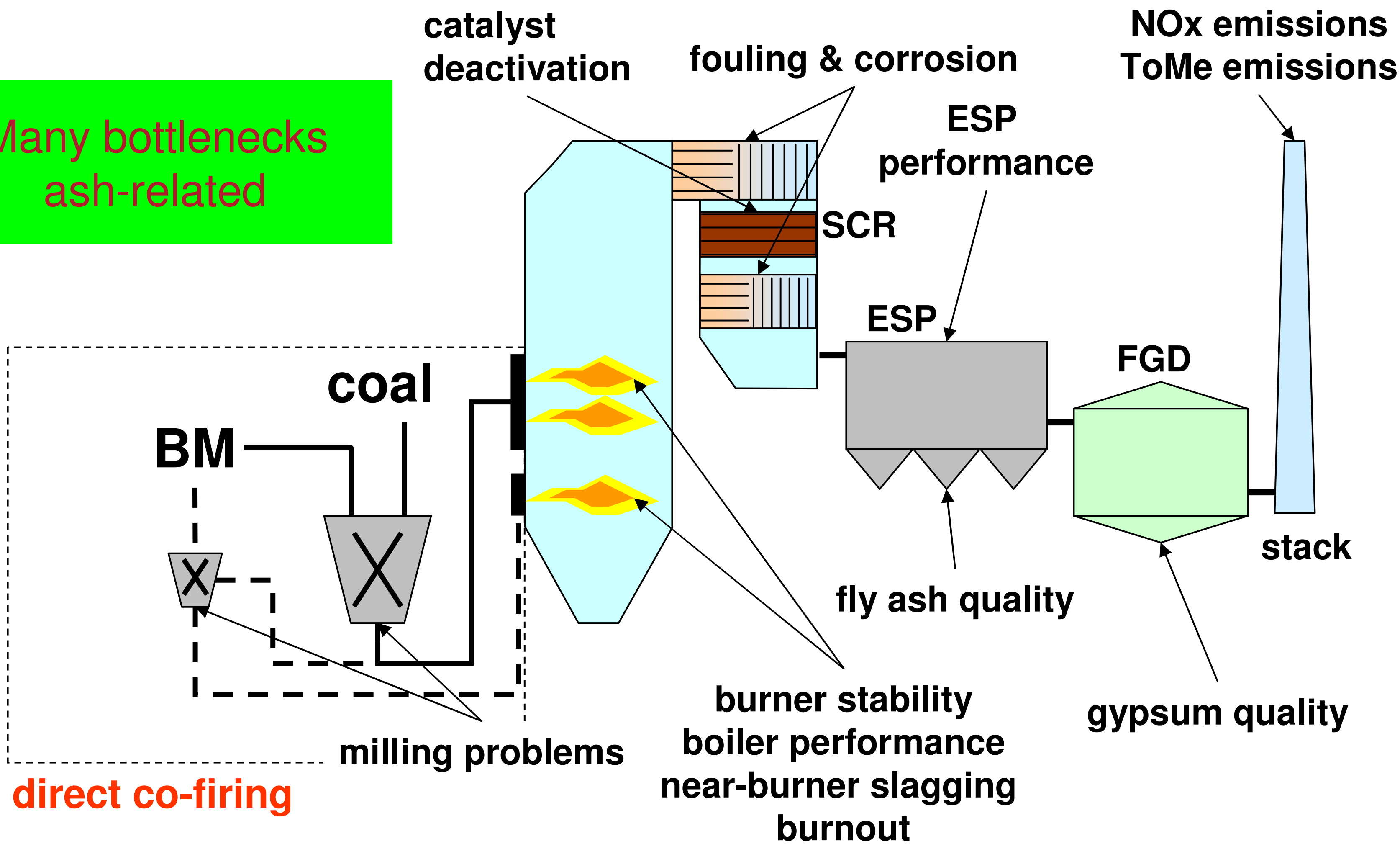
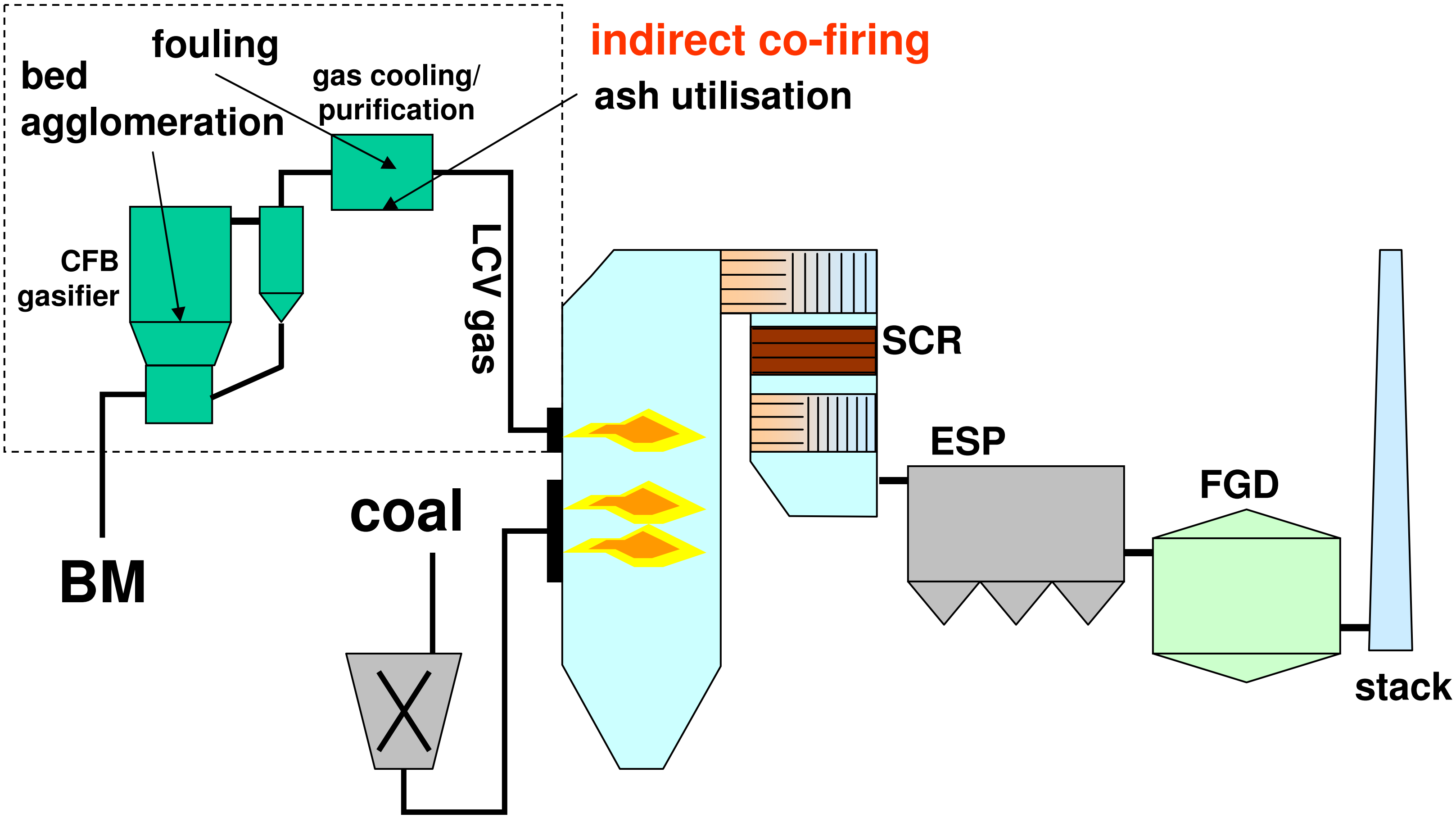
Technical bottlenecks

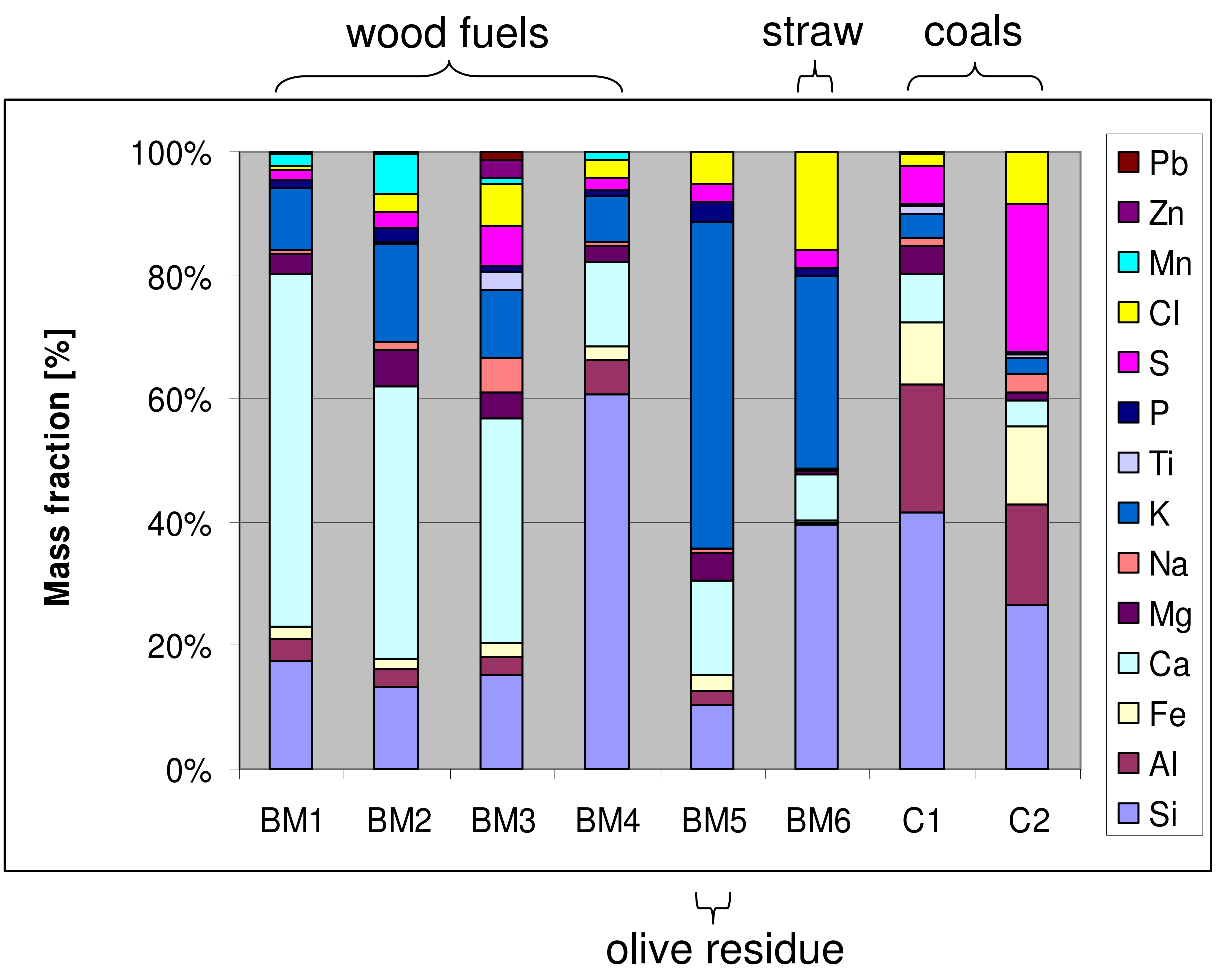
Many bottlenecks ash-related



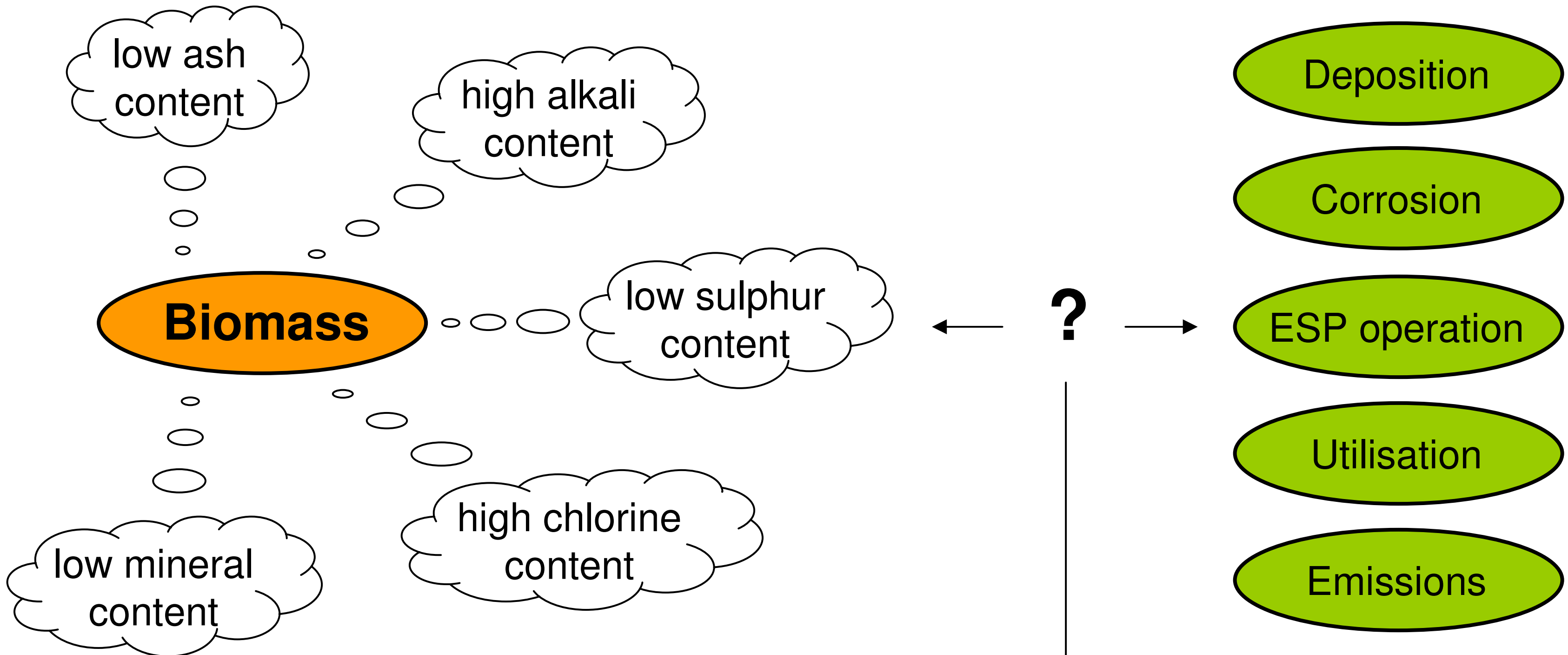
Technical bottlenecks



Ash forming elements in biomass vs. coal

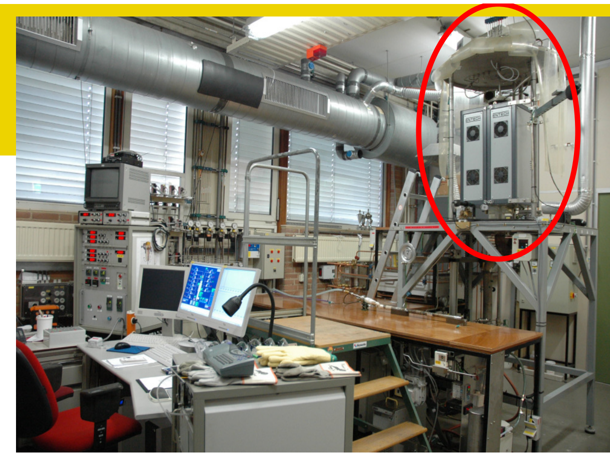


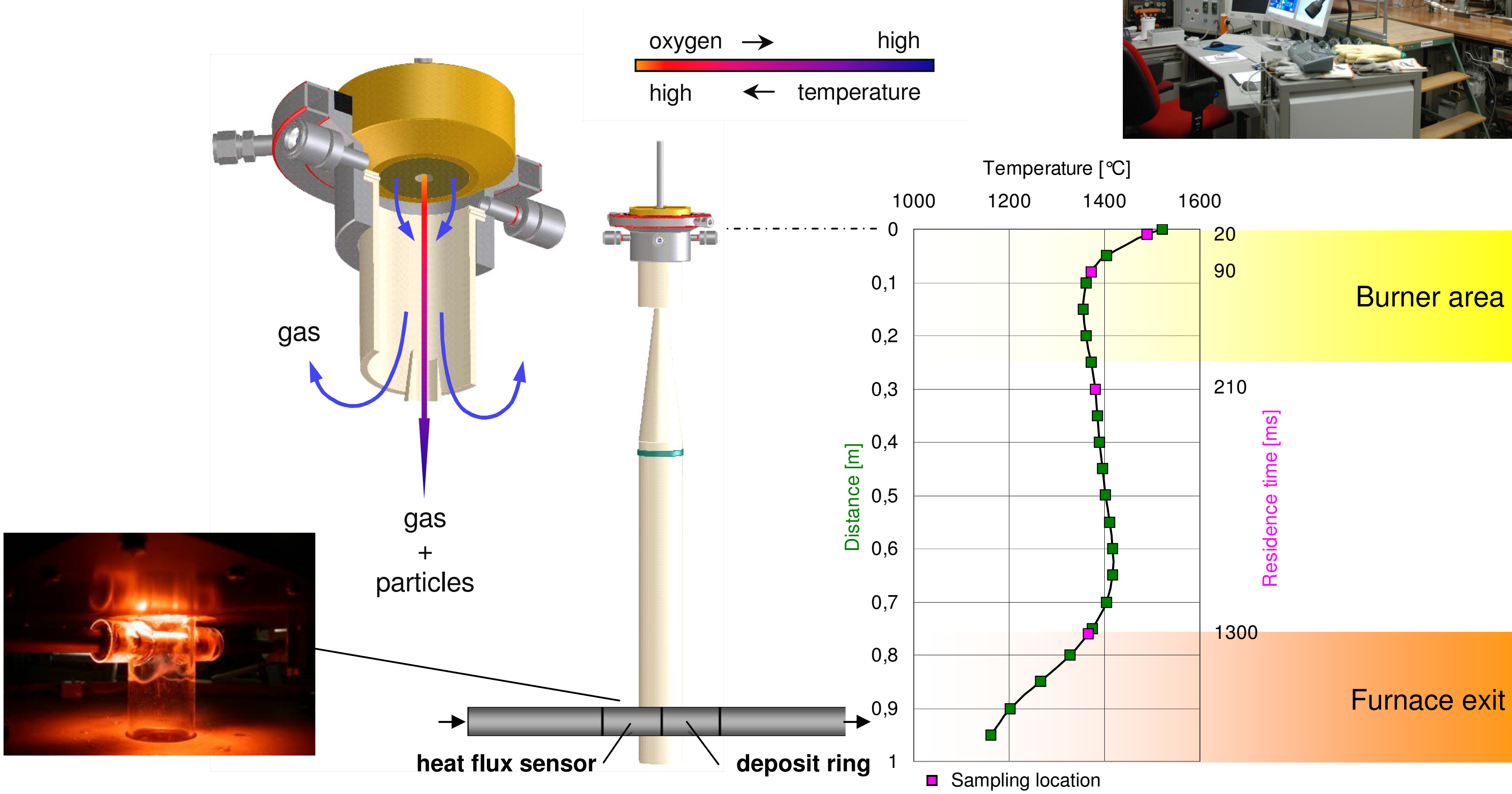
Ash related issues to consider for a 'typical' biomass



Answers lie in ash formation !

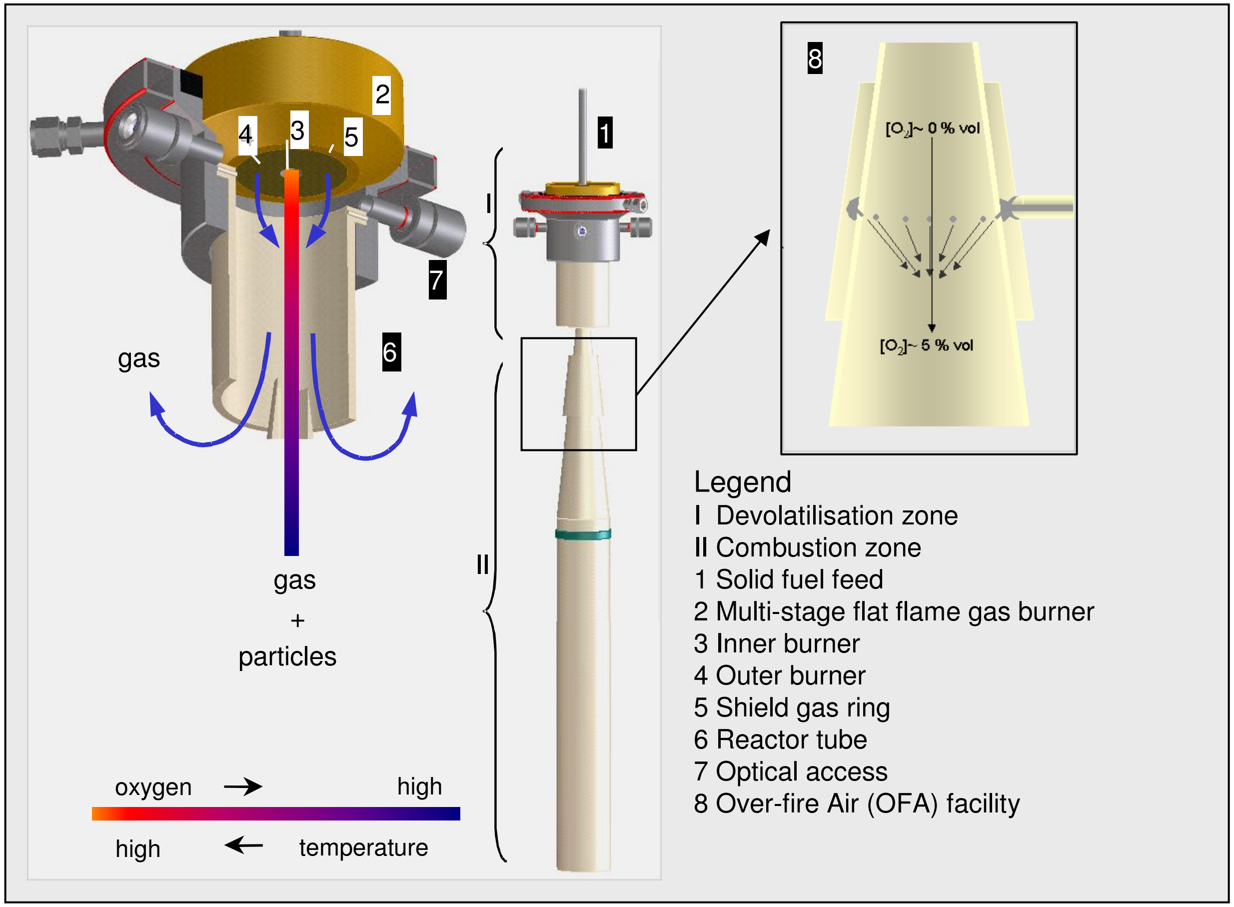
Lab-scale Combustion Simulator (LCS)





Realistic gas temperature and gas composition profiles, sampling 5-2500 ms

Lab-scale Combustion Simulator (LCS)

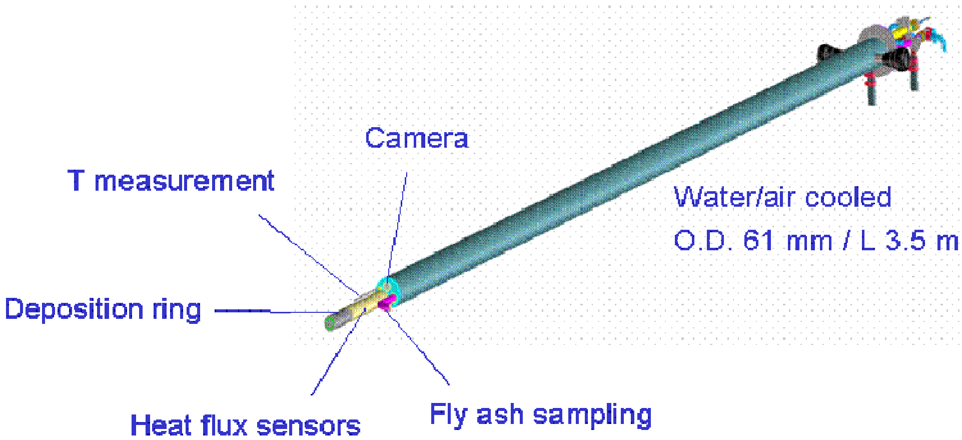


Entrained-flow reactor with integrated, premixed and multi-stage flat flame burner

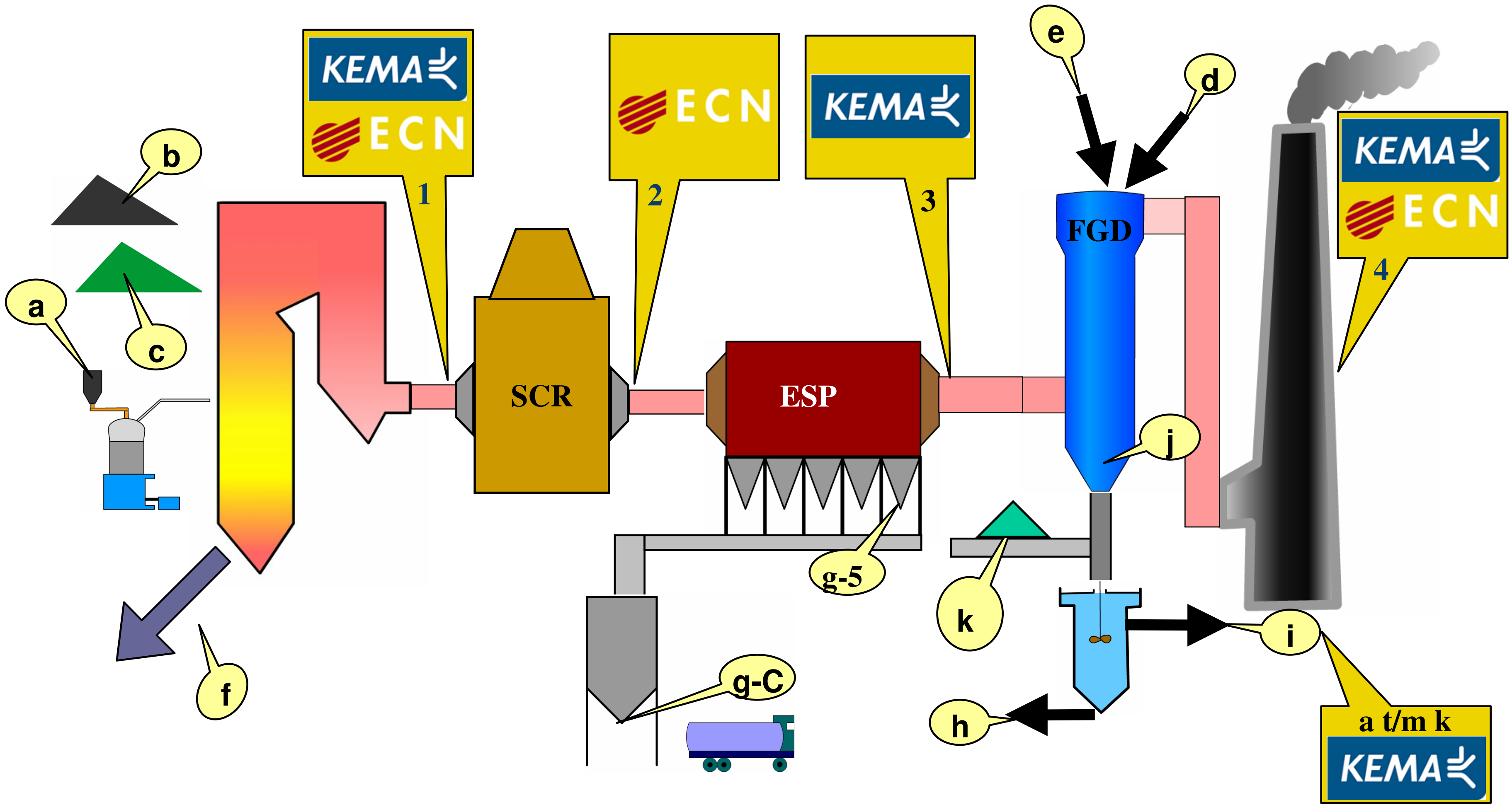
- high particle heating rates
- high flame/particle temperature
- realistic gas temperature / environment history
- Controllable, long particle residence time

Full-scale probe measurements

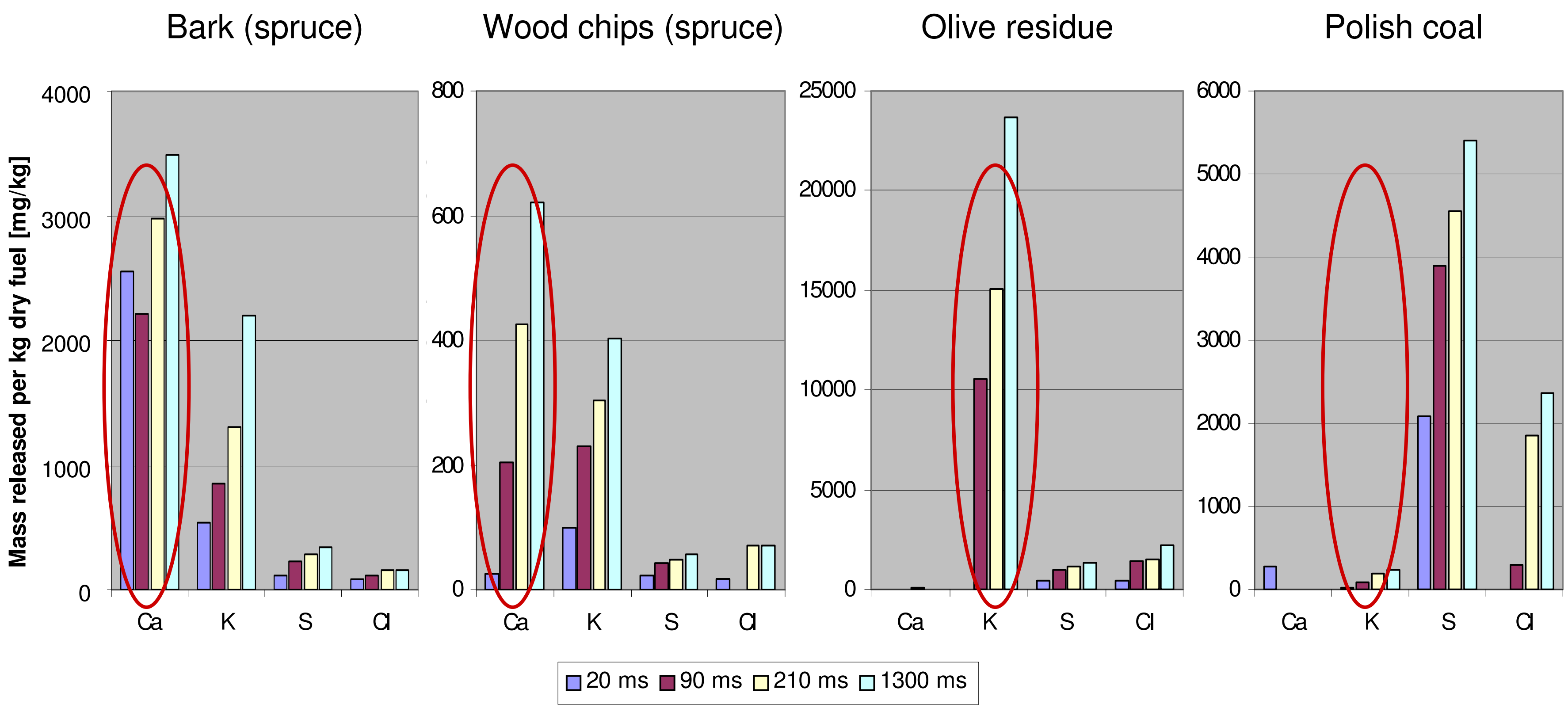
ECN mobile heat flux & ash deposition probe



Full-scale mass-balance measurements

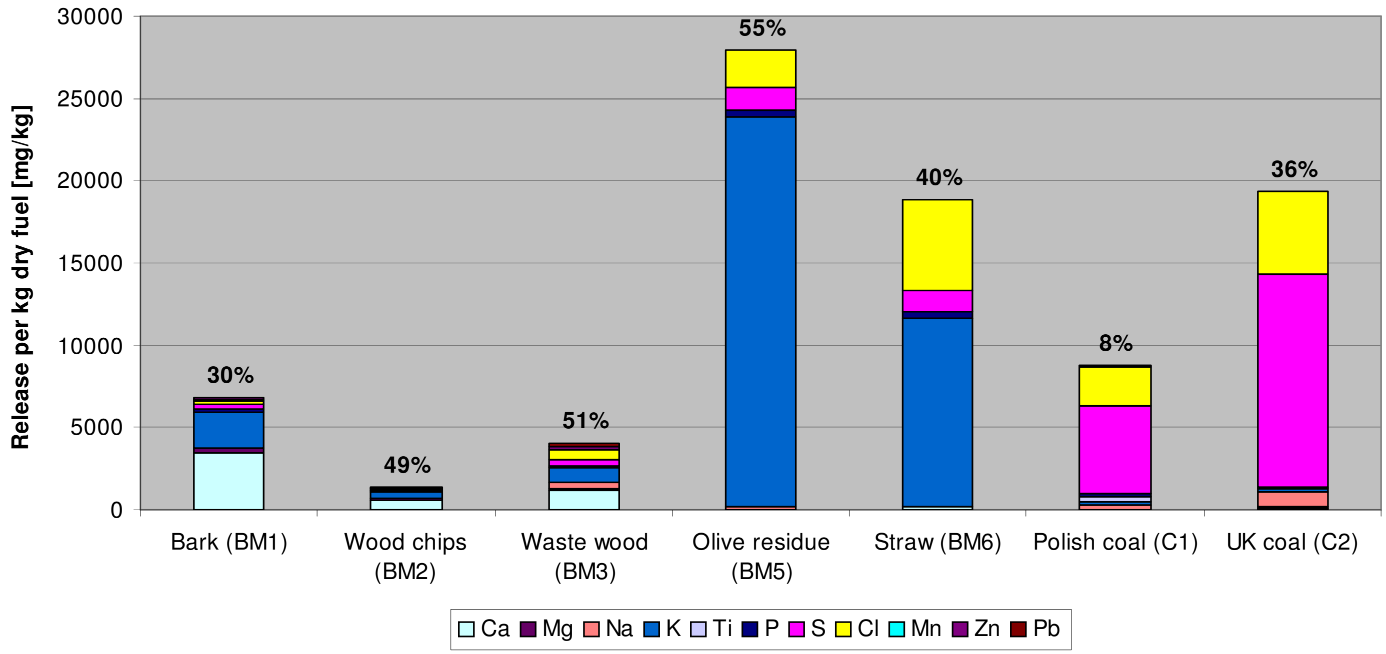


Ash release results – top-4 elements



mineral calcium organic calcium potassium salt mineral potassium

Comparison of ash release between fuels



Release biomass very different from coal:

– total release biomass 30-55% (incl. S and Cl)

– total release coal 0.3-2.6% (excl. S and Cl) or 8-36% (incl. S and Cl)

Release behaviour in MBM co-firing

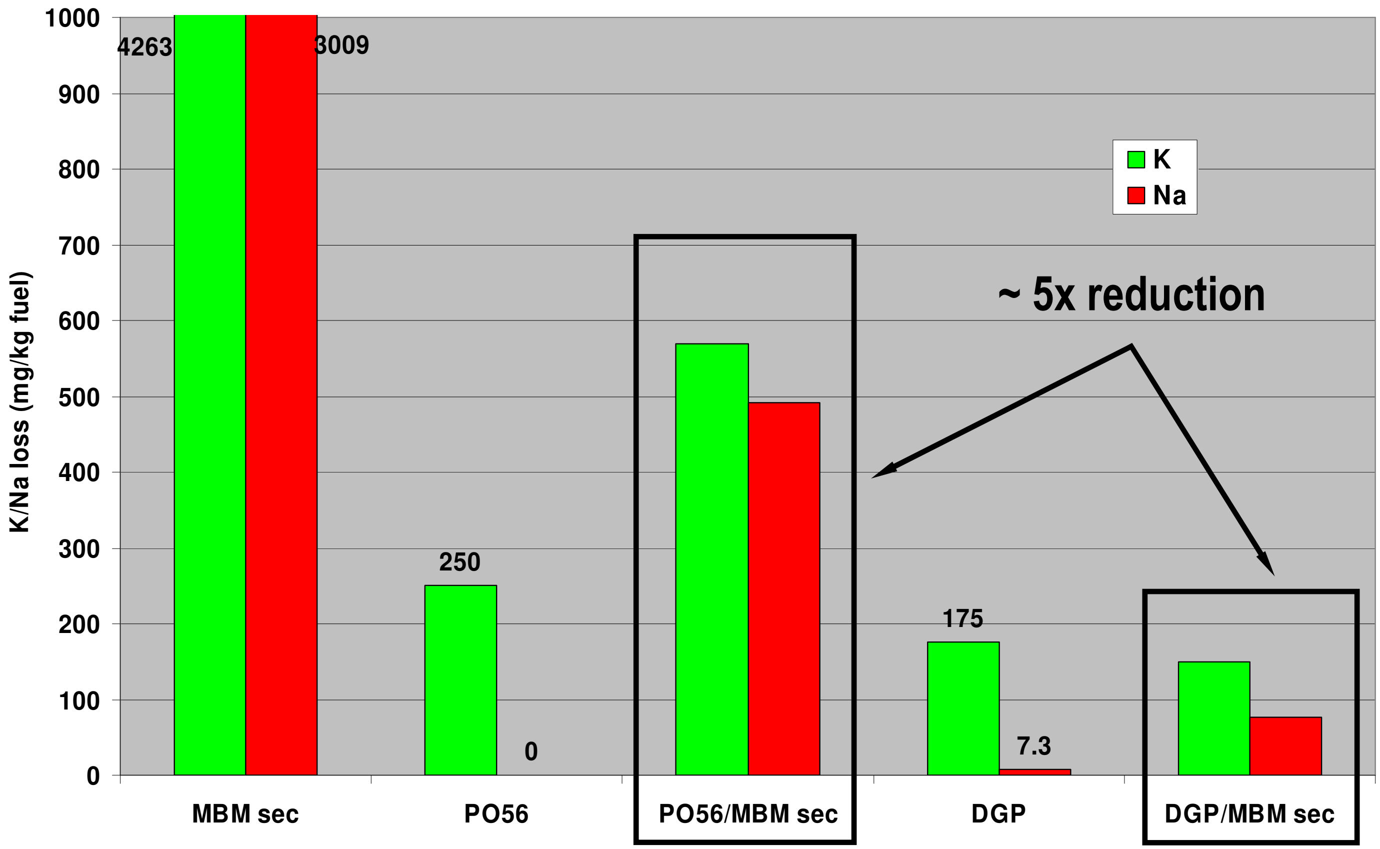
Alkali metals in MBM significantly increase risk of corrosion and fouling.
Can coal non-alkaline clay minerals interact with alkalis in MBM?

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

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

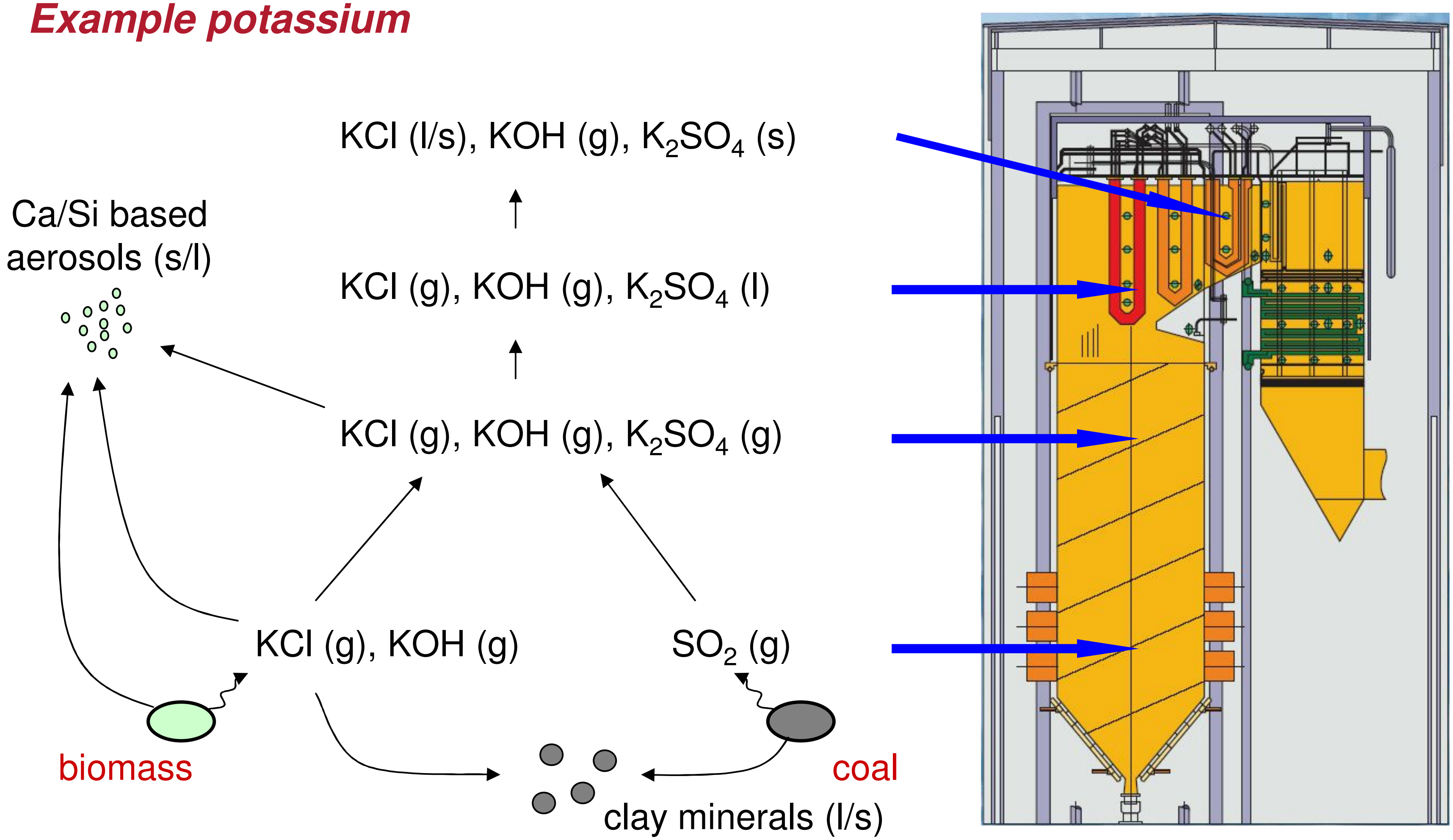
Release behaviour in MBM co-firing

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

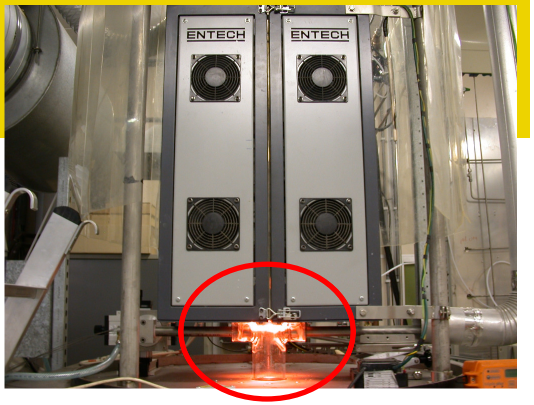


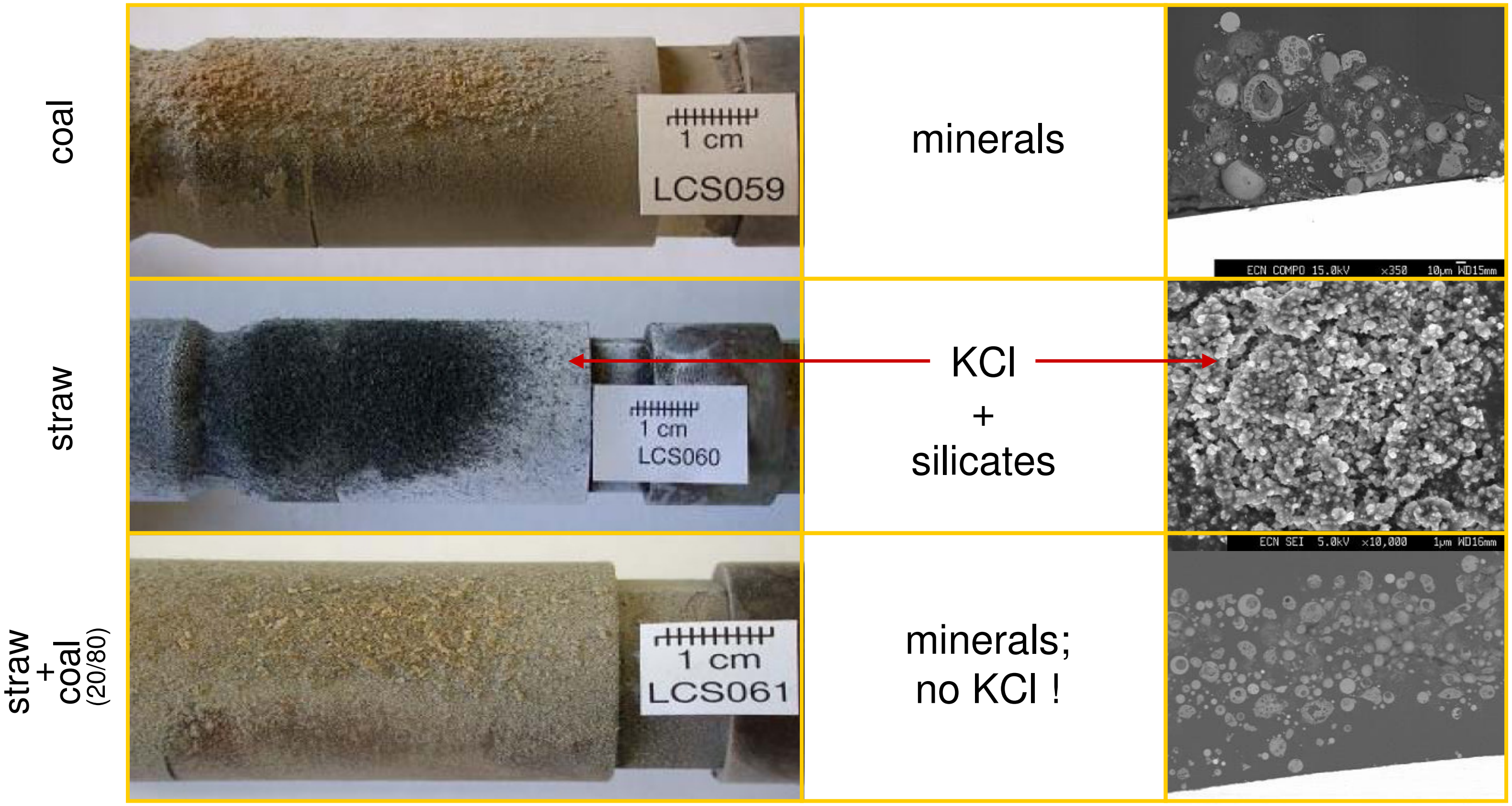
General understanding of fuel interactions

Example potassium



Interactions demonstrated in ash deposition

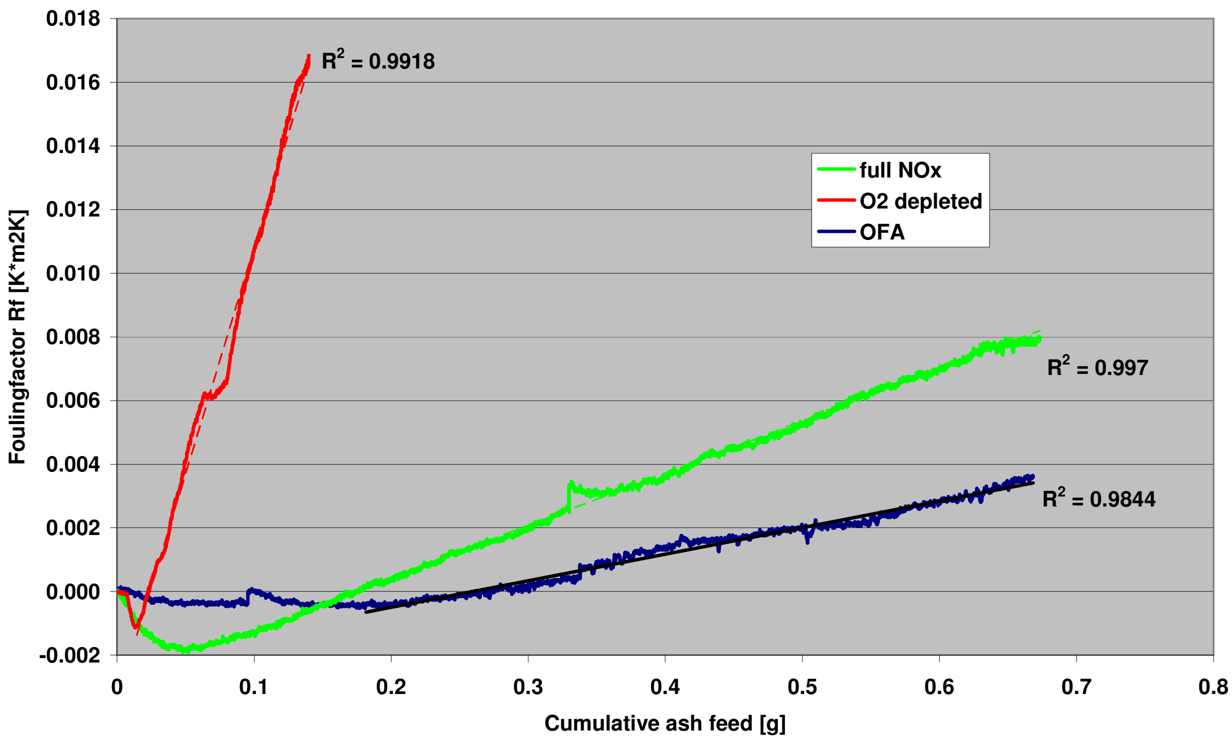




Impact deposition on heat transfer – fouling factor

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

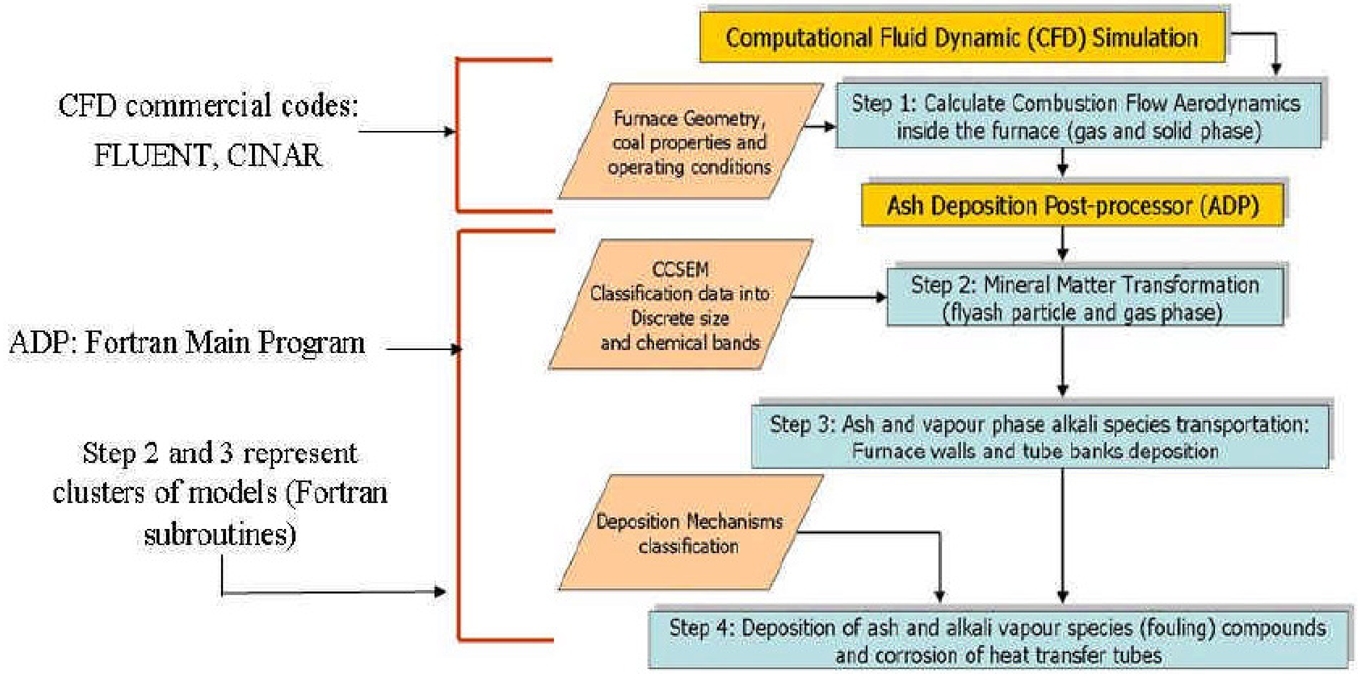
Fuel: MVC + olive residue



mass ≠ thickness ≠ fouling factor!

Predictive tools – aggregating mechanistic knowledge

- Low-cost screening
- Biofuel impact prediction (empirical modelling, esp. ash-related)
  - release, formation, properties, deposition, quality, emission
- Ash Deposition Post-Processor (CFD-based)

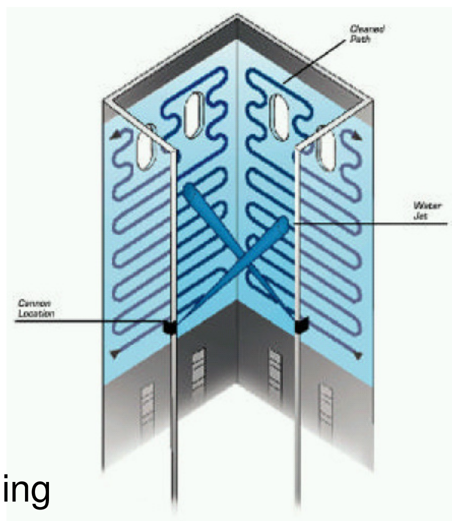


On-line deposition monitoring and control

- Membrane walls: heat flux measurement + water canons (Clyde Bergemann)
- Super-/reheaters: section-wise evaluation using cleanliness factors (ratio of actual vs theoretical heat transfer rate, e.g. ABB system)

Technology challenge: direct monitoring (and control) of super-/reheater fouling

Heat flux measurement



Water canon cleaning

Clyde Bergemann system

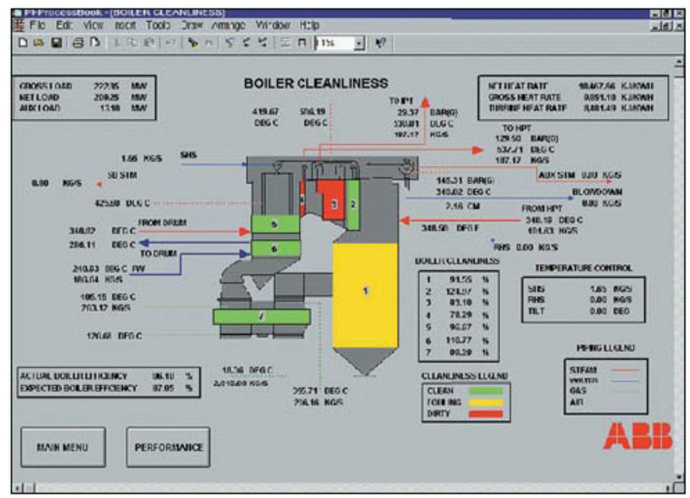
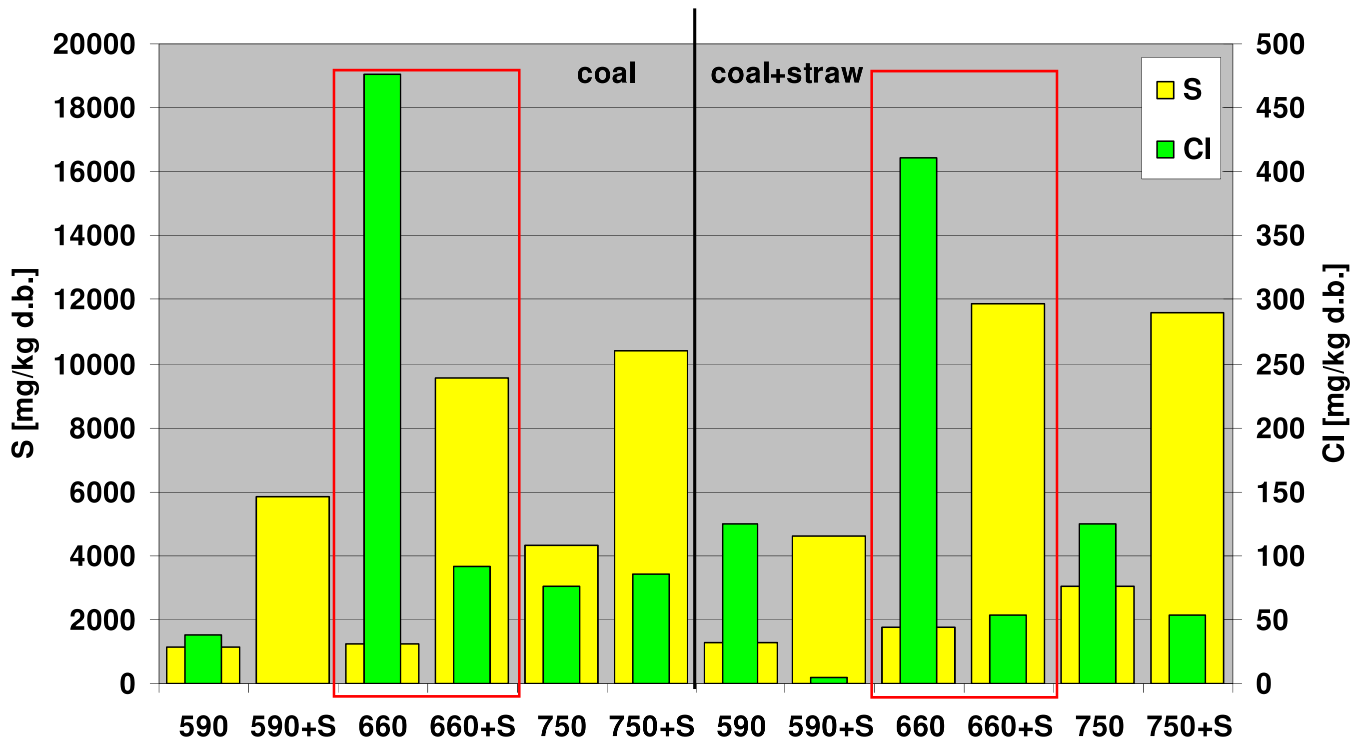


ABB system

Fouling under USC conditions

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



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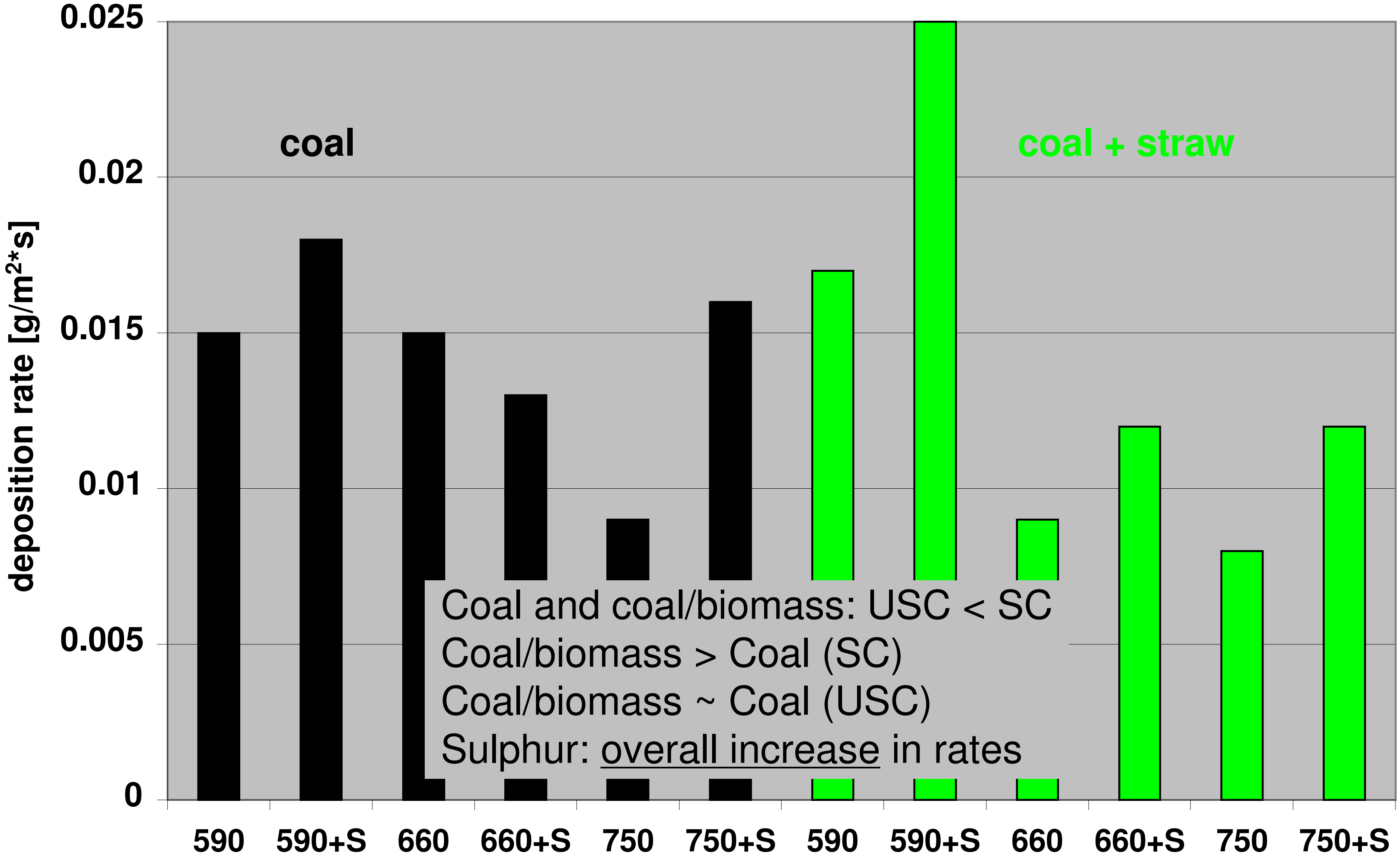
Lab-scale ash deposition (USC conditions)



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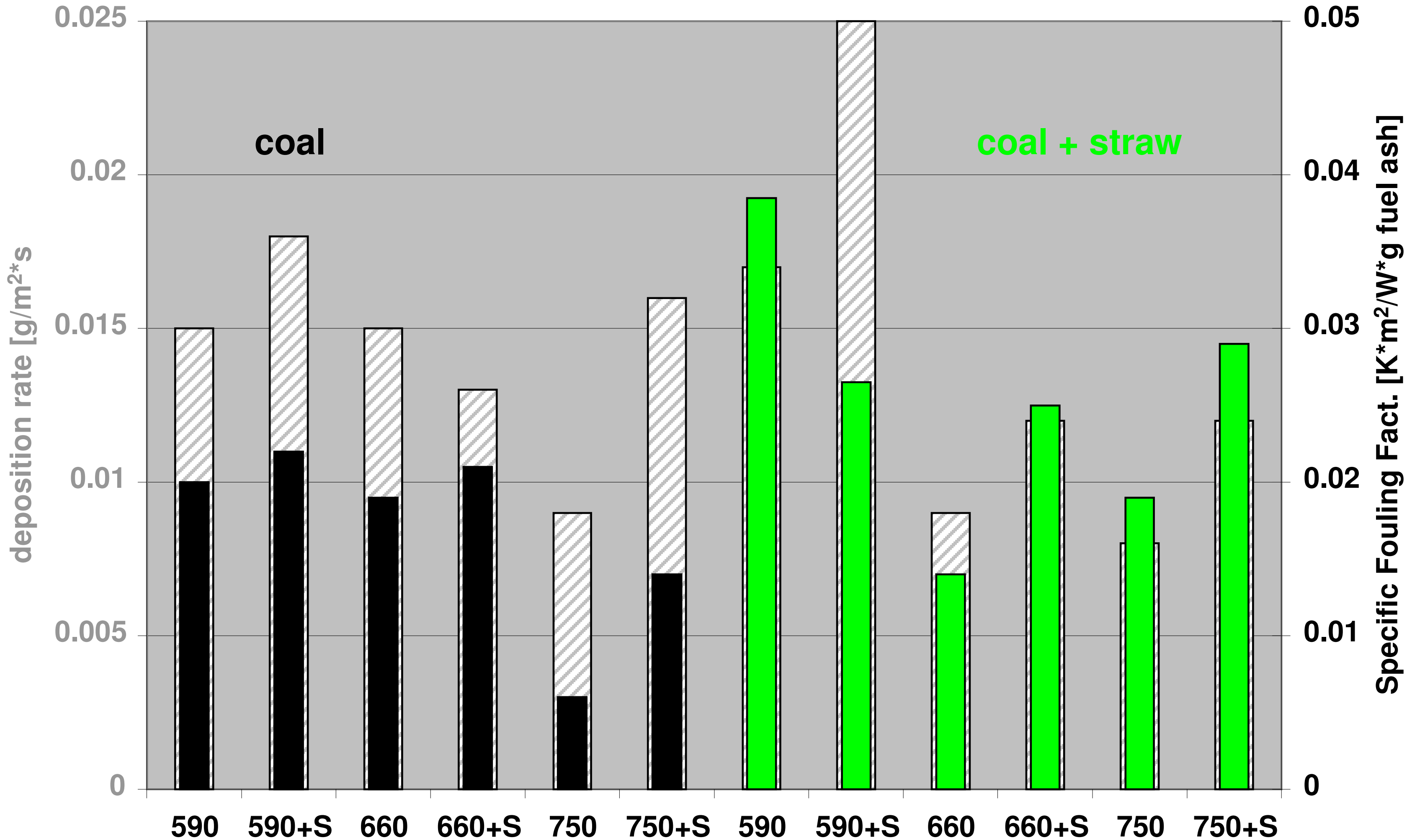
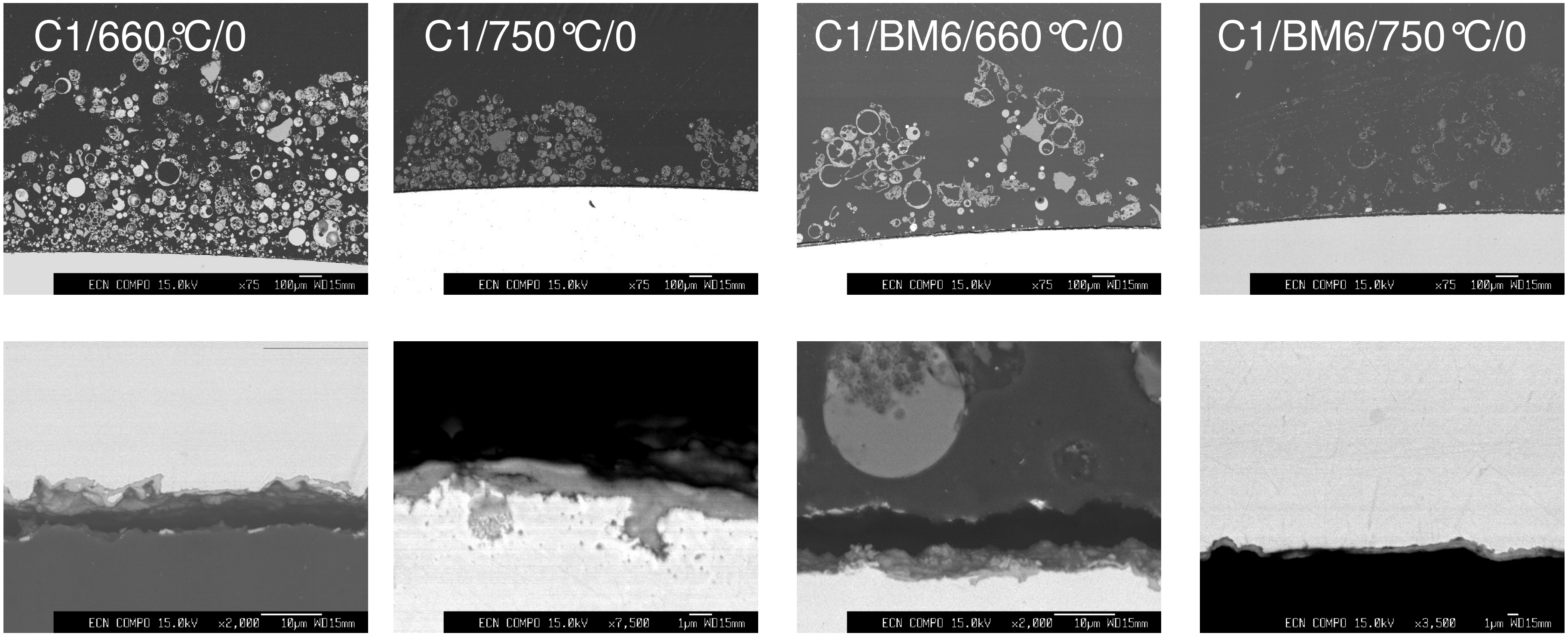


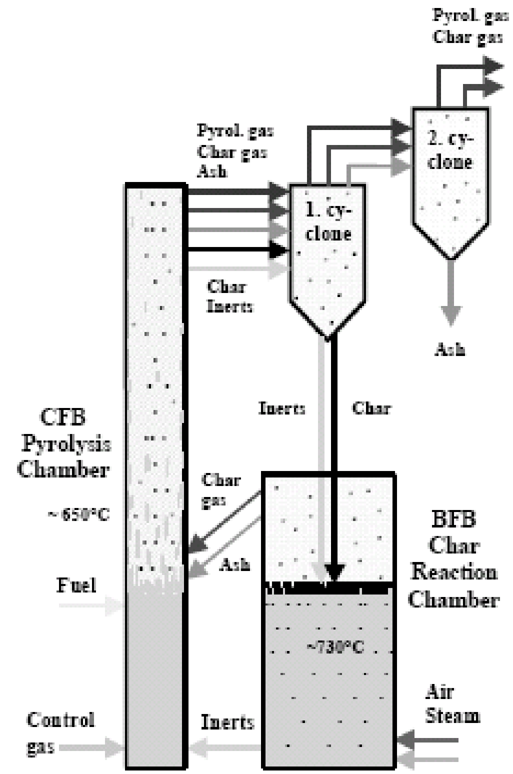
Lab-scale ash deposition (USC conditions) – initial corrosion



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

Biomass co-firing – new challenges

- Biomass should be sustainable and certified
- Biomass is scarce and costly → maximise efficiency → optimise heat utilisation
- Other biomass applications with higher added value → low quality biomass for co-firing (e.g. high alkali/chlorine content) → Low-temperature gasification (650 °C)
- Large, increasing fraction of wet biomass → need for special upgrading technology



Source: Peder Stoholm

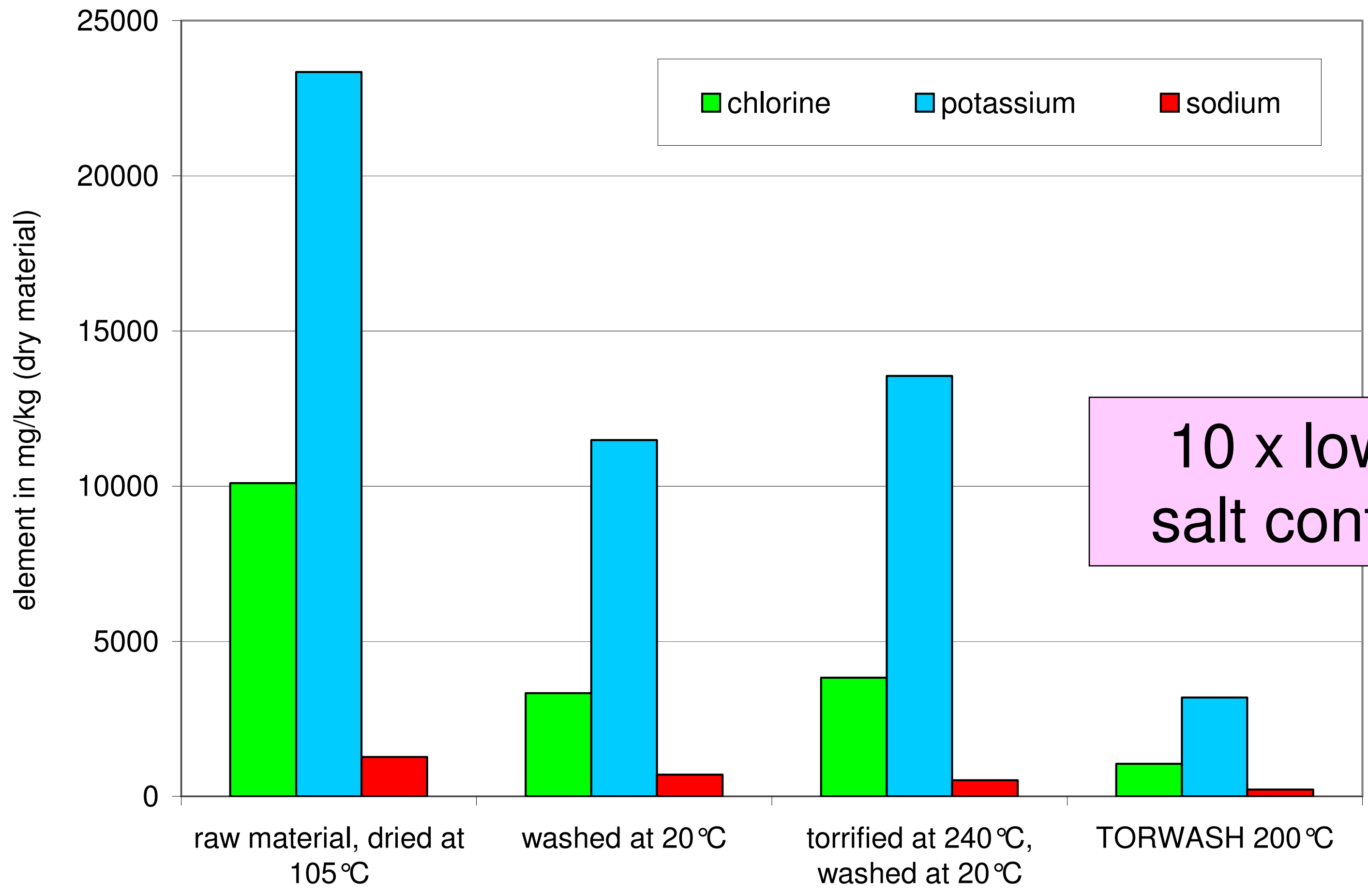
Increasing amounts of wet biomass: TORWASH?

E.g. residues from wet/biochemical biomass processing and aquatic biomass

TORWASH = Torrefaction + Washing + Drying

- Salt removal (K, Na, Cl, SO_4)
  - better ash quality → utilisation instead of land fill
- Torrified product
  - energy densification, logistics, etc.
  - chemical conversion makes biomass water repellent
- Dry biomass
  - higher caloric value

TORWASH (hay)



10 x lower salt content

Concluding remarks

- Biomass co-firing is established technology for co-firing percentages up to 10-20% (e/e)
- Biomass co-firing at high percentages (30-50% e/e) is feasible, but needs/highly benefits from:
  - Innovative biomass upgrading technology
  - Better mechanistic understanding of technical bottlenecks
  - Better predictive tools
  - On-line monitoring and control (e.g. fouling, corrosion)
- Torrefaction + pelletisation allows cost-effective, high-efficiency production of commodity biomass fuels with superior logistic and conversion properties
- Many technical bottlenecks in biomass co-firing are ash related. Main mechanisms of ash formation and ash behaviour have been mapped. R&D focus now on quantification and incorporation of mechanistic knowledge in predictive tools
- Combination of predictive tools and on-line monitoring is key to successful management of ash behaviour
- New challenges in biomass co-firing include sustainability, heat utilisation, lower quality ("salty") biomass, wet biomass

Thank you for your attention!

For more information,
please contact:

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