Safety/Environmental Considerations of Using Waste Streams for Energy Generation

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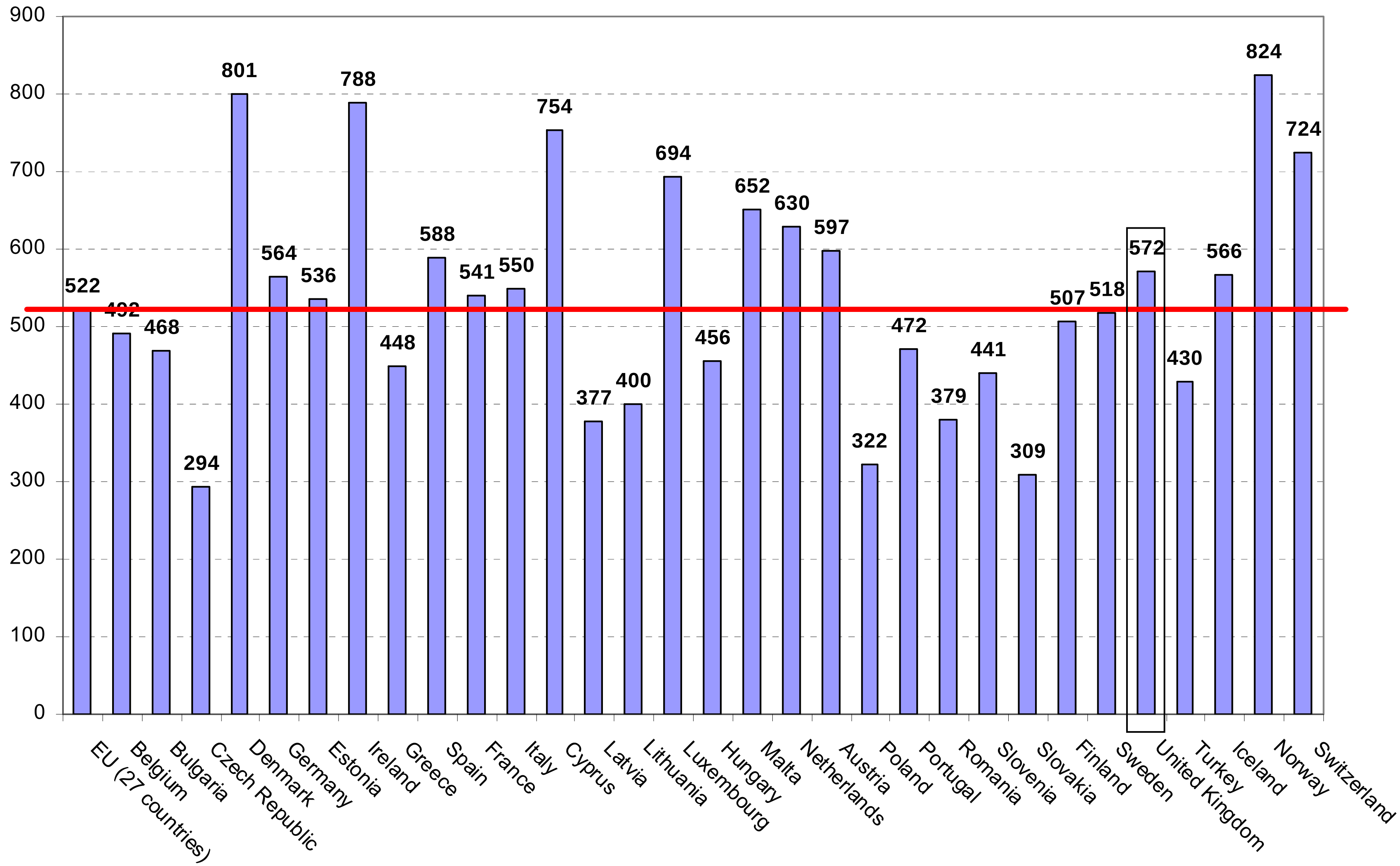
Municipal waste generated - Kg per person per year (2007)



http://epp.eurostat.ec.europa.eu

Typical values of energy content of residential MSW

Source: Tchobanoglous *et al.* pp. 84

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	Inert Residue percent		Energy kJ/kg
Component	**Range**	**Typical**	**Typical**
Organic			
Food wastes	2-8	5	4600
Paper	4-8	6	16700
Cardboard	3-6	5	16200
Plastics	6-20	10	32400
Textiles	2-4	2.5	17360
Rubber	8-20	10	23150
Leather	8-20	10	17360
Yard waste	2-6	4.5	6480
Wood	0.6-2	1.5	18500
Misc. organics	-	-	-
Inorganic			
Glass	96-99	98	140
Tin cans	96-99	98	690
Aluminium	90-99	96	-
Other- Metal	94-99	98	690
Dirt, ashes, etc.	60-80	70	6900
MSW			**11600**

Advanced Waste Thermal Treatment Technologies (AWTTT)

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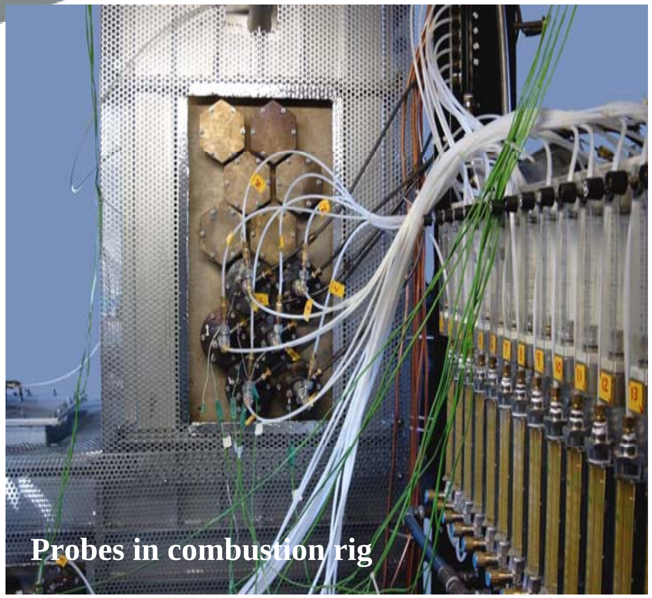
FBC base


Probes in combustion rig


Fluidised bed combustion rig

Advanced Waste Thermal Treatment Technologies (AWTTT) are considered as the modern means for energy recovery in the waste management hierarchy.

Solid Recovered Fuels (SRF)

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The quality of the waste feedstock though is as, or more, important than AWTTT and was standardised for waste fuels under the term **Solid Recovered Fuels (SRF)** (DD CEN/ TS 15359, 2006).

Mastering the heterogeneous nature of waste through MBT to produce a fuel with quality assured levels of calorific value, chlorine and mercury content.

What is SRF?

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SRF is a waste derived fuel produced from the pre-treatment of MSW or commercial and industrial waste in a mechanical biological treatment (“MBT”) plant, autoclave or other intermediate technology processing facility.

Materials balance in a typical MBT plant

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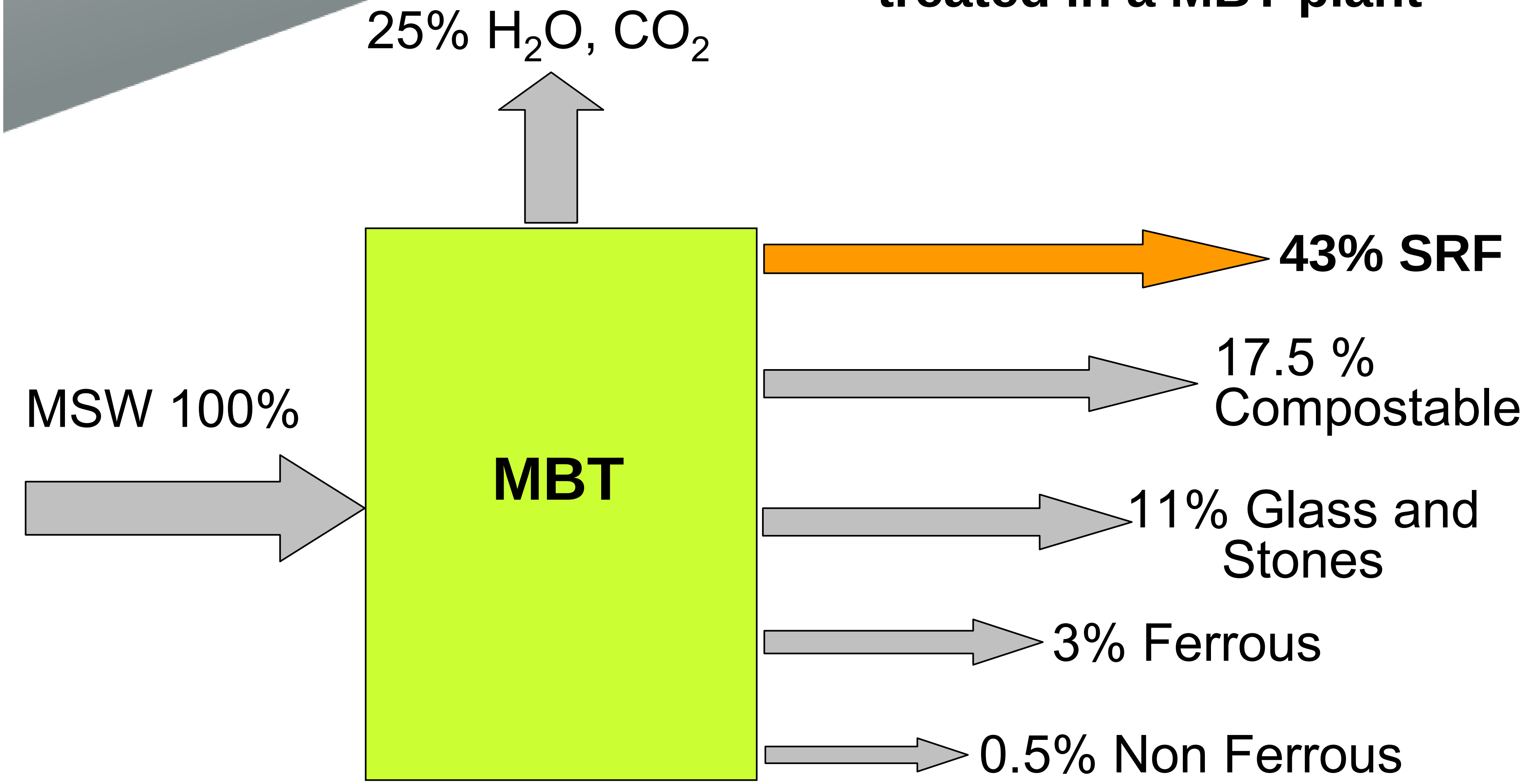
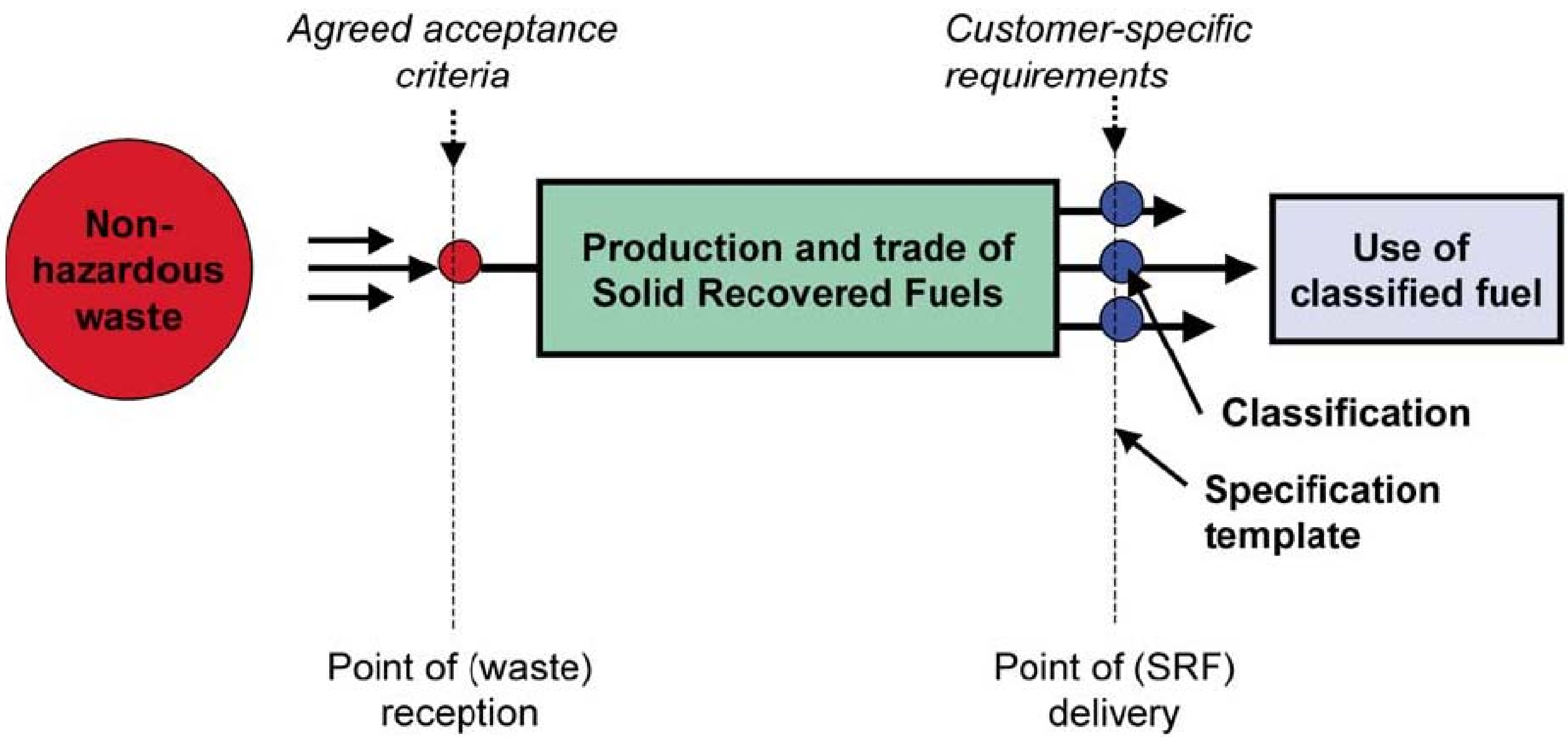
100 tonne sample of MSW treated in a MBT plant



http://www.defra.gov.uk/environment/waste/wip/widp/documents/chp-information-note090127.pdf

Solid Recovered Fuels

Flexibility exists within MBT plants to alter the composition of SRF to meet the requirements of end users.



Source: CEN/TS 15359:2006

Why is there a need for a SRF Standard?

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British Standards Institute has issued CEN/TS 15359 as a draft standard

"Solid fuel prepared from non-hazardous waste to be utilised for energy recovery in incineration or co-incineration plants, and meeting the classification and specification requirements laid down in CEN/TS 15359 where "prepared" means processed, homogenised and upgraded to a quality that can be traded amongst producers and users."

Classification of SRF

Table 1 — Classification system for solid recovered fuels

Classification property	Statistical measure	Unit	Classes				
			1	2	3	4	5
Net calorific value (NCV)	Mean	MJ/kg (ar)	≥ 25	≥ 20	≥ 15	≥ 10	≥ 3

Classification property	Statistical measure	Unit	Classes				
			1	2	3	4	5
Chlorine (Cl)	Mean	% (d)	≤ 0,2	≤ 0,6	≤ 1,0	≤ 1,5	≤ 3

Classification property	Statistical measure	Unit	Classes				
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Mercury (Hg)	Median	mg/MJ (ar)	≤ 0,02	≤ 0,03	≤ 0,08	≤ 0,15	≤ 0,50
	80^{th} percentile	mg/MJ (ar)	≤ 0,04	≤ 0,06	≤ 0,16	≤ 0,30	≤ 1,00

Example of classification:

The class code of a SRF having a mean net calorific value of 19 MJ/kg (ar), a mean chlorine content of 0,5 % (d) and a median mercury content of 0,016 mg/MJ (ar) with a 80^{th} percentile value of 0,05 mg/MJ (ar) is designated as:

Class code NCV 3; Cl 2; Hg 2.

Source: CEN/TS 15359:2006

Layout of a typical MBT plant

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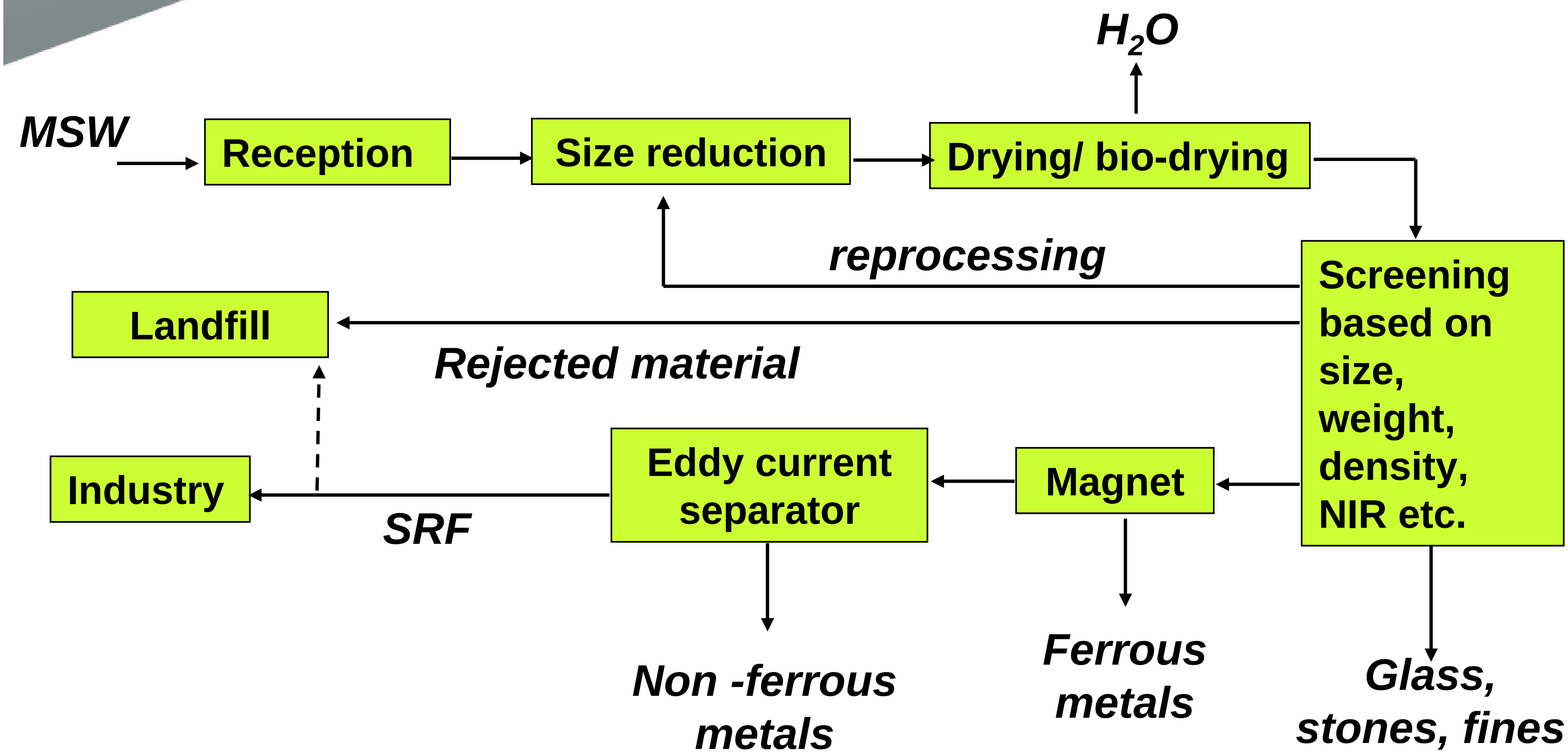

Coal vs SRF

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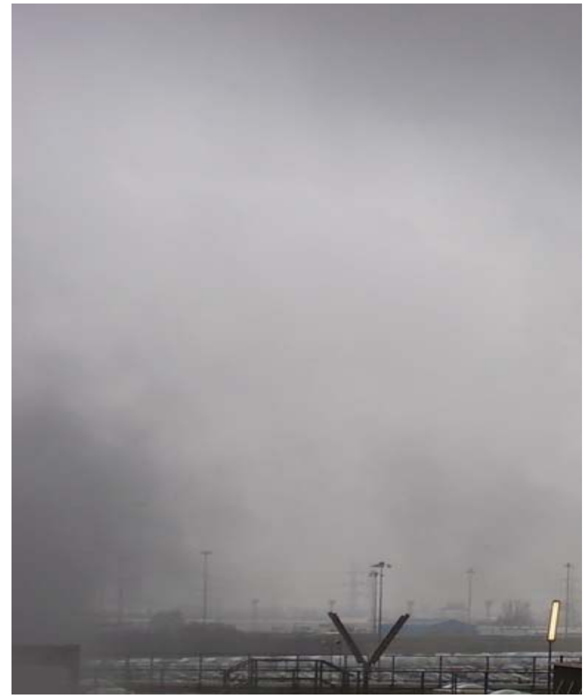
Typical characteristics

	SRF	Coal
NCV- MJ/ kg	18	31.5
Moisture w/w %	15	1.7
Ash w/w %	13	5
Bulk density kg/m^3	120	603
Chlorine w/w %	0.6	0.68

SRF co-firing case study: Garg *et al*., Waste Management, 2009

SRF issues



- Corrosion issues from the use of SRF
- Is it really a renewable fuel ?
- Transportation, storage, odour, safety issues
- Post treatment of thermal treatment residues
- Atmospheric pollutants

Chlorine as environmental and technological marker

- Part of several Persistent Organic Pollutants (POPs) like Poly Chlorinated Biphenyl's (PCB's) and Polychlorinated Dibenzodioxins/Furans (PCDD/ F's)
- Basic element of corrosive species like Hydrogen Chloride (HCl)
- Used as quality indicator for Solid Recovered Fuels (SRF)
- Used as legislative signpost for the characterisation of waste as 'hazardous'

Poly Chlorinated Biphenyl's (PCB's) and Polychlorinated Dibenzodioxins/Furans (PCDD/ F's)

- They are highly toxic to humans and animals
- They are persistent, lasting for years or even decades before degrading into less dangerous forms
- They evaporate and travel long distances through the air and through water
- They accumulate in fatty tissue

International Toxic Equivalent

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PCDD/Fs values are reported as Toxic Equivalent or International Toxic Equivalent (TEQ and I- TEQ respectively) due to the number of congener species (75 PCDD's and 135 PCDF's congener species, each differing in the number and position of the chlorine atoms)

At EU level, maximum air emissions from major industrial sources are set at 0.1 ng TEQ/m^3

Mechanisms for formation of dioxins and furans

- Already present in the fuel
- Formation during combustion
- ‘De novo’ formation in the post combustion chamber

McKay (2001)

Chlorine content of the feedstock

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The chlorine content of the feedstock has a direct relation with the amount of the specific pollutants.

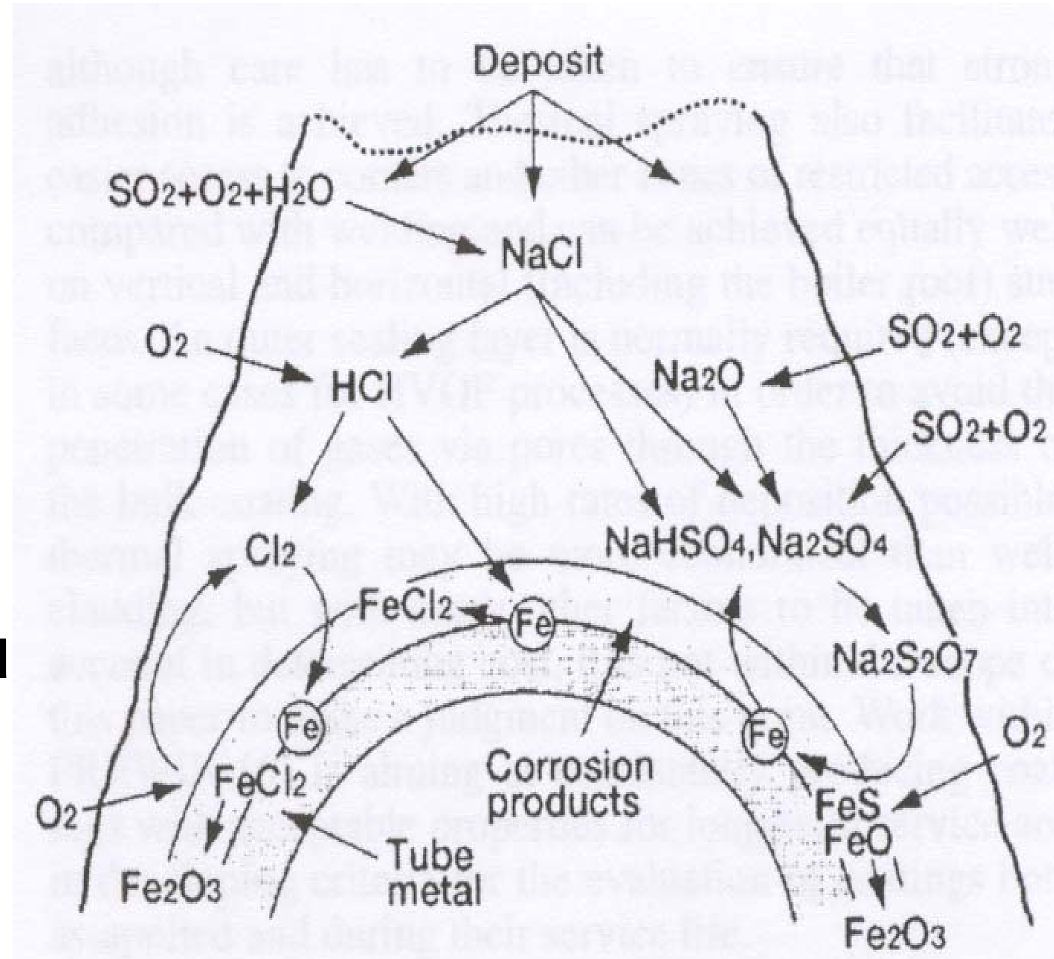
The correlation of PCBs and PCDD/Fs with Cl content in the fuel is only confirmed for concentrations of the latter >1%

This might be due to the ‘memory effect’ especially in large scale incinerators, to the sensitivity of the PCDD/Fs capturing and detection methods, or even the sensitivity in the detailed analytical detection of chlorine in the original feedstock

Source: Wikstrom et al., 1996

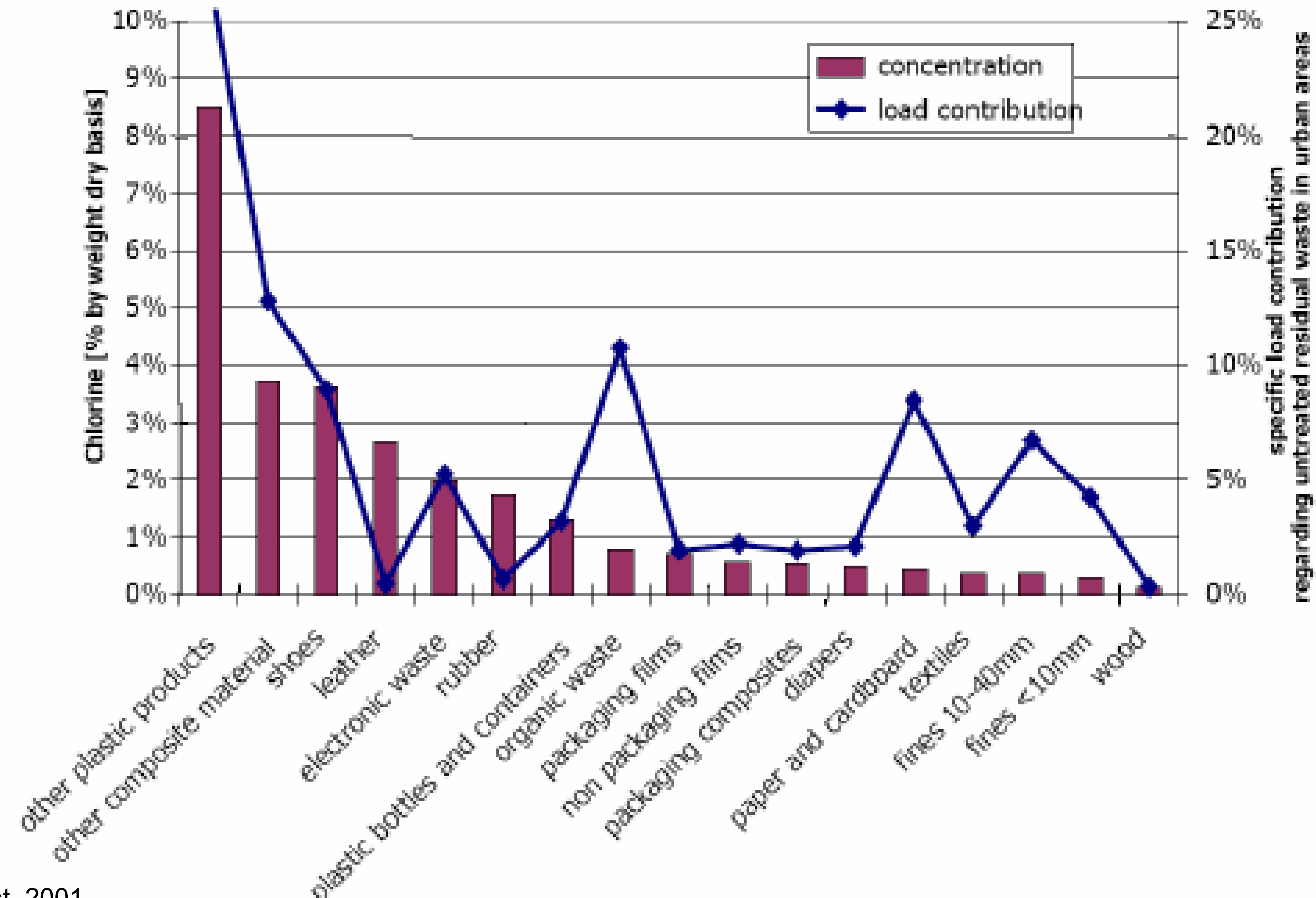
Inorganic chlorides and corrosion

- **Gaseous corrosion by HCl**
  (active oxidation)
- **Hot or high temperatu corrosion**
  (deposits corrosion)
- **Dew point corrosion**



Source: Fordham et al., 2002

Chlorine concentration and specific load in MSW fractions



Source: Kost, 2001

Project overview

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- Chlorine behaviour (phases, partitioning and speciation) using real waste derived fuel with quality assured knowledge over its properties
- Pilot plant conditions
- Comparative investigation between combustion and gasification based on chlorine analysis

SRF
NCV 3, Cl 2, and Hg 1

SRF composition

	Mean % wt dm	Standard deviation
C	47.44	4.27
H	5.75	2.91
N	0.81	0.36
S	0.15	0.02
Cl	0.71	0.14
O	45.15*	-

Classification system for Solid Recovered Fuels

Classification property	Statistical measure	Unit	Classes 1	2	3	4	5
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Source: CEN/TS 15359, 2006

Moisture content: 13.2 ±1.5 %wt

Ash content: 13.7 ± 1.5 %wt

Material preparation

Combustion vs Gasification

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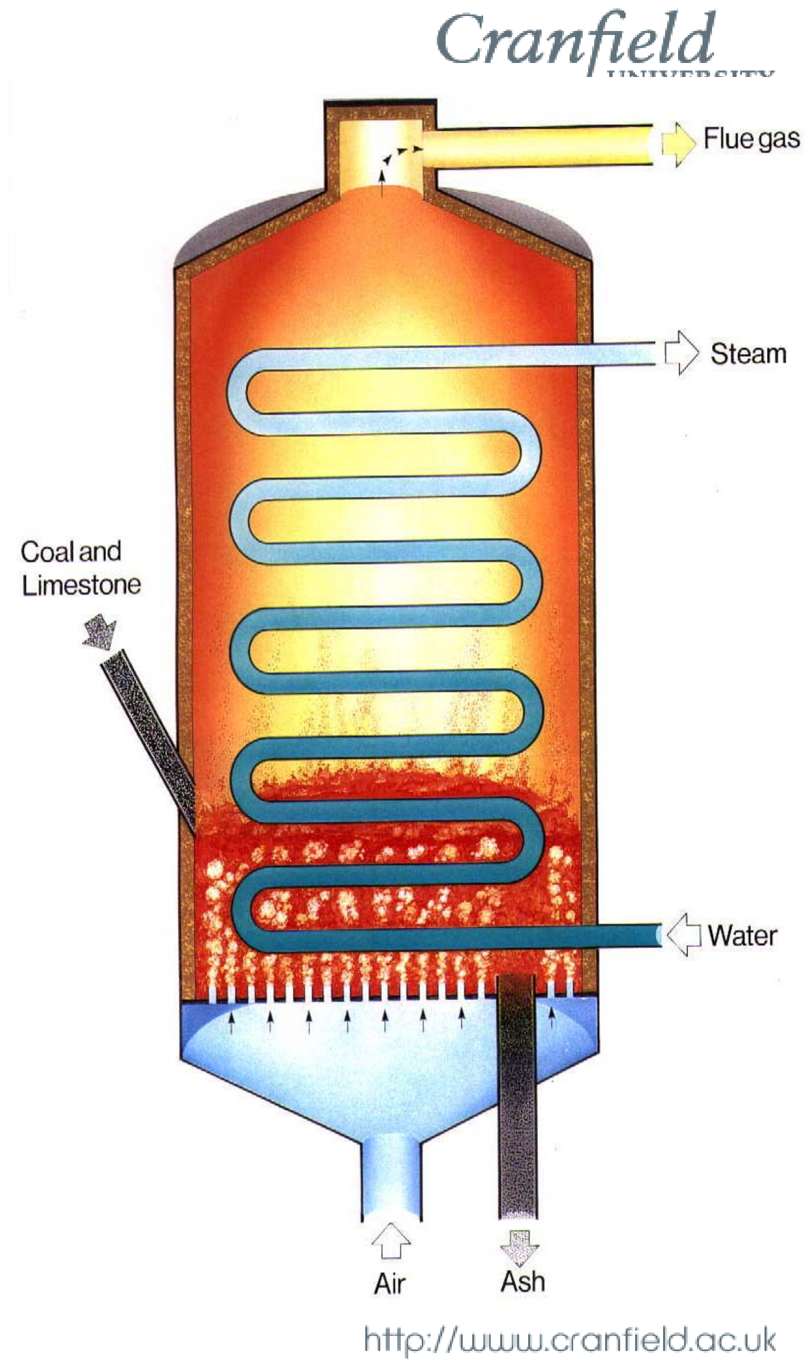
Fluidised bed combustion



Fluidised Bed Combustor

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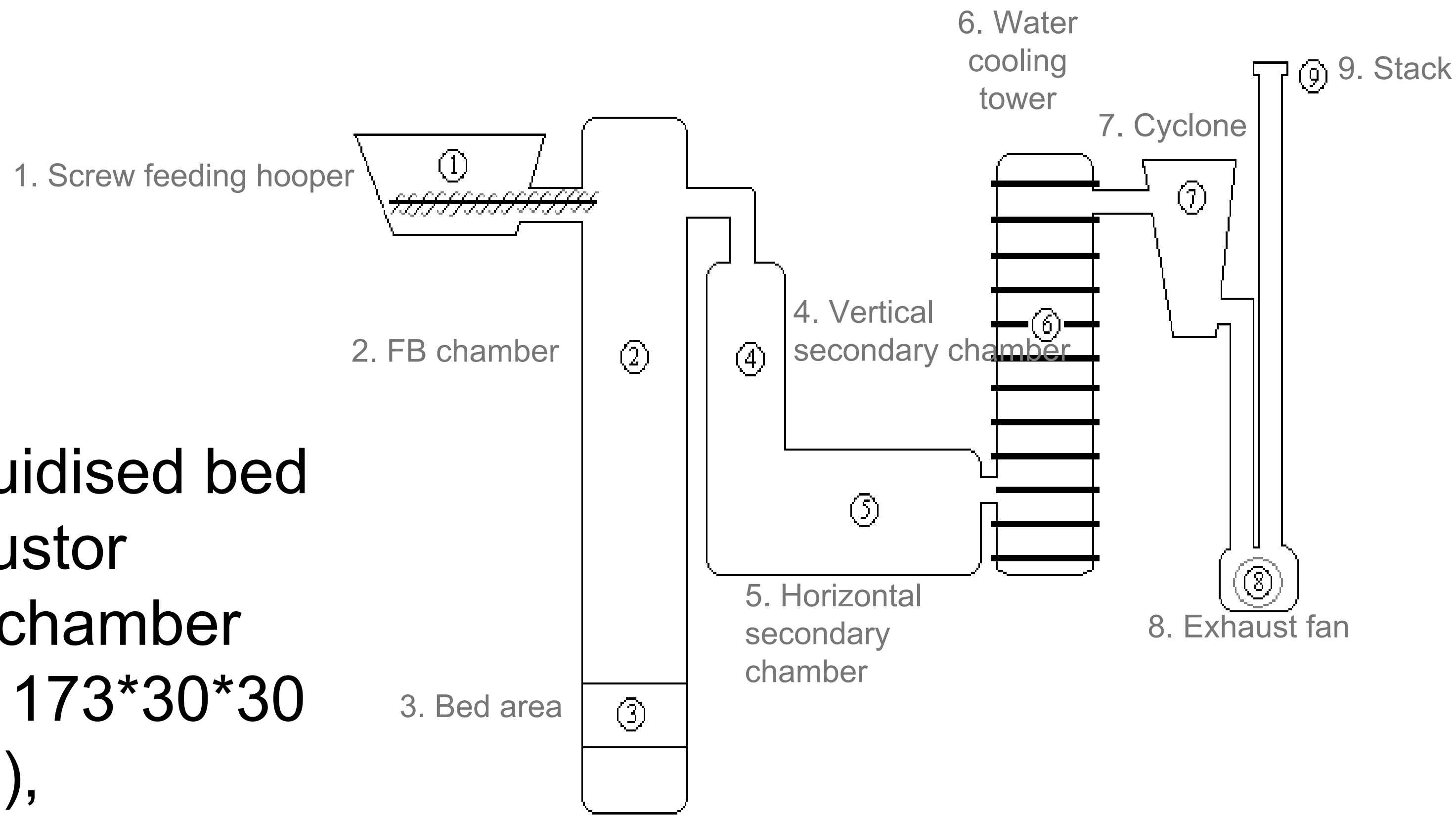

The 50kW fluidised bed combustor
Main bed chamber (dimensions 173*30*30 cm),

Fluidised Bed Combustor

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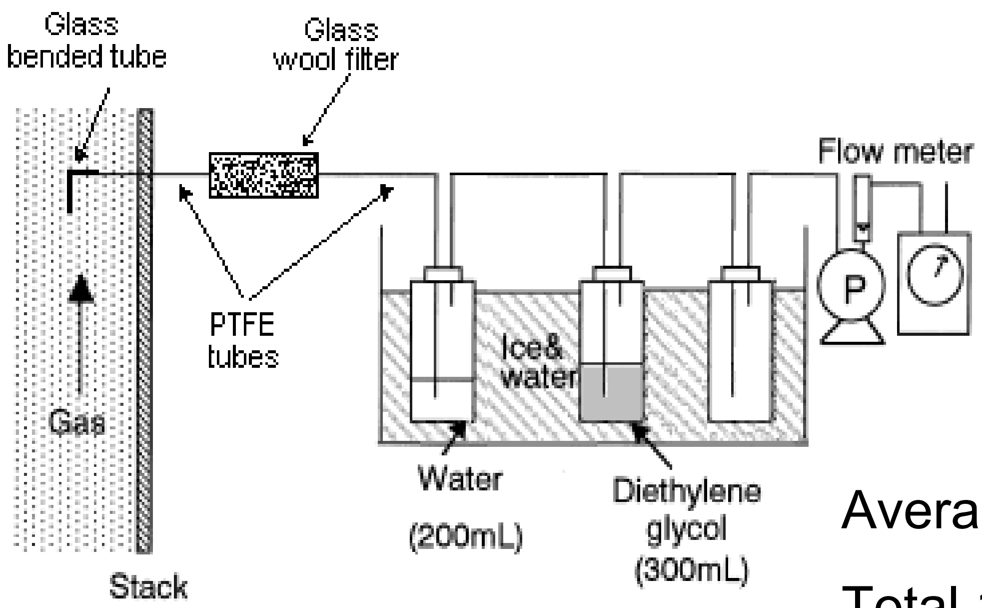
The bed area was filled with 30.2 kg of silica sand

The supply of primary, secondary air and natural gas before the SRF feeding was 450, 600 and 11.5 l/min respectively.
The SRF incoming flow 117g/min (mean value)
Lambda (λ) coefficient equal to 1.6

Combustion Time: 300 min
Target temperature 850˚C – average temperature 800 ± 20 ˚C

Gas phase analysis
Sampling train



Chlorobenzenes liquid extraction and GC - GC/MS analysis

Inorganic chlorine analysis – titration $AgNO_3$

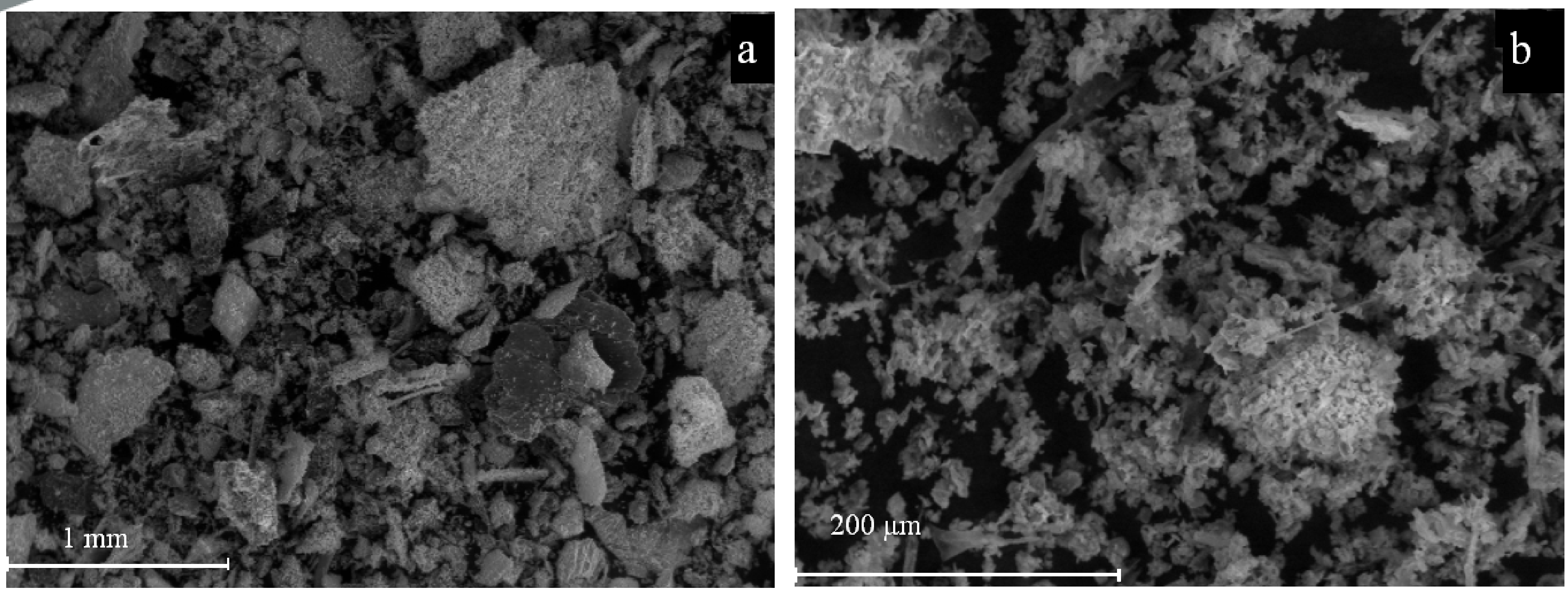
Average flow: 7.5l/ml

Total 1950 l

Source: Kato and Urano, 2001

Ash analysis

Horizontal chamber: 479 g
Cyclone: 422 g



SEM pictures. (a) Horizontal chamber – coarse
(b) Cyclone ash - fine fly ash

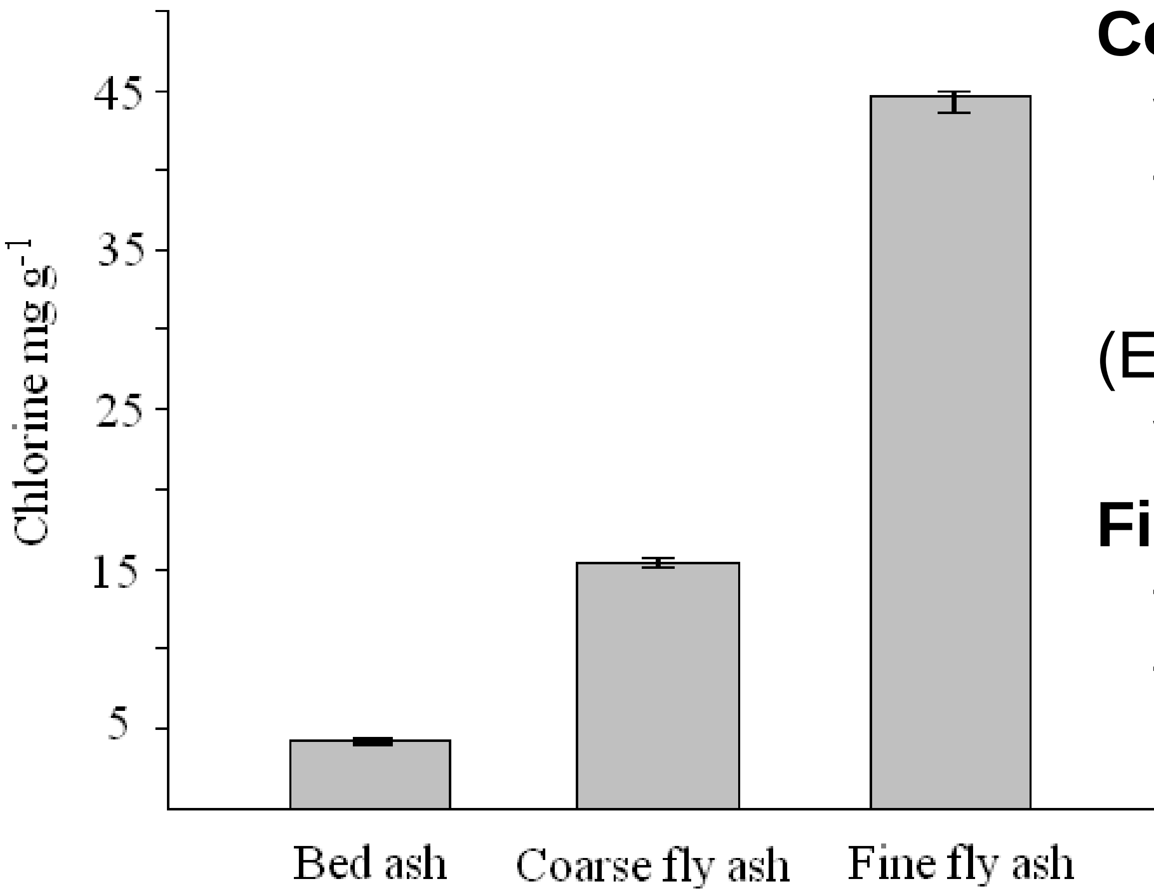
Ash analysis

- Inorganic ash bounded chlorine analysis by ion chromatography

- Organic ash bounded chlorine analysis

  by Soxhlet/ ASE/ ultrasonic extraction followed by GC/MS + GC analysis (1,3,5 tribromo benzene as extraction standard)

Inorganic chlorine



Bed ash: co- disposal in a non hazardous landfill (Cl^-< 15,000 mg/kg)

Coarse fly ash: hazardous waste landfill without further treatment (Cl^-< 25000 mg/kg)

(EC, 2002 for granular waste)

Fine fly ash: would require further stabilisation before final disposal

Higher chlorinated benzenes (Cl_5Bz and Cl_6Bz)

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Cl_5Bz and Cl_6Bz were quantified as indicators for the organochloride load of the fly ashes

SRF fly ash indicative toxicity indicators

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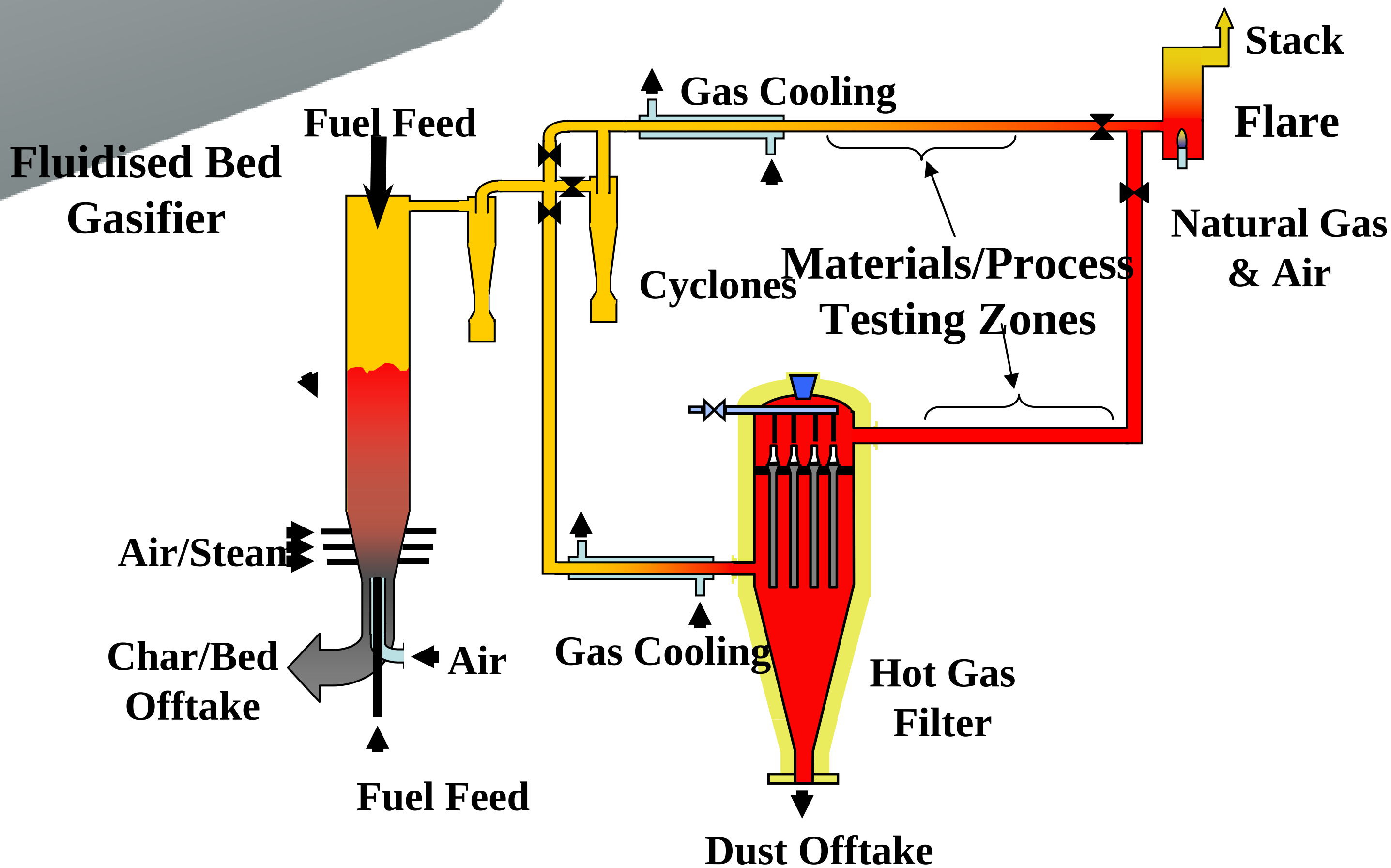
	This study	MSWI fly ash UK [a]	MSWI fly ash Sweden[b]
Cl^* mg g^{-1}	**15-45**	140-170	6-81
Cd mg g^{-1}	**0.003- 0.007**	0.1- 0.15	0.0035- 0.31
Pb mg g^{-1}	**0.76- 1.22**	2.5- 3.5	0.73- 36
Cu mg g^{-1}	**0.36- 0.47**	0.35- 0.6	0.22- 1.8
Cr mg g^{-1}	**0.41- 1.07**	0.012- 0.2	0.2- 1.6
Ni mg g^{-1}	**0.18- 0.42**	0.015- 0.035	0.036-0.11
Cl_5Bz ng g^{-1}	**5.1- 17.8**	nd	43- 610
Cl_6Bz ng g^{-1}	**0.5- 10**	nd	47- 260

nd- not determined * Water soluble or total

[a] Aqua regia total metals (Amutha Rani *et al*., 2008), [b] Total content (Öberg *et al*., 2007)

Gasification Facility at Cranfield



Spouted fluidised bed gasifier – 0.15m diameter
In- and above-bed feed systems for all types of solid fuels (up to 15kg/h) and sorbents
Fluidisation with air and/or steam

Acknowledgements

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Knight Energy Services laboratories are also acknowledged for their kind support in providing the oxygen bomb analysis.