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Fuel and Energy Research Forum
& EPSRC Bioenergy CDT

energy 2050

Low-Grade Biomass Symposium – Challenges and Opportunities

Metal Aerosol Emissions from Biomass Combustion

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Introduction

- **Bioenergy**: produces lower net (biogenic) CO_2 emissions – so is considered to be fuel with a lower carbon intensity
- **CCS**: carbon capture and storage could play a vital role in a low-carbon future
- **BECCS**: integration biomass energy with carbon capture and storage technologies

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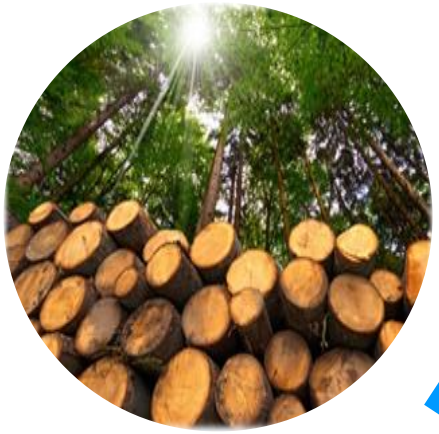

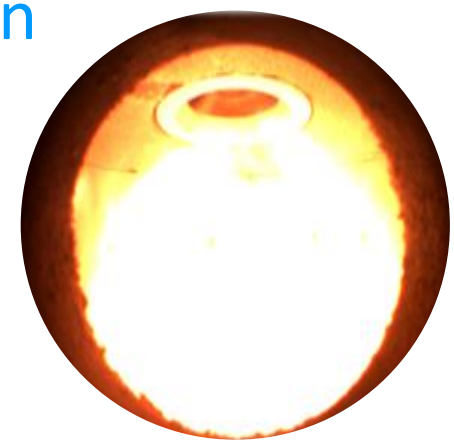

BECCS enables the potential for zero or **net negative emissions** and can therefore be used to decarbonise energy production

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Bio-CAP-UK Programme

- **Aim:** to accelerate progress towards achieving operational excellence for flexible, efficient and environmentally sustainable BECCS thermal power plants
- **Objectives**: to develop and assess fundamental knowledge, pilot plant tests, large-scale plant simulations and techno economic and life cycle studies

SUPERGEN Bioenergy Hub

UKCCS RESEARCH CENTRE

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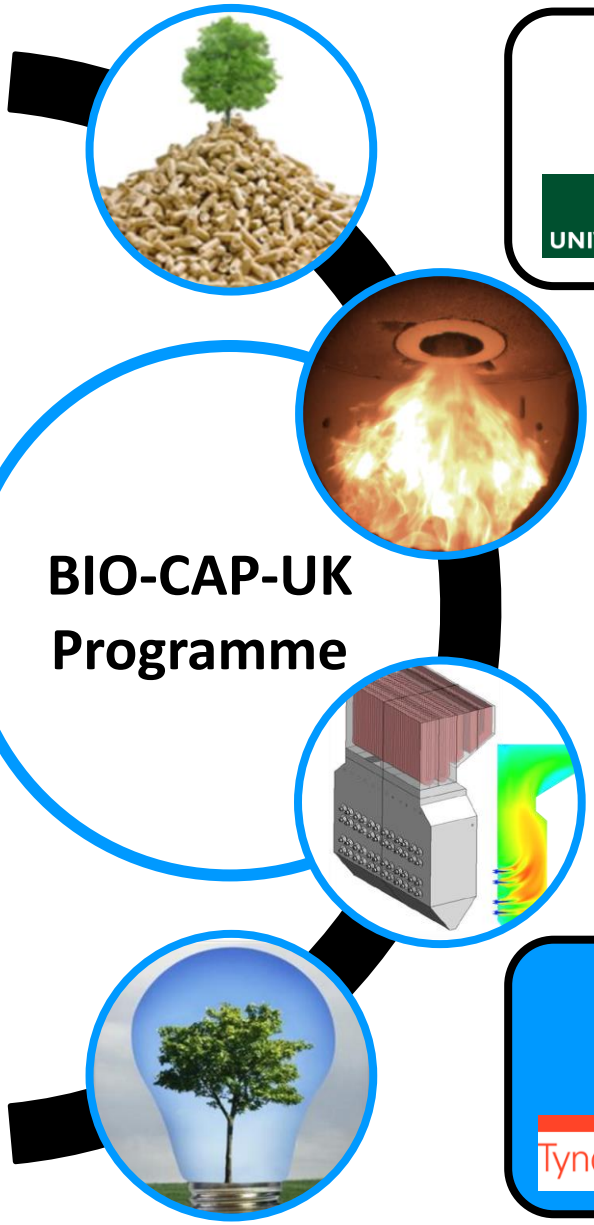

BIO-CAP-UK Programme

WP1: fundamental studies and characterisation

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fuel/char/ash characterisation

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WP2: pilot-scale combustion campaign at PACT

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air- and oxy-combustion capture tests

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WP3: power plant simulations

process simulations linked to CFD models of rate-controlling components

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WP4: BECCS value chains in the UK

life cycle and techno-economic assessments of BECCS options

TyndallManchester Climate Change Research

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UKCCSRC PACT FACILITIES

PACT Facilities

- UKCCSRC facilities for **P**ilot-scale **A**dvanced CO_2 **C**apture **T**echnologies
- National facilities for advanced fossil-fuel energy, bioenergy and carbon capture technologies
- The PACT facilities form part of the UK Carbon Capture and Storage Research Centre
- They are supported by the Department for Business, Energy and Industrial Strategy and the EPSRC, through the RCUK Energy Programme

www.pact.ac.uk

Department for Business, Energy & Industrial Strategy

EPSRC Engineering and Physical Sciences Research Council

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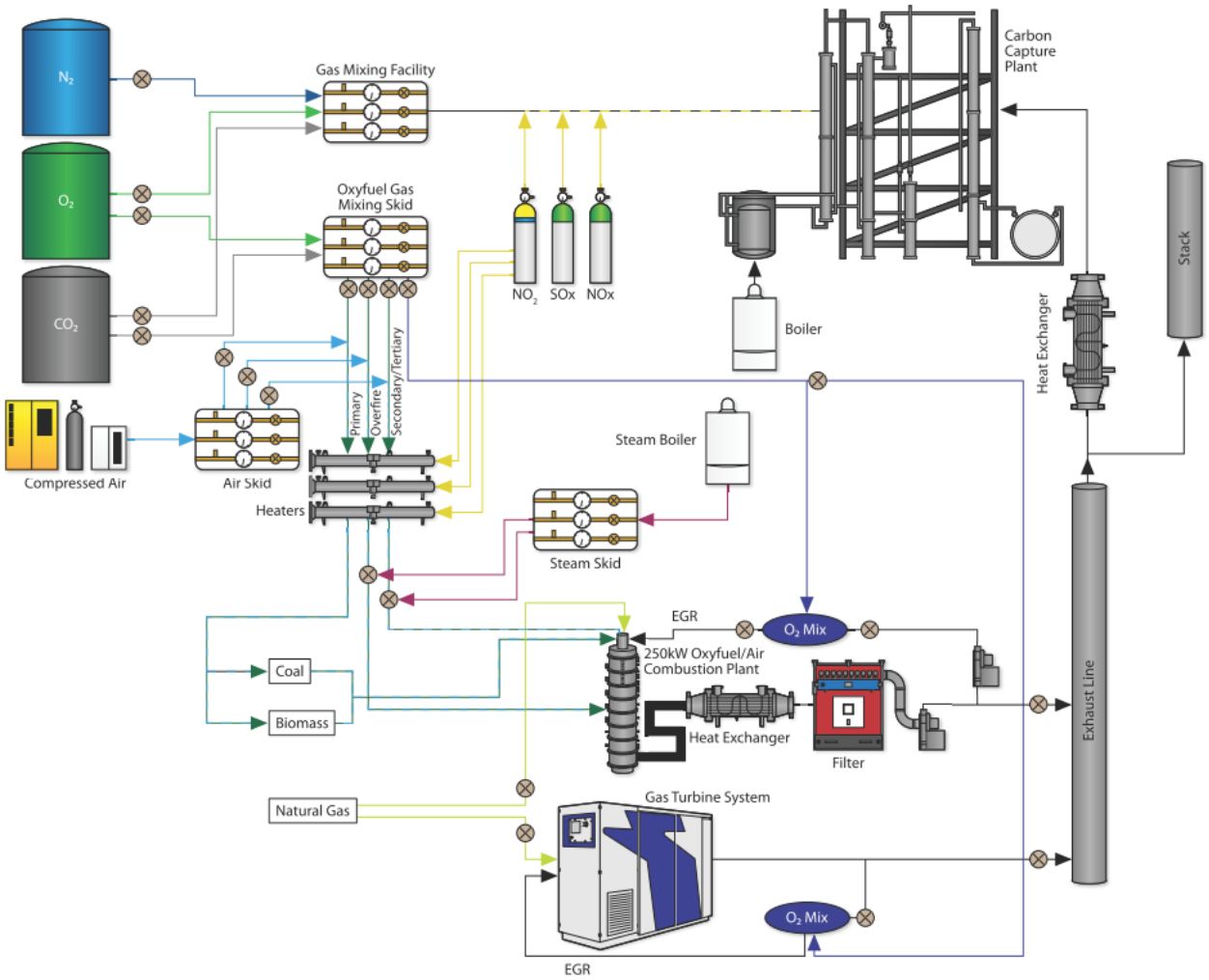
UKCCSRC PACT FACILITIES

PACT Facilities



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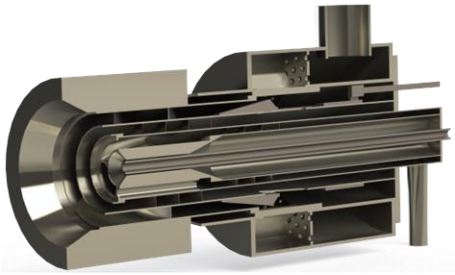
PACT Test Campaigns

- Pulverised fuel combustion test facility was used to compare coal and biomass combustion

Coal firing baselines:



~ bituminous Columbian coal from El Cerrejon region

~ air-firing with post-combustion carbon capture

Biomass firing tests:

~ Grade A white wood pellets from forestry residues

~ air-firing with post-combustion carbon capture

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Range of alkali, transition and heavy metals:
Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Na, Ni, Pb, S, Sb, Se, Sr, Ti, Tl, V, Zn

PACT Test Campaigns

- Unique metal emissions monitoring lab using **i**nductively **c**oupled **p**lasma **o**ptical **e**mission **s**pectrometry (ICP-OES)
- Real-time, online diagnostics for quantitative simultaneous multi-elemental detection of entrained metal aerosols (species/concentrations determinations)
- Assess emissions spectra (spectral lines) of various volatile/non-volatile elements, from major to ultra-trace
- Calibrations for elements that cause of operational issues, are toxic, are easily vaporised and/or are found in high concentrations in the fuels

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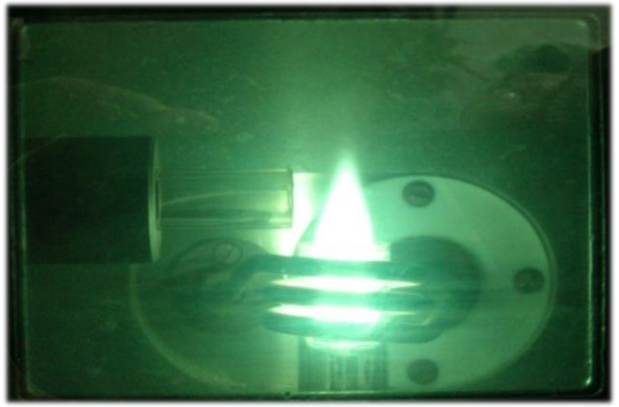
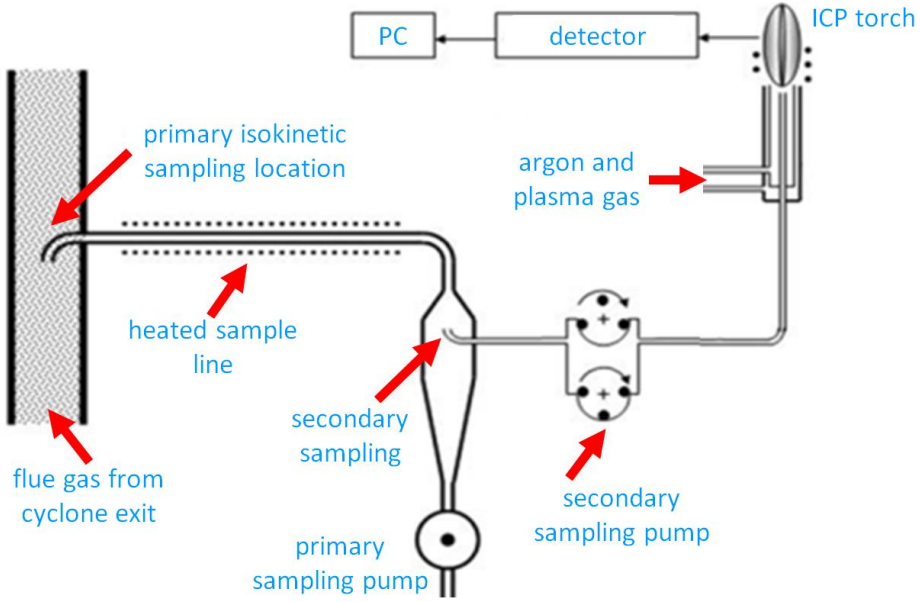
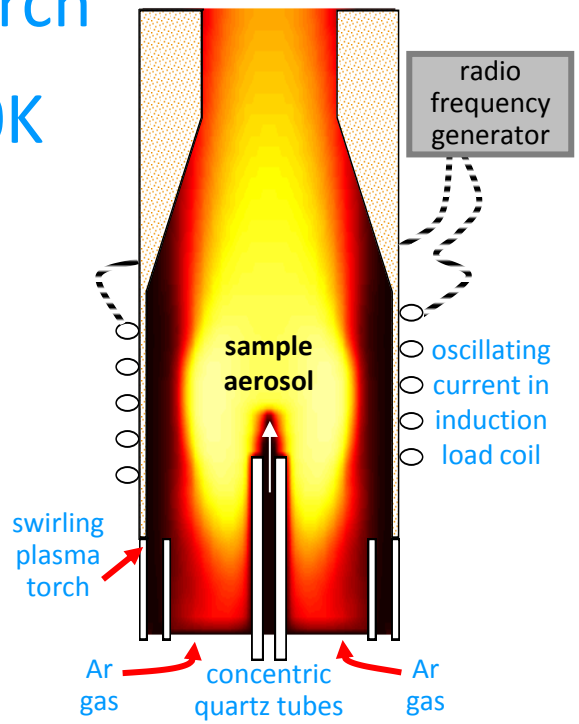


PACT Test Campaigns

- Spectro CIROS^{CCD} with custom-built torch
- Argon plasma torch operates at ~6000K





- ICP monitoring at the cyclone outlet in the combustion plant

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Alkali/Alkali Earth Metals

- K, Na, Mg and Ca
- Cause operational issues through deposition – slagging (high-temperature regions) and fouling (lower temperature areas) within the boiler, including in the furnace, superheaters, reheaters and economiser
- K (and Na) tend to be more prevalent in biomass than in coal, thus the phenomena are exacerbated for biomass-fired plants

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Alkali Metals

Fuel Analysis	Coal	Biomass
Potassium (as K_2O, %)	1.0	10.1
Sodium (as Na_2O, %)	1.3	1.3
Magnesium (as MgO, %)	2.2	5.5
Calcium (as CaO, %)	14.3	27.0

Biomass analysis from University of Leeds partner for the Bio-CAP-UK Project

- K aerosol emissions were consistently much greater from biomass combustion than those from coal
- Other emissions of alkali/alkali earth metals were significantly lower from biomass combustion than for coal

Relative Aerosol Emissions Ratio	Coal		Biomass	
	average	max	average	max
Potassium K 766.491	1	1.80	6.53	10.41
Sodium Na 589.592	1	1.59	0.19	0.37
Magnesium Mg 279.553	1	1.70	0.18	0.40
Calcium Ca 422.673	1	2.05	0.29	0.70

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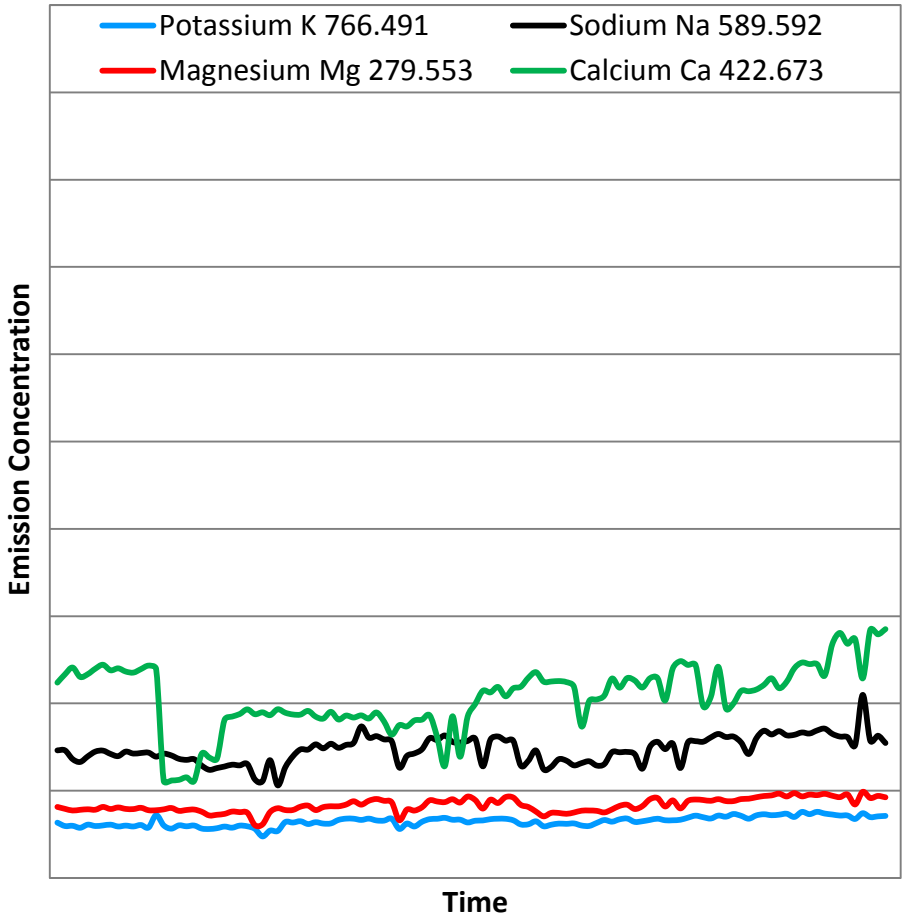
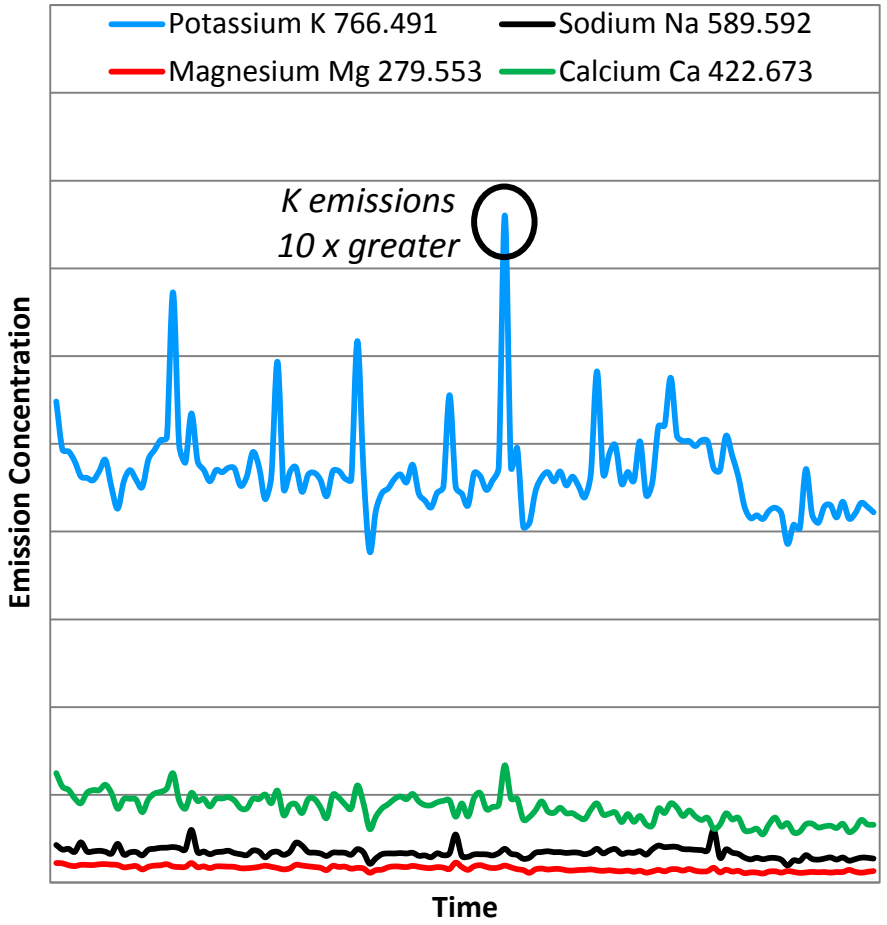
Alkali/Alkali Earth Metals

EL CERREJON COAL



BIOMASS - WHITE WOOD PELLETS



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Transition Metals

- Cu, Cr, Ni, Fe, V: can dissolve to initiate and catalyse oxidative solvent degradation
- Strong metallic anions have the potential to directly react with amine cations to form heat-stable salts

Heavy/Toxic Metals

- These include Hg, Cd, Cr, As, etc. – often very volatile and are of interest for their environmental and health effects

Transition Metals

Element	Coal	Biomass
Iron (as Fe_2O_3, %)	10.1	1.3
Copper (Cu, mg/kg)	3.5	2.6
Zinc (Zn, mg/kg)	4.9	10.2
Nickel (Ni, mg/kg)	3.9	0.7
Vanadium (V, mg/kg)	12.5	<0.6

Heavy Metals

Element	Coal	Biomass
Cadmium (Cd, mg/kg)	<0.1	0.1
Mercury (Hg, mg/kg)	<0.1	<0.1
Arsenic (As, mg/kg)	2.4	0.3
Chromium (Cr, mg/kg)	4.7	2.2

Biomass analysis from University of Leeds partner for the Bio-CAP-UK Project

- Cu – not detected as aerosols
- Fe/V – minor from biomass
- Ni aerosol emissions were lower for biomass than coal, with Zn relatively similar

- Cd and As were not present
- Hg only detected in small concentrations from coal
- Cr levels were similar largely below the instrument detection limit

Relative Aerosol Emissions Ratio

	Coal		Biomass	
	average	max	average	max
Iron	1	1.72	0.04	0.07
~~Copper~~	~~0~~	~~0.00~~	~~0.00~~	~~0.00~~
Zinc	1	2.04	1.13	1.84
Nickel	1	1.72	0.68	1.04
Vanadium	1	2.03	0.03	0.05

	Coal		Biomass	
	average	max	average	max
~~Cadmium~~	~~0~~	~~0.00~~	~~0.00~~	~~0.00~~
Mercury	1	1.71	~~0.00~~	~~0.00~~
~~Arsenic~~	~~0~~	~~0.00~~	~~0.00~~	~~0.00~~
Chromium	1	1.84	0.02	0.04

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What about Lower-Grade Fuels?

Fuel Analysis	Coal	Biomass Wood	Waste Wood
Potassium (as K_2O, %)	1.0	10.1	2.1
Sodium (as Na_2O, %)	1.3	1.3	1.2
Magnesium (as MgO, %)	2.2	5.5	3.3
Calcium (as CaO, %)	14.3	27.0	23.6
Aluminium (as Al_2O_3, %)	15.6	1.9	4.6
Iron (as Fe_2O_3, %)	10.1	1.3	6.1
Copper (Cu, mg/kg)	3.5	2.6	24.7
Zinc (Zn, mg/kg)	4.9	10.2	48.2
Nickel (Ni, mg/kg)	3.9	0.7	5.0
Vanadium (V, mg/kg)	12.5	<0.6	2.2
Cadmium (Cd, mg/kg)	<0.1	0.1	0.3
Chromium (Cr, mg/kg)	4.7	2.2	16.2
Arsenic (As, mg/kg)	2.4	0.3	3.8
Mercury (Hg, mg/kg)	<0.1	<0.1	<0.1
Lead (Pb, mg/kg)	3.8	0.7	16.2

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Conclusions

- ICP can provide useful data on metal aerosol emissions in the flue gases from coal and biomass combustion
- Alkali metals: elevated **K** aerosols were found in the flue gas from biomass combustion compared to coal; **Na**, **Ca** and **Mg** were all much lower for biomass
- Transition metals: low amounts of various species were detected for both fuels, but were more prominent for coal (**Fe**, **Ni**, **V**)
- Heavy/toxic metals: **As**, **Cd** and **Cu** not detected; **Hg** in limited concentrations for coal; **Cr** below detection limit
- **Future work:** other fuels, oxy-combustion tests, impacts on capture solvent degradation, further ash characterisation

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THANK YOU

Metal Aerosol Emissions from Biomass Combustion

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