PACT-UPDATE

M. Pourkashanian

UKCCSRC-PACT National Facilities

International Test Centre Network
Huaneng Clean Energy Research Instititute
Beijing, PR-China
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Contents

BECCS and net negative emissions

Technology Challenges of using Biomass +CCS

Energy from Waste + CCS

- Technology challenges on
  - ~ Sub-Micron Metal Emission
  - ~ Deposition and Slagging
- Concluding remarks

Operating IFRF

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Combustion Challenges of Biomass

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- Biomass has a number of characteristics that makes it more difficult to handle and combust than fossil fuels.
- The low energy density (handling and transport of the biomass)
- Biomass content of inorganic constituents.
  - significant amounts of chlorine, sulfur and potassium.
  - The salts, KCl and K2SO4, heavy deposition on heat transfer surfaces resulting in reduced heat transfer and enhanced corrosion rates.
  - The release of alkali metals, chlorine and sulfur to the gas-phase (generation of significant amounts of aerosols along with relatively high emissions of HCl and SO2).

Research Challenges on Biomass Utilization /Combustion with BECCS

- Some of Key challenges with biomass utilisation:
  - Sourcing and availability
  - Biomass Types and its Impacts on milling and combustion, Consistency of supply in terms of properties and characteristics
  - Acidic components, which can initiate corrosion of boiler tubes and other vulnerable surfaces
  - Ash Related Impact: alkali metals, which can increase the propensity for deposition within the furnace and heat recovery systems (slagging and fouling)
  - Environmental Impact: Total particulate emissions control, NOx emission control, trace metal release (impurities)
  - Dynamic simulation and modelling: De-rating power plant, dynamic behaviour and
  - Full life cycle analyses including techno economic analysis

Biomass Types and its Impacts on milling and combustion

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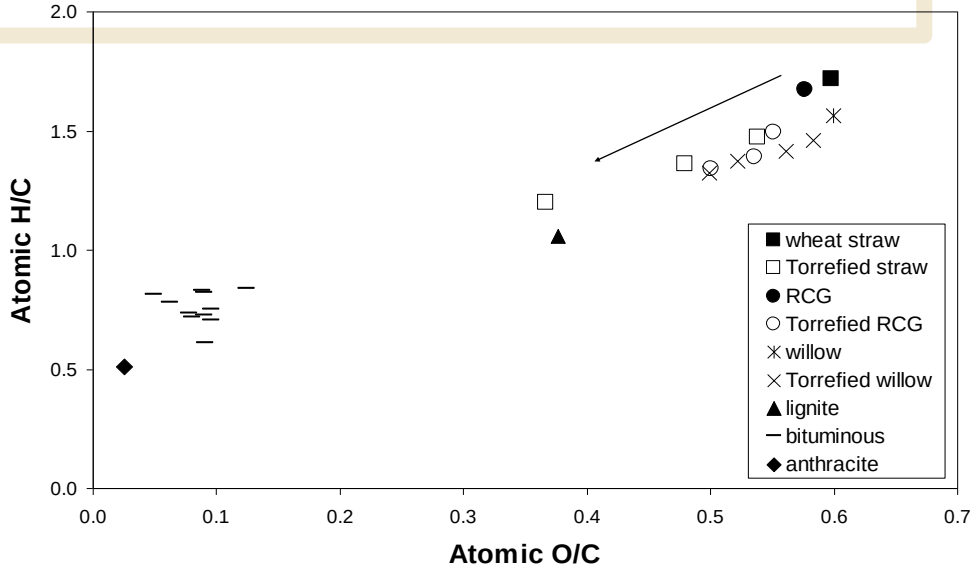
Untreated | Miscanthus C | Miscanthus B | Miscanthus A | Miscanthus D

- ✓Properties start to resemble those of low rank coals
- ✓Fuel does not degrade on storage- hydrophobic
- ✓Easier to mill (for co-firing or gasification applications)
- ✓Combined torrefaction and pelleting process a possibility



PACT Facilities

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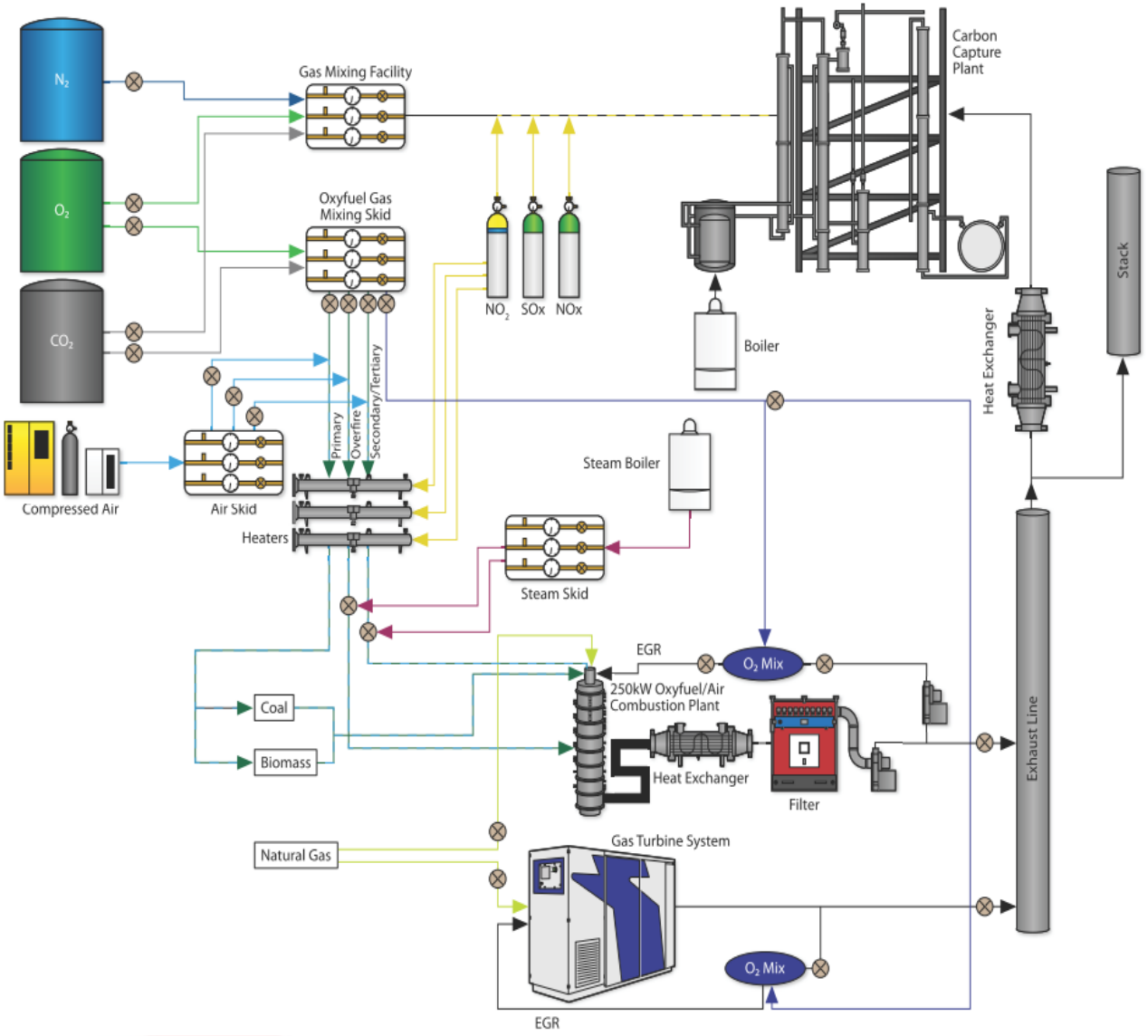

Pilot-Scale Integrated Experimental Facilities for BECCS

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Gas Mixing Facilities

250kW Air/Oxy Rig

ICP-OES & DMS 500

Carbon Capture Plant

250kW Air/Oxyfuel Plant

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Element partitioning and fate of species:
ICP monitoring plus 3 ash collection locations

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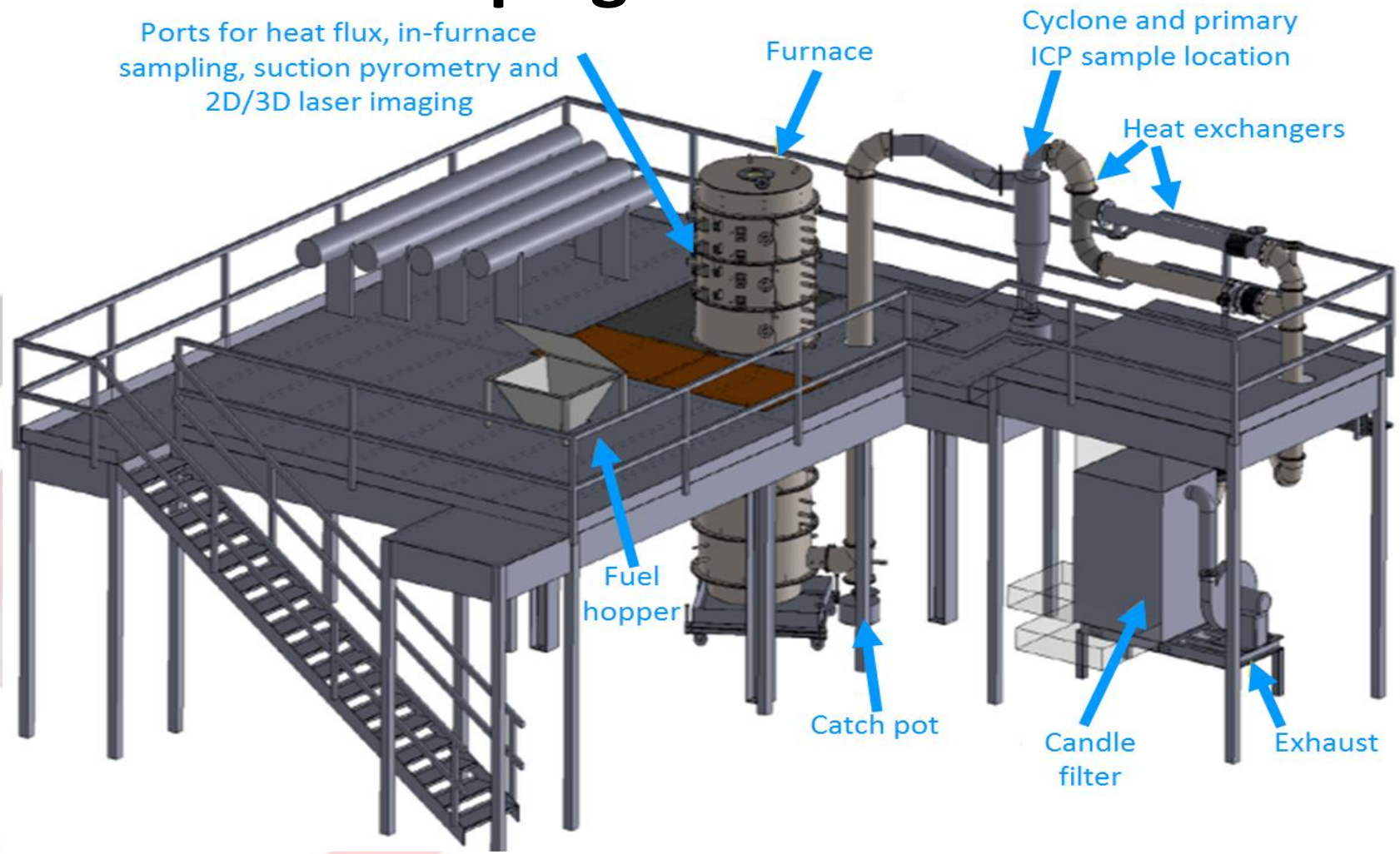
PACT Test Campaigns



The University Of Sheffield.

ACP Gas Sampling

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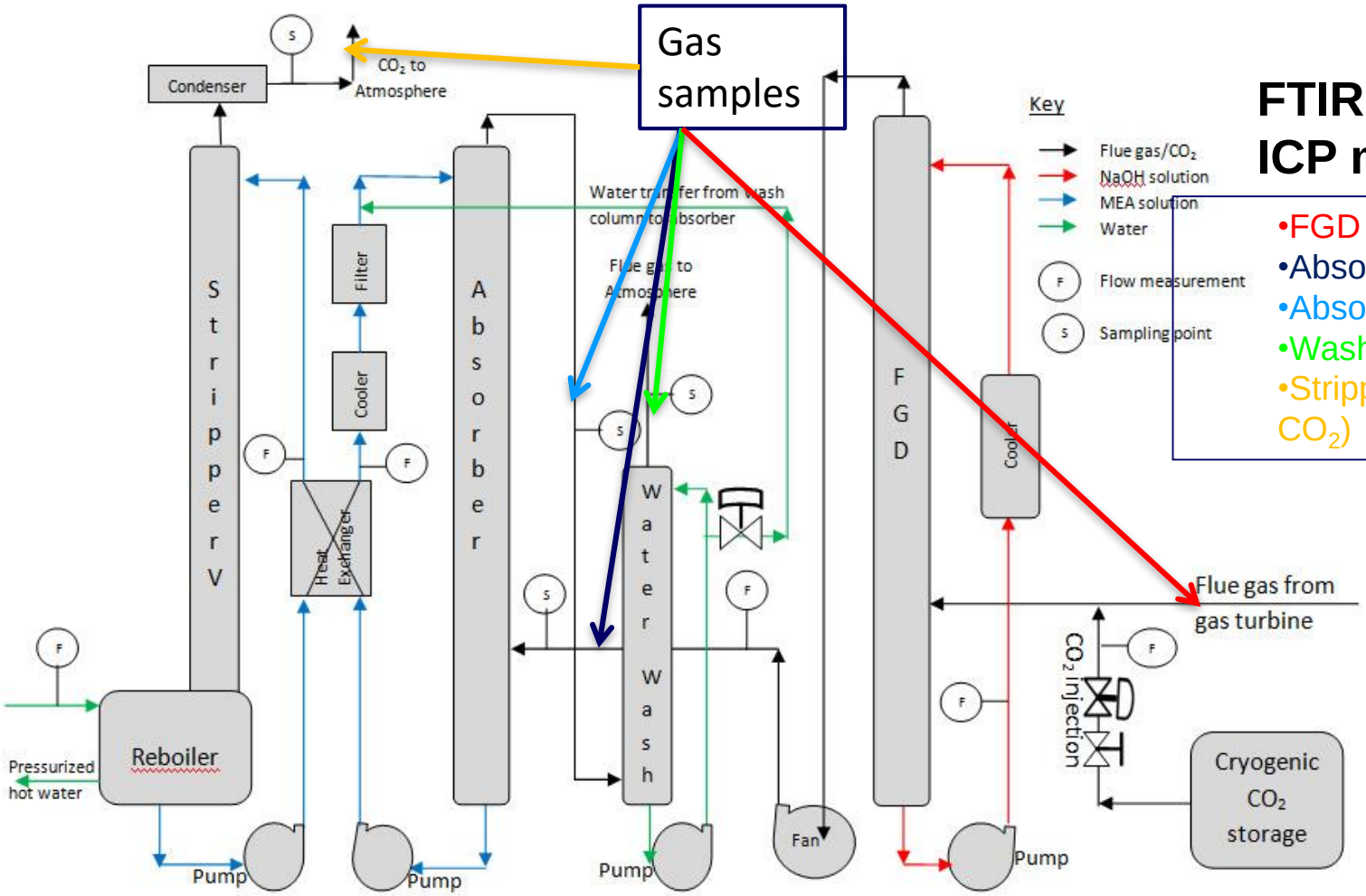

FTIR, DMS500 and ICP measurements:

- FGD inlet
- Absorber inlet
- Absorber outlet
- Wash column outlet
- Stripper outlet (High Purity CO_2)

Coal & Biomass Combustion

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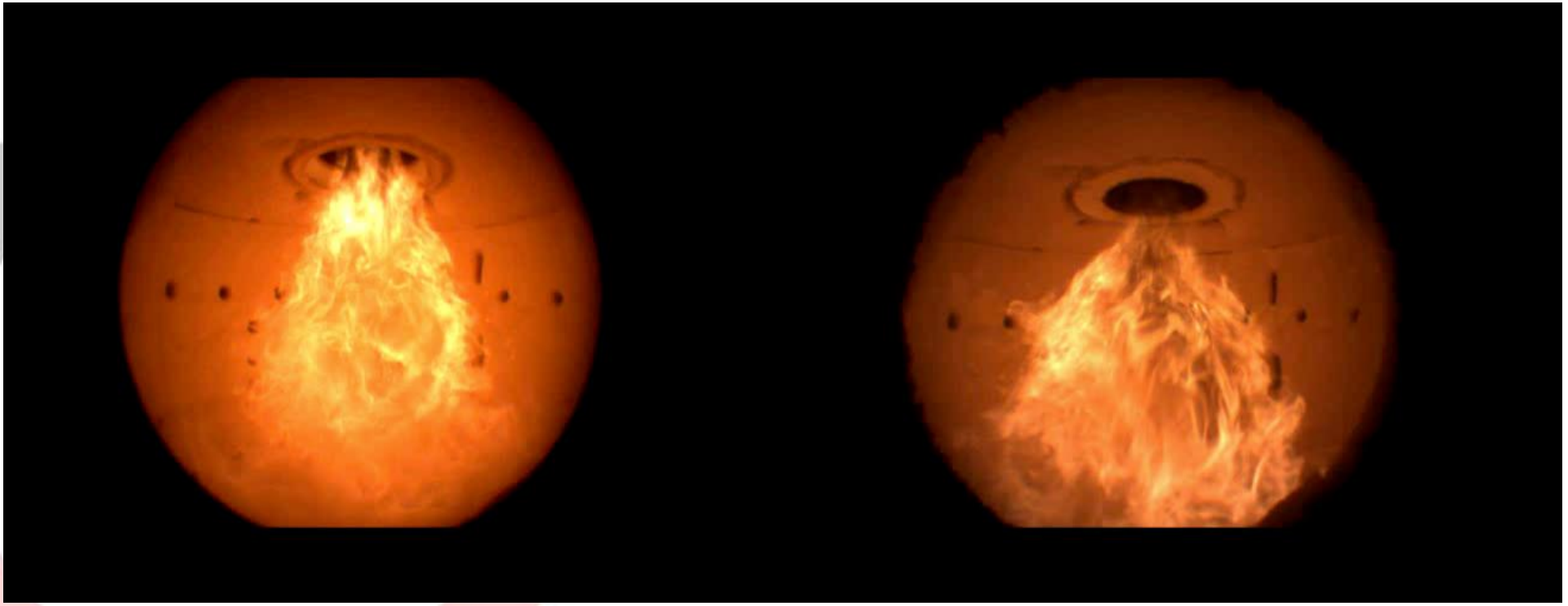
- Flame volume, Radiative Properties, Flickering,
- State of the Fuel/Air Unmixedness and Flame Lift-off and Stabilization

Air-Coal (225KW)

Air-Biomass (225KW)

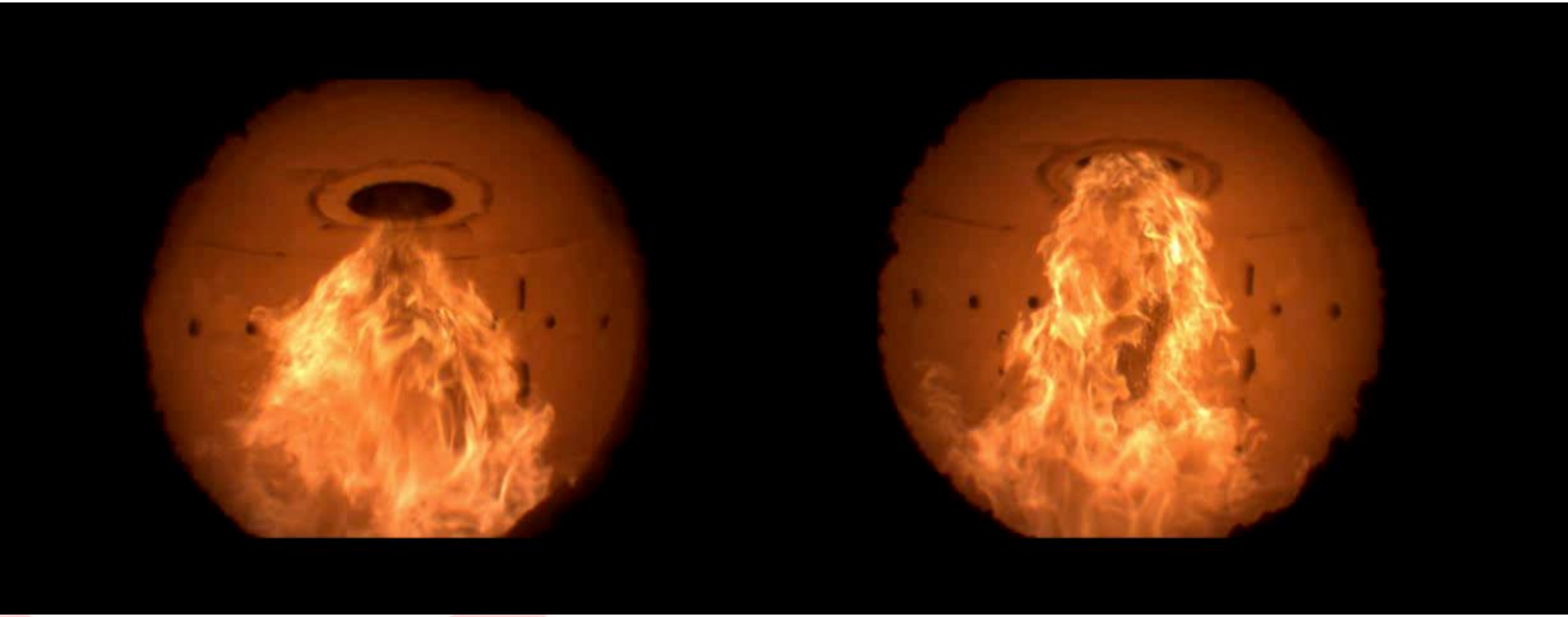


Introduction

- Flame volume, Radiative Properties, Flickering,
- State of the Fuel/Air Unmixedness and Flame Lift-off and Stabilization

Oxy (30%)-Coal (225KW)

Oxy(30%)-Biomass (225KW)

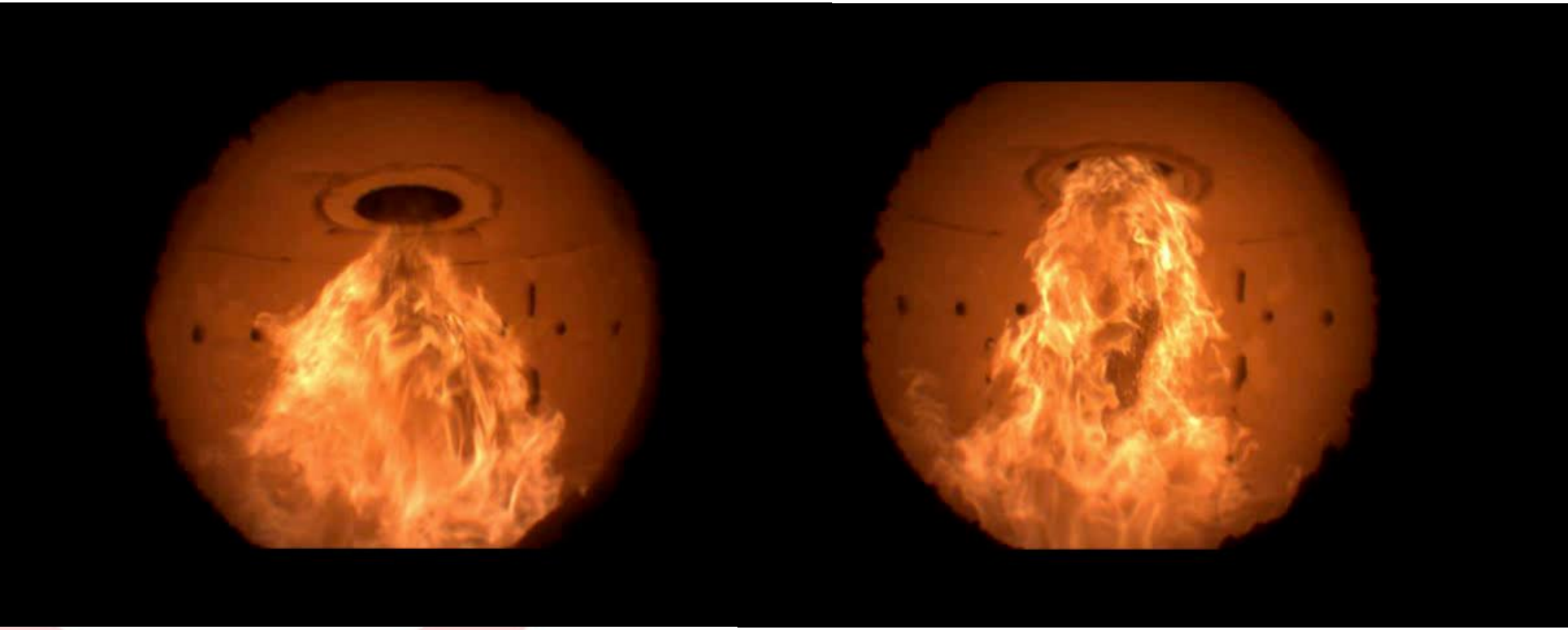


Introduction

- Flame volume, Radiative Properties, Flickering,
- State of the Fuel/Air Unmixedness and Flame Lift-off and Stabilization

Air-Biomass (225KW)

Air-Torrefied Biomass (225KW)



PACT Test Campaigns

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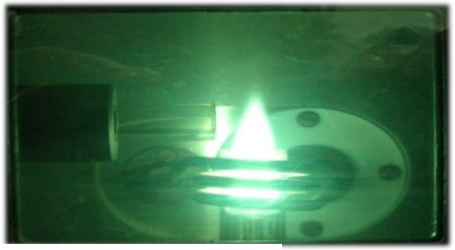
Range of alkali, transition and heavy metals:
Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Na, Ni, Pb, S, Sb, Se, Sr, Ti, Tl, V, Zn

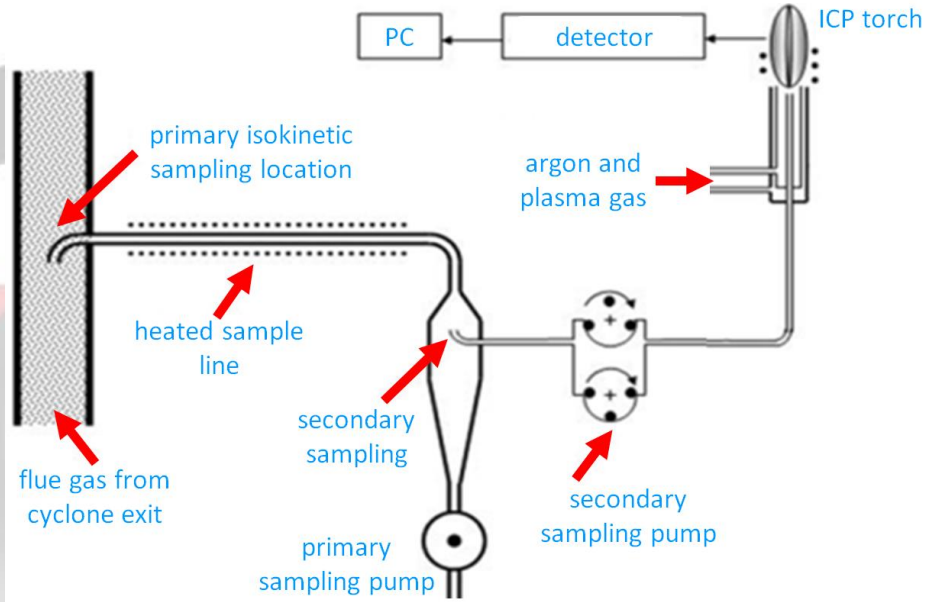
- Unique metal emissions monitoring lab using **i**nductively **c**oupled **p**lasma **o**ptical **e**mission **s**pectrometry (ICP-OES)
- Real-time, online diagnostics for quantitative simultaneous multi-elemental detection of entrained metal aerosols (species/concentrations determinations)
- Assess 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

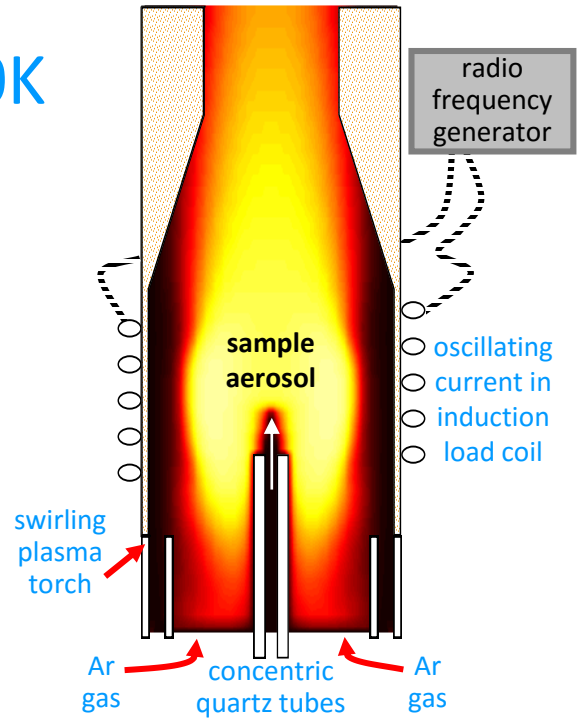
PACT Test Campaigns

UKCCSRC PACT FACILITIES



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





- Evaluation of element partitioning through assessments of ash samples collected throughout the furnace (XRF)

DMS DATA SUMMARY

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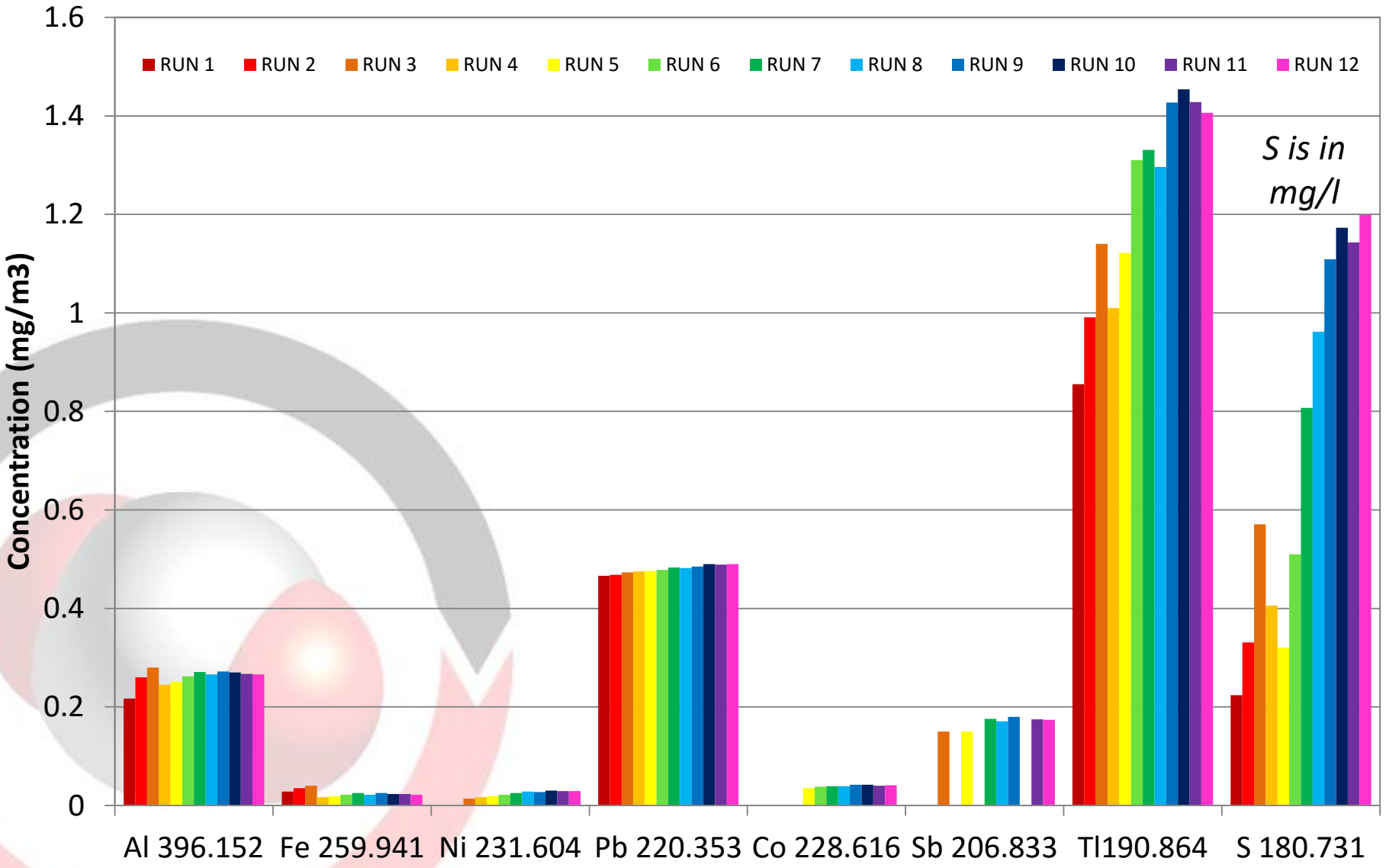
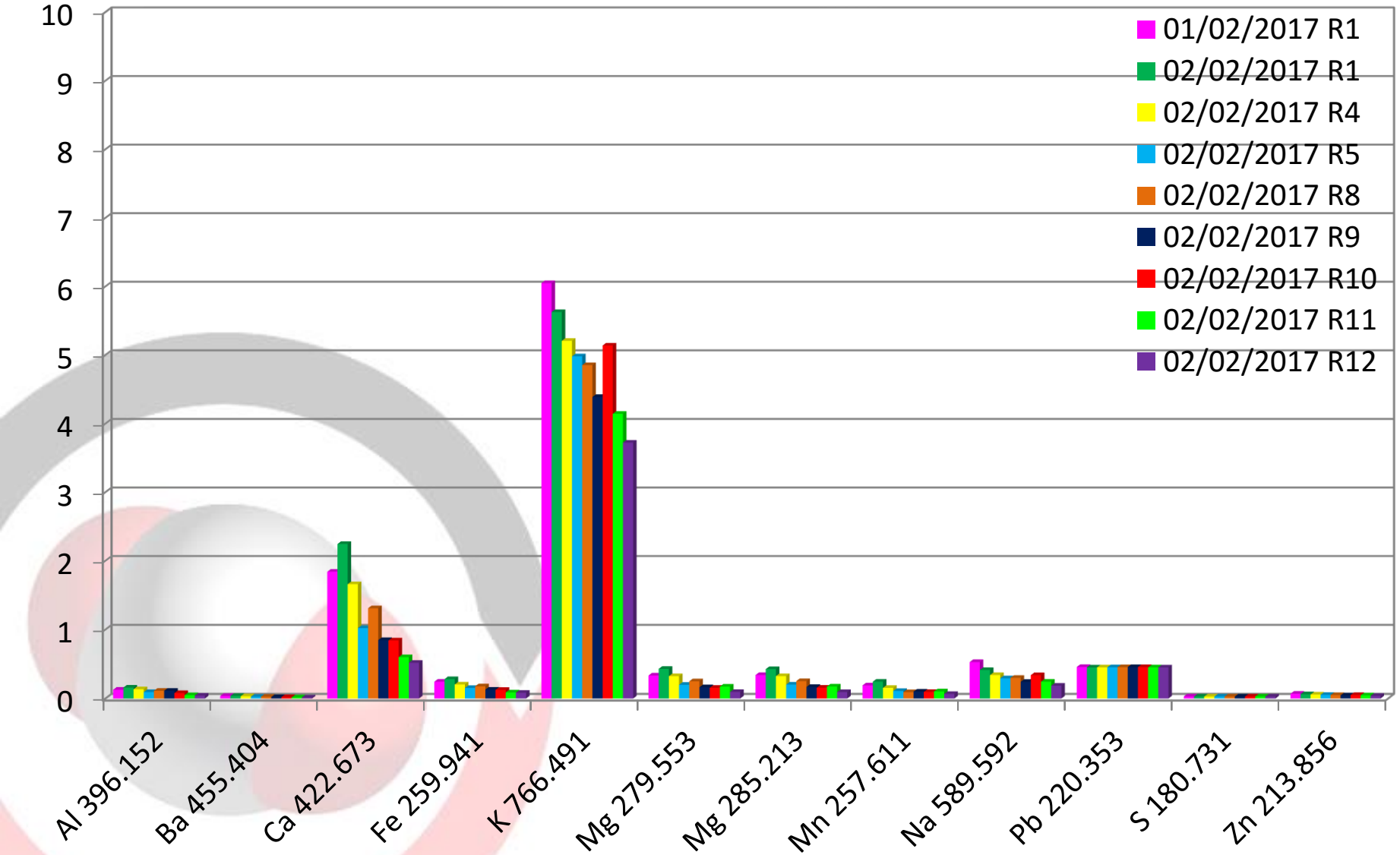
	Total Concentration (N/cc)	Geometric Mean Diameter (nm)	Geometric Standard Deviation of Diameter	Count Median Diameter (nm)
Air-coal	5537.52	48.16	5.25	90.11
Oxy-coal	2677.39	71.44	3.87	95.95
Air-biomass	12065.72	131.06	2.81	176.52
Air-torrified	17576.22	106.51	2.64	125.12

Much higher PM_1 concentrations in the biomass flue gas samples than the coal samples

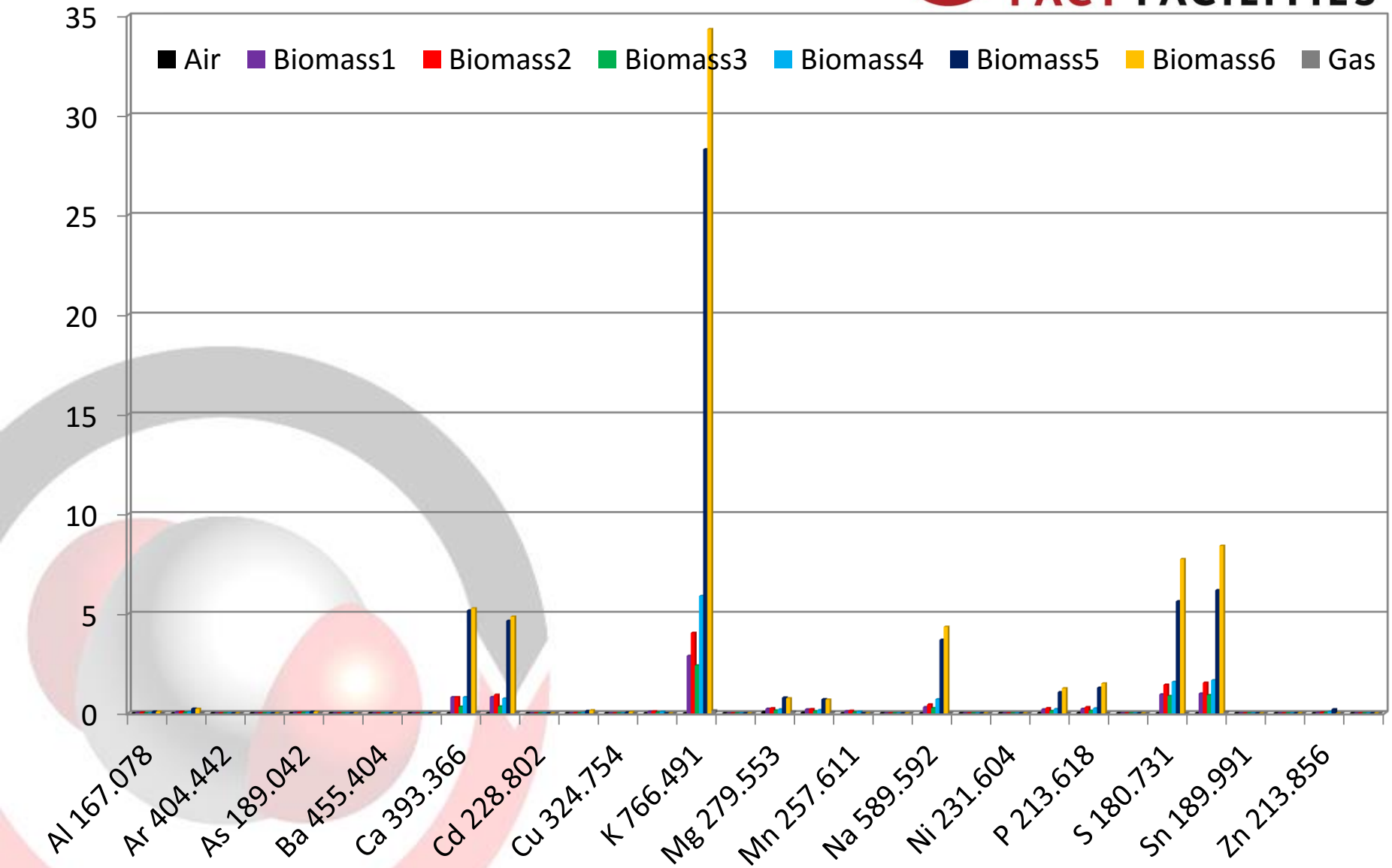
Oxy coal


RUN 1
RUN 2
RUN 3
RUN 4
RUN 5
RUN 6
RUN 7
RUN 8
RUN 9
RUN 10
RUN 11
RUN 12
S is in mg/l
Concentration (mg/m3)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Al 396.152
Fe 259.941
Ni 231.604
Pb 220.353
Co 228.616
Sb 206.833
Tl190.864
S 180.731

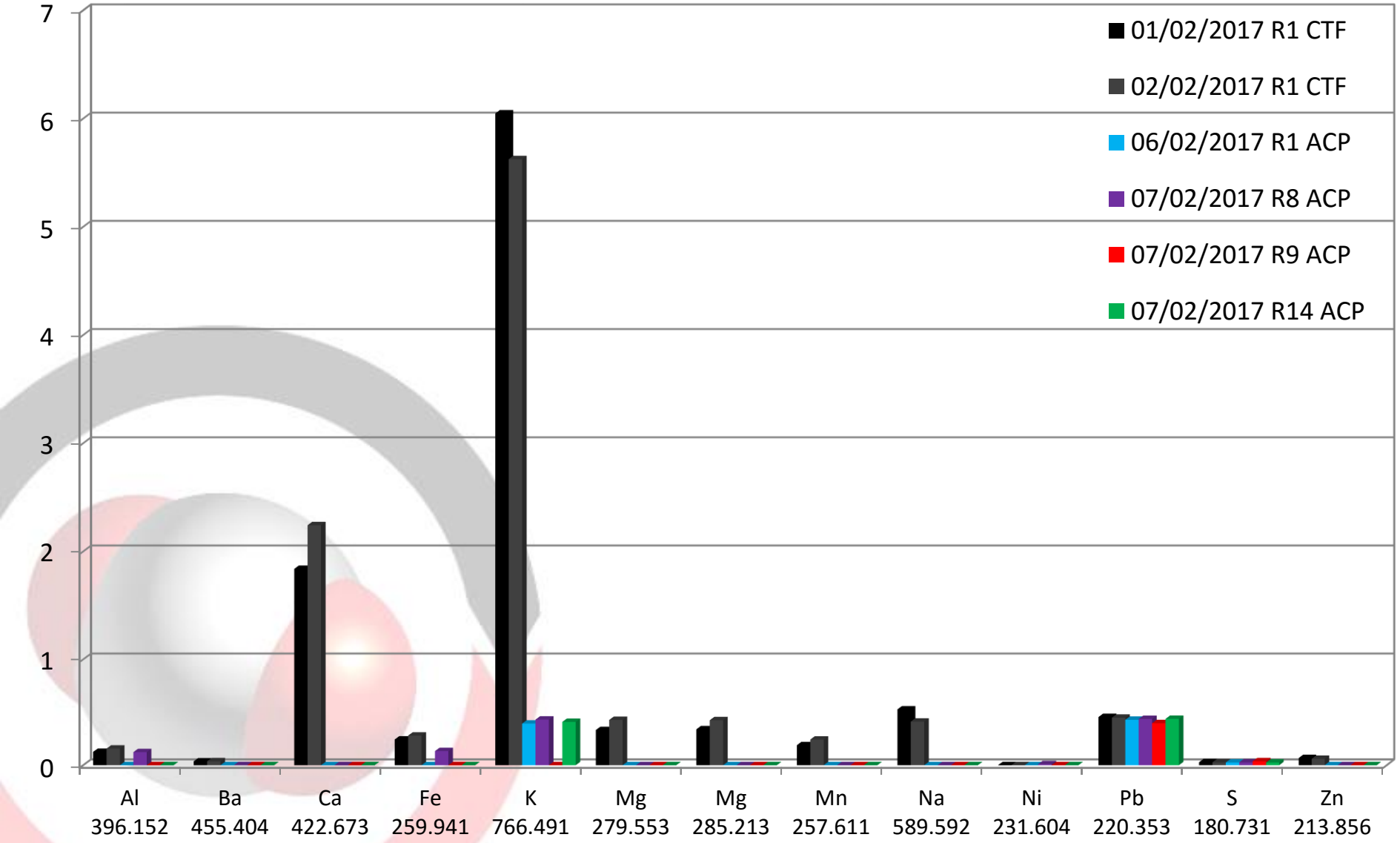
Air biomass

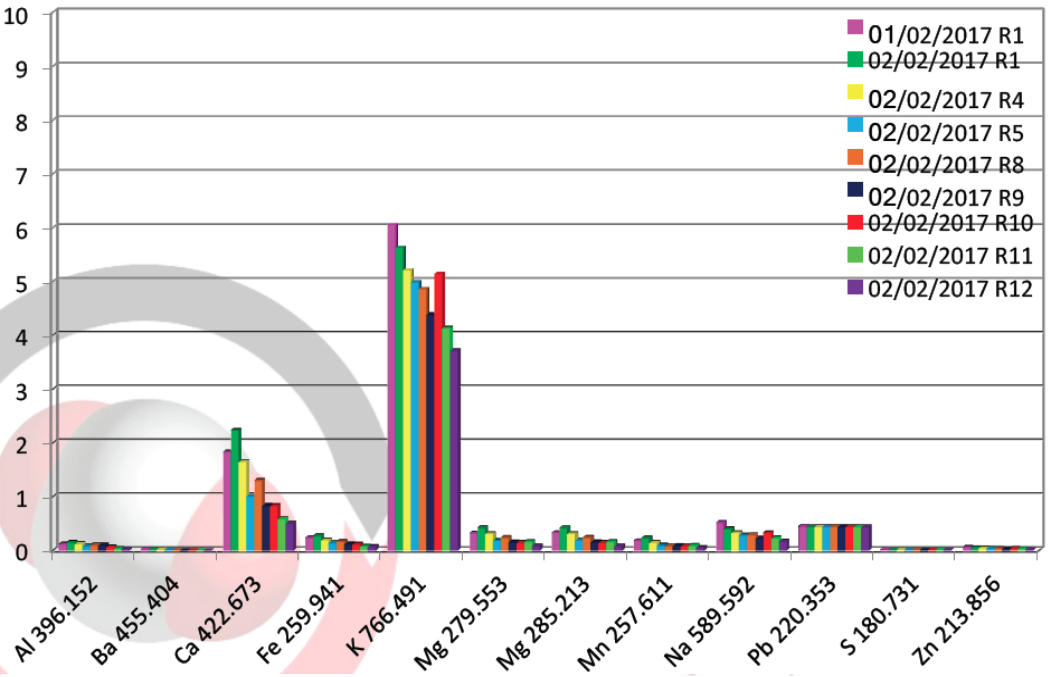

10
9
8
7
6
5
4
3
2
1
0
01/02/2017 R1
02/02/2017 R1
02/02/2017 R4
02/02/2017 R5
02/02/2017 R8
02/02/2017 R9
02/02/2017 R10
02/02/2017 R11
02/02/2017 R12
Al 396.152
Ba 455.404
Ca 422.673
Fe 259.941
K 766.491
Mg 279.553
Mg 285.213
Mn 257.611
Na 589.592
Pb 220.353
S 180.731
Zn 213.856

Air biomass


35
30
25
20
15
10
5
0
Air
Biomass1
Biomass2
Biomass3
Biomass4
Biomass5
Biomass6
Gas
Al 167.078
Ar 404.442
As 189.042
Ba 455.404
Ca 393.366
Cd 228.802
Cu 324.754
K 766.491
Mg 279.553
Mn 257.611
Na 589.592
Ni 231.604
P 213.618
S 180.731
Sn 189.991
Zn 213.856

Air biomass and amine plant




01/02/2017 R1
02/02/2017 R1
02/02/2017 R4
02/02/2017 R5
02/02/2017 R8
02/02/2017 R9
02/02/2017 R10
02/02/2017 R11
02/02/2017 R12
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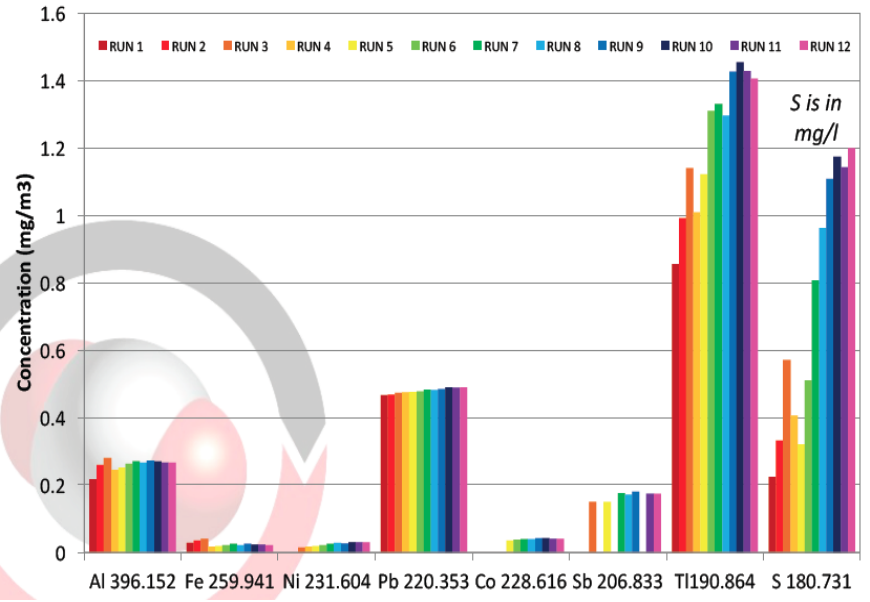
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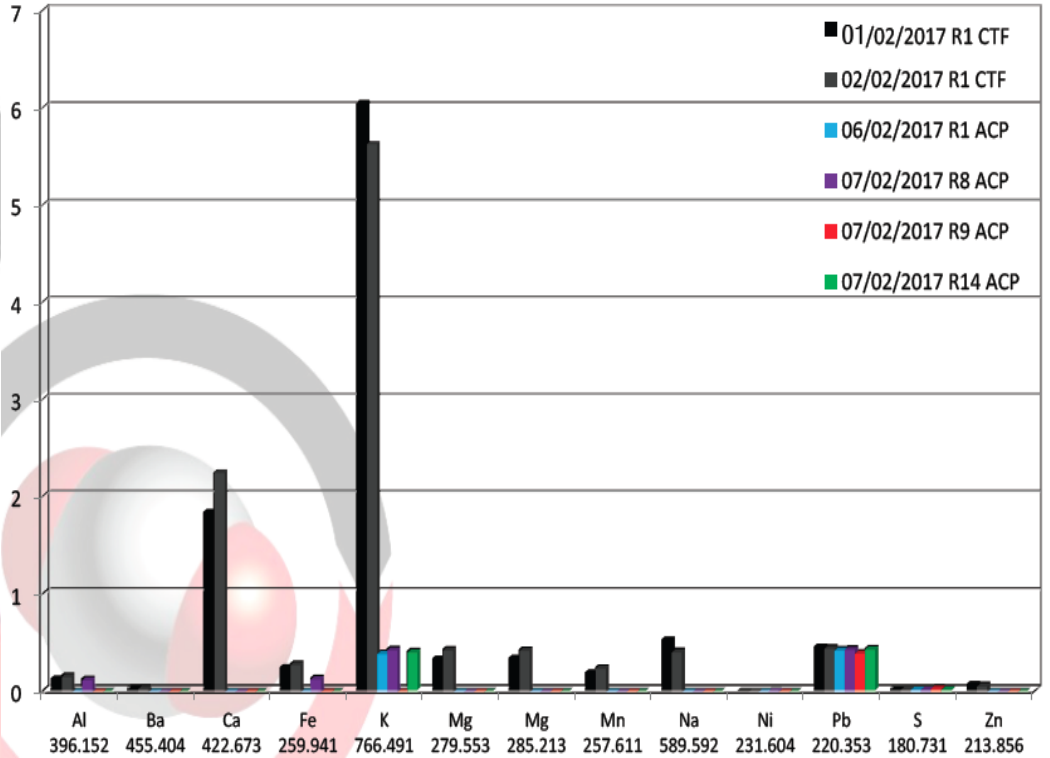
01/02/2017 R1 CTF
02/02/2017 R1 CTF
06/02/2017 R1 ACP
07/02/2017 R8 ACP
07/02/2017 R9 ACP
07/02/2017 R14 ACP
Al 396.152
Ba 455.404
Ca 422.673
Fe 259.941
K 766.491
Mg 279.553
Mg 285.213
Mn 257.611
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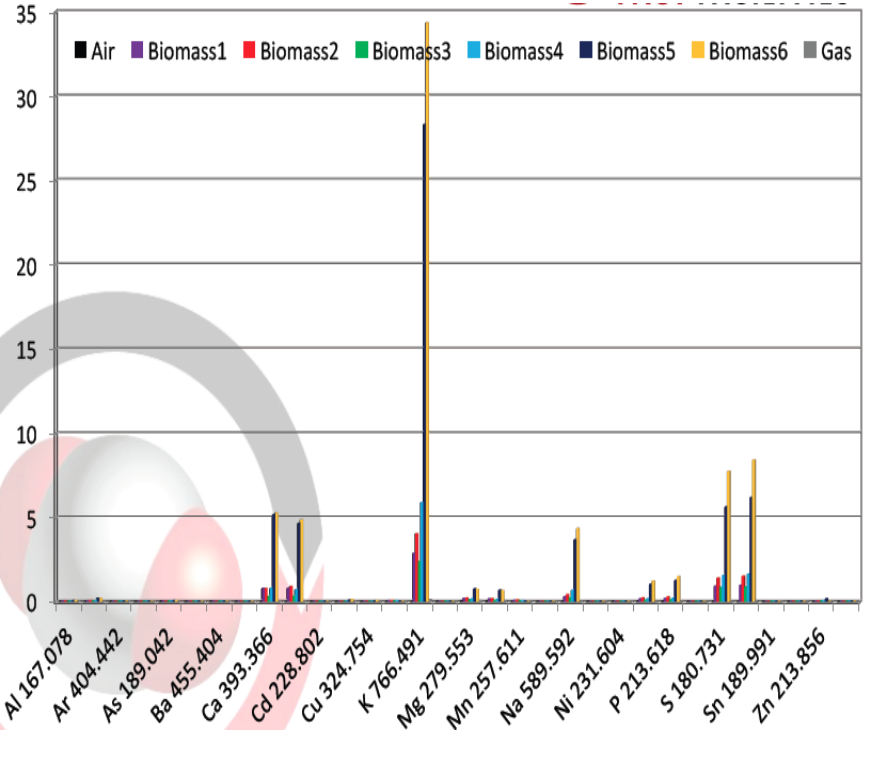
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Ni 231.604
P 213.618
S 180.731
Sn 189.991
Zn 213.856

Focus of BECCS Research

- Fly Ash formation and Characterisation during biomass combustion: Coarse fly ash and aerosols (DMS-500 Combustion)
- Relevant aerosols related issues for biomass combustion with CCS (BECCS) that need to be addressed:
  - Aerosol emission, impact on solvent, impurities
  - Plant internal problem (cost reduction)
  - Prediction of aerosols formation
- Metal release and related issues for BECCS:
  - Chemical composition: K, Cl, S, Na, Zn & Pb are the main constituents **(ICP-OES)**

Alkali/Alkali Earth Metals

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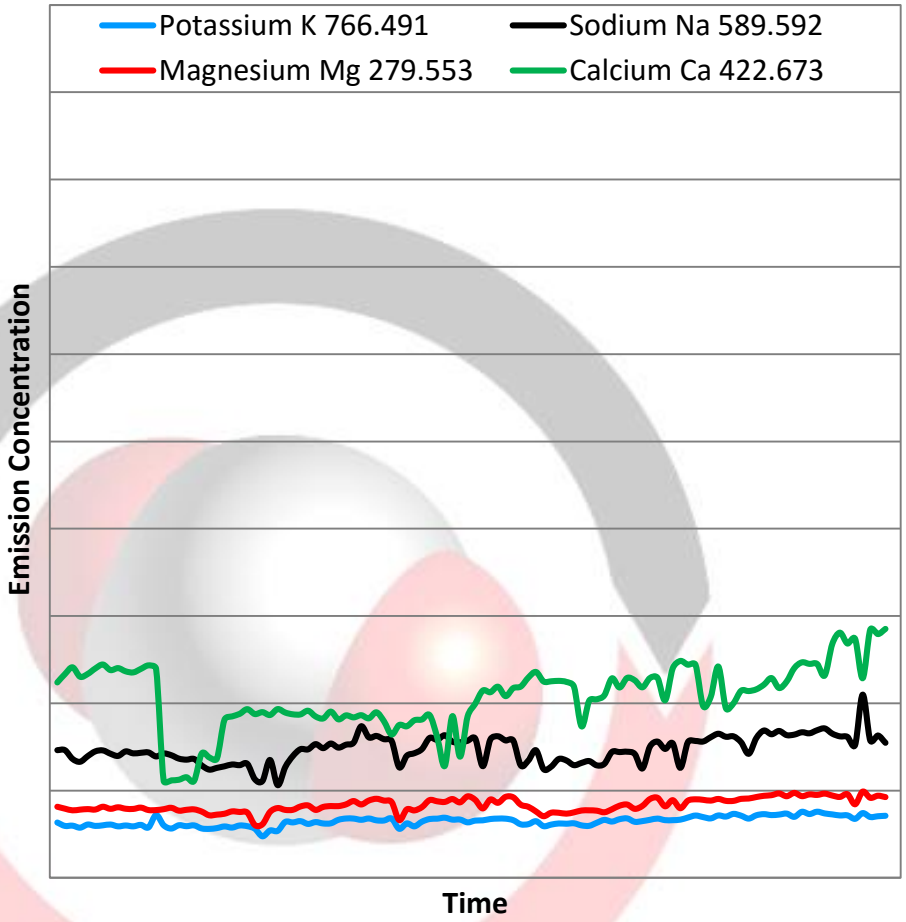
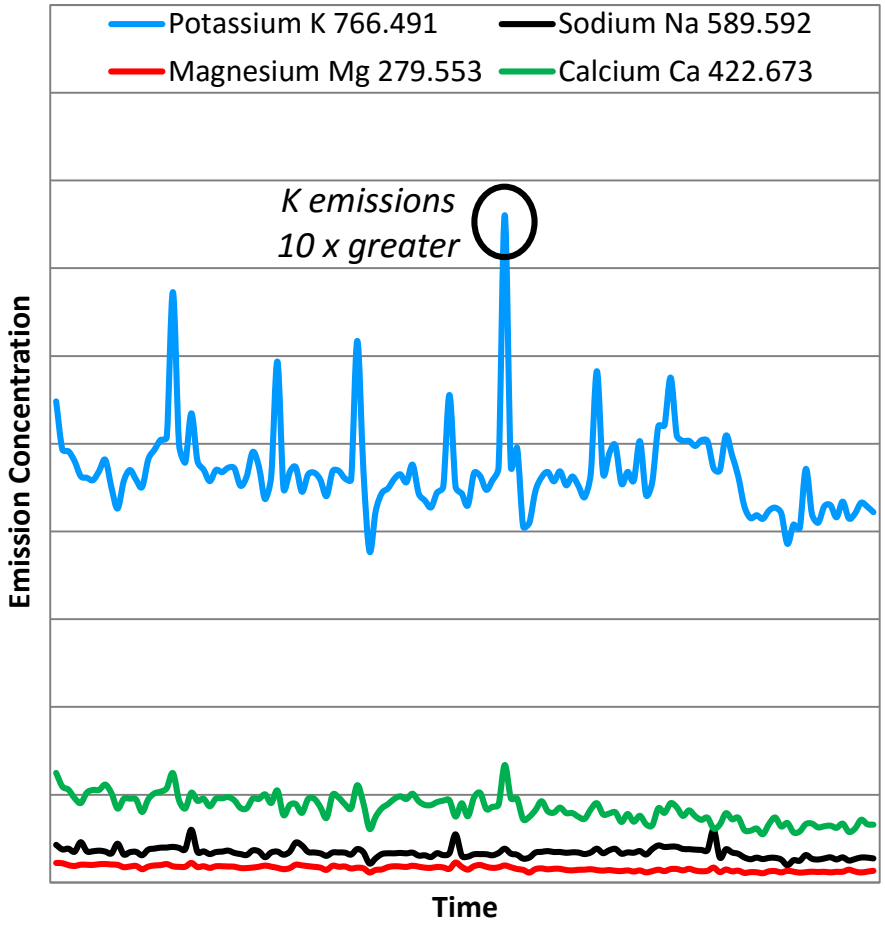
EL CERREJON COAL



BIOMASS - WHITE WOOD PELLETS



Heavy/Toxic/Other Metals

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

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
Aluminium (as Al_2O_3, %)	15.6	1.9

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

Relative Aerosol Emissions Ratio	Coal		Biomass	
	average	max	average	max
Cadmium Cd 228.802	0	0.00	0.00	0.00
Mercury Hg 253.652	1	1.71	0.00	0.00
Arsenic As 189.042	0	0.00	0.00	0.00
Chromium Cr 267.716	1	1.63	1.00	1.53
Aluminium Al 396.152	1	1.84	0.02	0.04

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	EL CERREJON COAL		WHITE WOOD PELLETS	
	average	maximum	average	maximum
ALKALI & ALKALI EARTH METALS				
Potassium (K 766.491)	1	1.80	6.53	10.41
Sodium (Na 589.592)	2.52	4.01	0.49	0.93
Magnesium (Mg 279.553)	1.46	2.48	0.26	0.58
Calcium (Ca 422.673)	4.59	9.41	1.35	3.23
TRANSITION METALS				
Copper (Cu 324.754)	0.00	0.00	0.00	0.00
Iron (Fe 259.941)	5.52	9.48	0.20	0.41
Nickel (Ni 231.604)	0.03	0.06	0.02	0.03
Vanadium (V 292.464)	0.05	0.10	0.00	0.00
Zinc (Zn 213.856)	0.06	0.12	0.07	0.11
HEAVY/TOXIC & OTHER METALS				
Aluminium (Al 396.152)	5.26	9.65	0.10	0.22
Arsenic (As 189.042)	0.00	0.00	0.00	0.00
Mercury (Hg 253.652)	0.04	0.06	0.00	0.00
Cadmium (Cd 228.802)	0.00	0.00	0.00	0.00
Chromium (Cr 267.716)	0.03	0.04	0.03	0.04

Summary of challenges

- Existing coal plants can be converted to co-fire or 100% biomass with white wood pellets or chips (preferred choice of fuel by operators).
- The substitution of coal for biomass, in whole or in part, can have an impact on the resulting CO_2 composition in CCS applications due to the altered fuel chemical composition.
- The chemical composition of biomass differs to that of coal generally contains less S, fixed carbon, and fuel bound N, but more O_2.
- A disadvantage of using biomass: higher concentration of alkali metal species can be found in derived flue-gases (unlike coal).
- K is mainly released to the gas-phase as KOH and KCl (dominant when the fuel Cl content is high). KOH can undergo transformation in the gas-phase to form K_2SO_4.
- **To date, no estimates or measurements of the composition of CO_2 derived from Bio-CCS are available.**
- Fly ashes from biomass combustion can be characterized: coarse fly ash with particle diameters of 1–250 um, and aerosols with particle diameters of 0.01–1.00 um

Planned modifications

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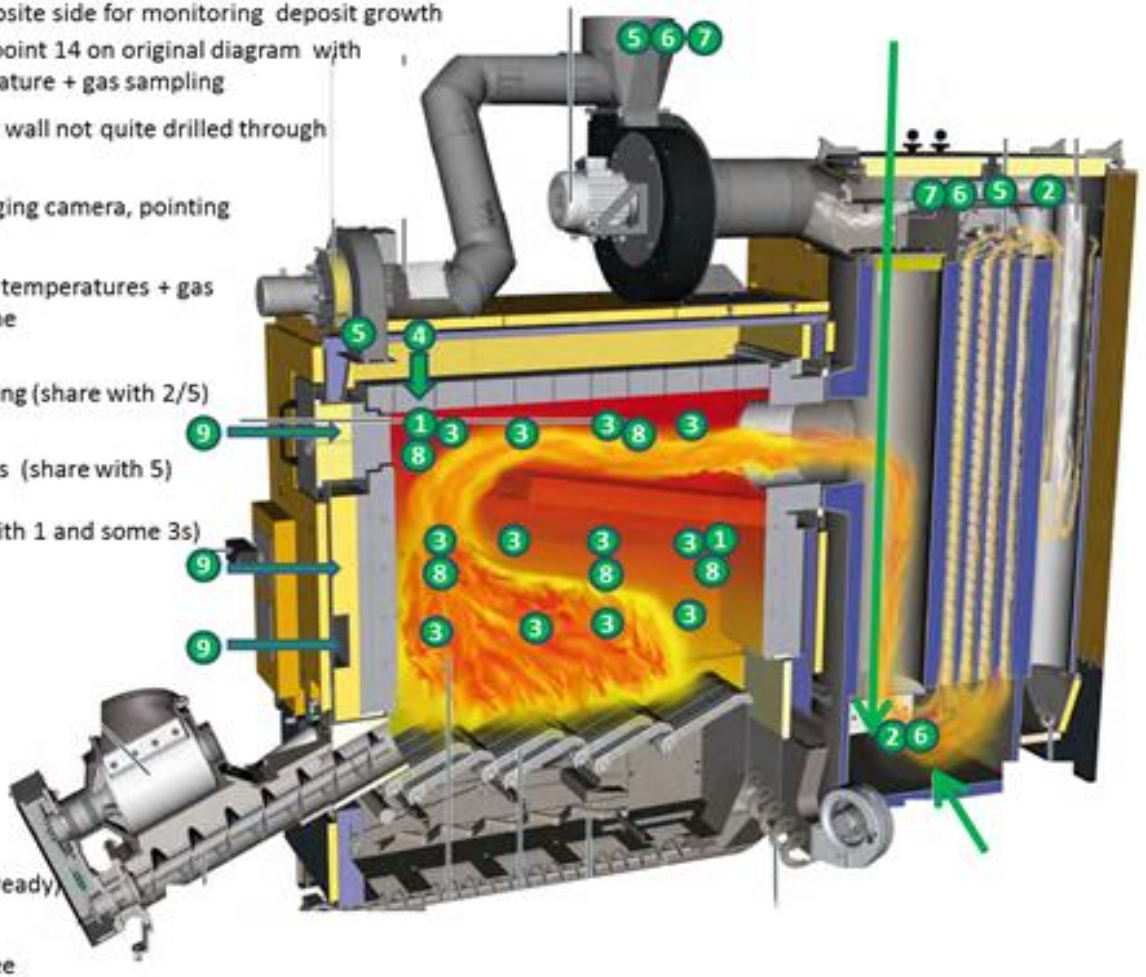
1. 2 off 3" ports for 1.5" deposition probes + temperature + 2 off 2" camera probes from opposite side for monitoring deposit growth
2. 2" corrosion probe ports , one by point 14 on original diagram with access from top and side + temperature + gas sampling
3. Array of 12 Fixed thermocouples at wall not quite drilled through chamber temperature profiling
4. 1 to 2 off 2" ports for thermal imaging camera, pointing down onto the flame
5. 3 off 1/2" port: gas compositions + temperatures + gas Composition and temperature of the Mixed flue gas recycled line
6. 3 off 1/2" port: ICP for metal profiling (share with 2/5)
7. 2 off 1/2" port: particle size analysis (share with 5)
8. 5 off Heat flux 38mm (can share with 1 and some 3s)
9. 3 off central 1.5" ports for suction pyrometer, other)



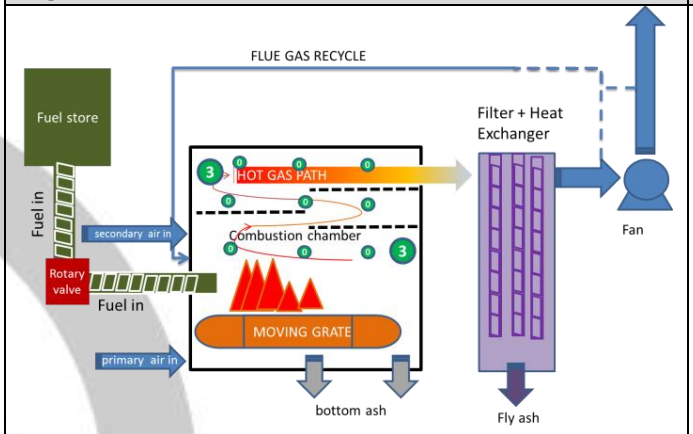
OTHER REQUIREMENTS

10. Air inlet metering + metering of recycled air
11. Separation of fly and bottom ash
11. Water energy metring (if not in already)
12. 3 fuel feeders for feeding three different fuels/ additives from three separate feeders tuned in to different operating rates and synchronised with the rotary valve
14. Additional channels for data recording on the system and/or data stream and inputs for external data monitoring and control system + remote access operation

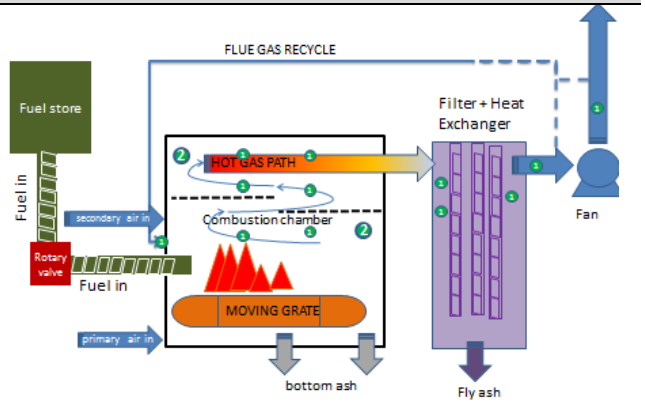
Open Tender

- ETA withdrew collaboration (unclear why)
- Proceeding to open tender to generic spec + mods
- Tender process, negotiation ~ 6 weeks
- Mod Specs and HAZOP: ~ April/May
- Completion with Mods ~June/July

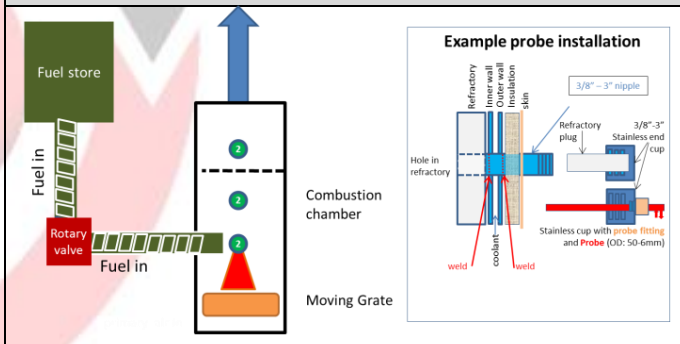
Right view



Left view



Front view



Port	QTY	Port size	Designation
0	6-9 (monitor hot gas path)	3/8 " nipple + endcap	A: 6mm thermocouple
1	12 (6 in chamber)	1" nipple + 2x endcap (w/o plug)	B: Suction pyrometer C: Heat Flux probe D: gas sampling probe E: Corrosion probe
2	5	2" nipple + 2x endcaps (w/o plug)	G: Camera probe B; C; D; E
3	2	3" nipple + 2x endcaps (w/o plug)	F: Deposition probe