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Biomass and Recycled Wood Utilisation in the PACT CTF: Experimental Characterisation and Comparison of Emissions

Presented by: M. Pourkashanian

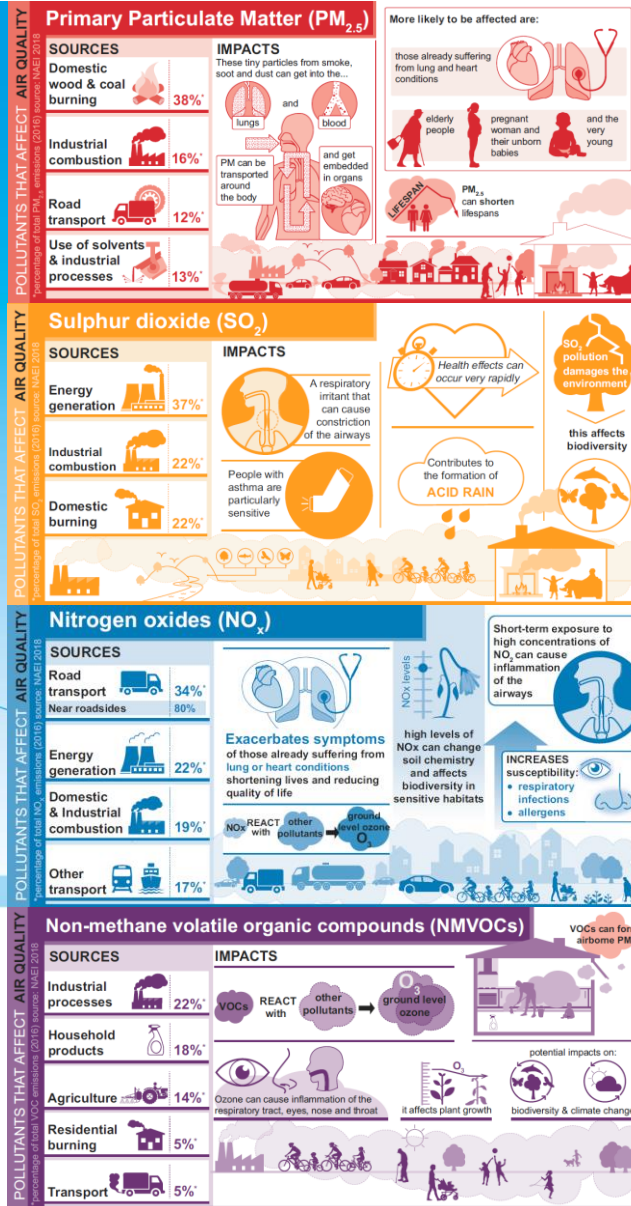
K.N. Finney, J. Szuhanszki, K. Milkowski, M. Akram



Biomass and Emission

Department for Environment Food & Rural Affairs

CLEAN AIR STRATEGY 2018



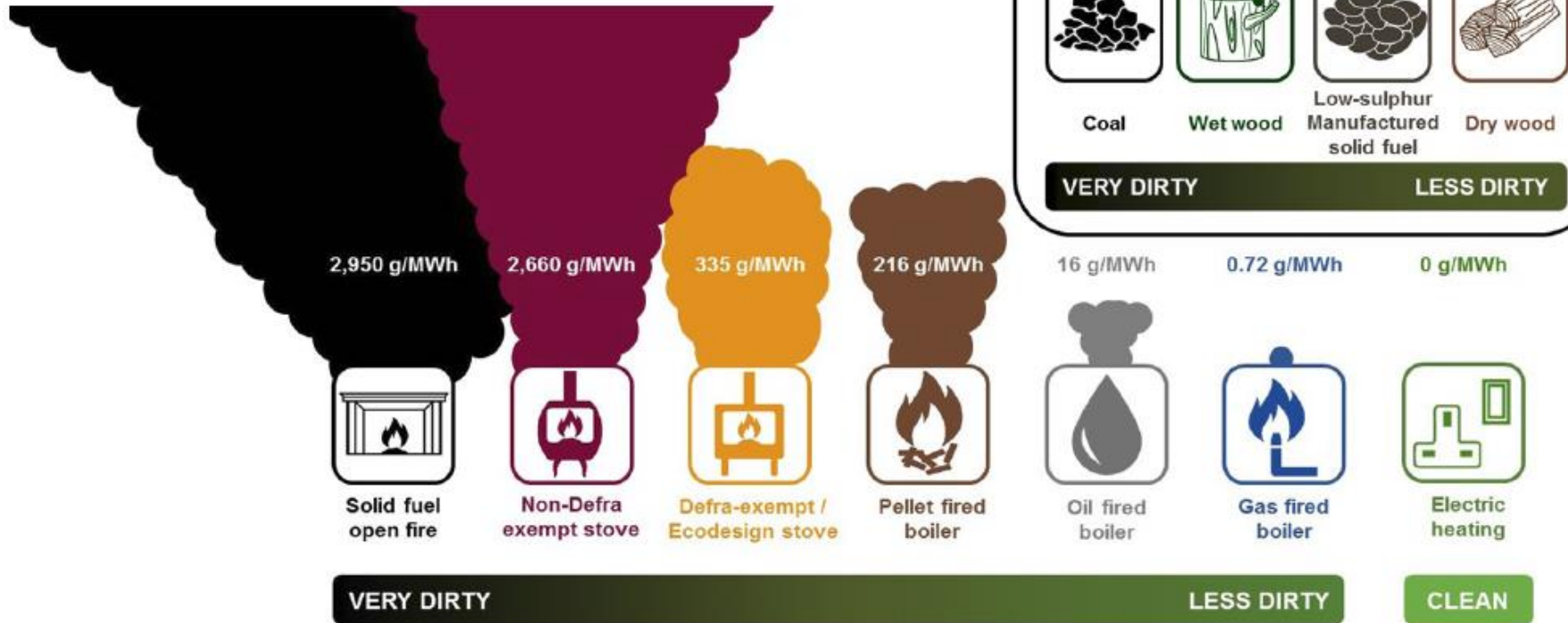
- Particulate matter (PM)
 - impacts on the env.
- Open fires and wood-burning stoves as additional form of heating for many households in both urban and rural areas;
- Growth of biomass boilers for home heating.
 - an impact on our air quality
 - single largest contributor to our national PM emissions at 38%.
- Industrial combustion (16%) and road transport (12%).

- Directly measured emissions
- Data and our understanding of the activities that produce air pollution



Reducing the impact of domestic burning

Relative PM_{2.5} emissions in your home from domestic heating methods



Smoke plumes are not to scale. Emission factors show emissions in the home – emissions during production of fuel or electricity are not included here. Emission factors taken from EMEP 2016 Guidebook (1A4 - small combustion tables). The following definitions were used: *Solid fuel open fire*: wood burned in an open fire; *Non-Defra approved stove*: wood in a conventional stove; *Defra-approved / Ecodesign stove*: wood in an advanced / ecolabelled stove; *Pellet fired boiler*: wood in pellet stoves and boilers; *Oil fired boiler*: fuel oil in a medium (>50kWh <1MWh) boiler; *Gas fired boiler*: natural gas in a small (≤50 kWh) boiler.



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Challenges of biomass utilisation

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Mould during storage



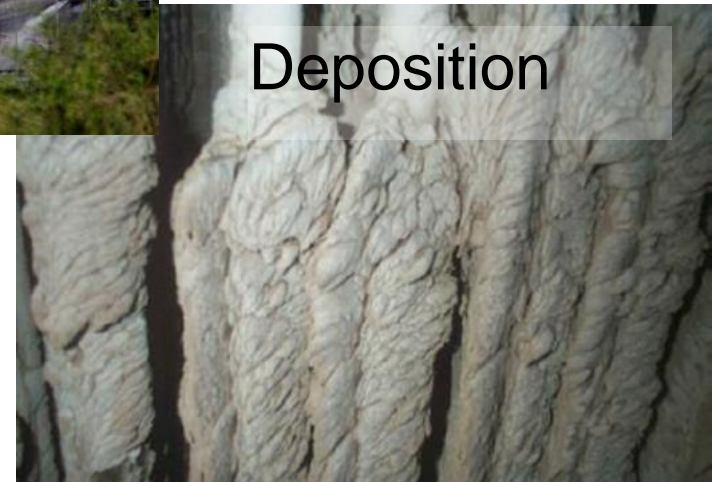
Heterogeneity and particle size reduction



Fire and explosion risk



Deposition





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Current Fuels Tested at PACT

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Virgin Wood (SCR Willow)

Grade A recycled wood

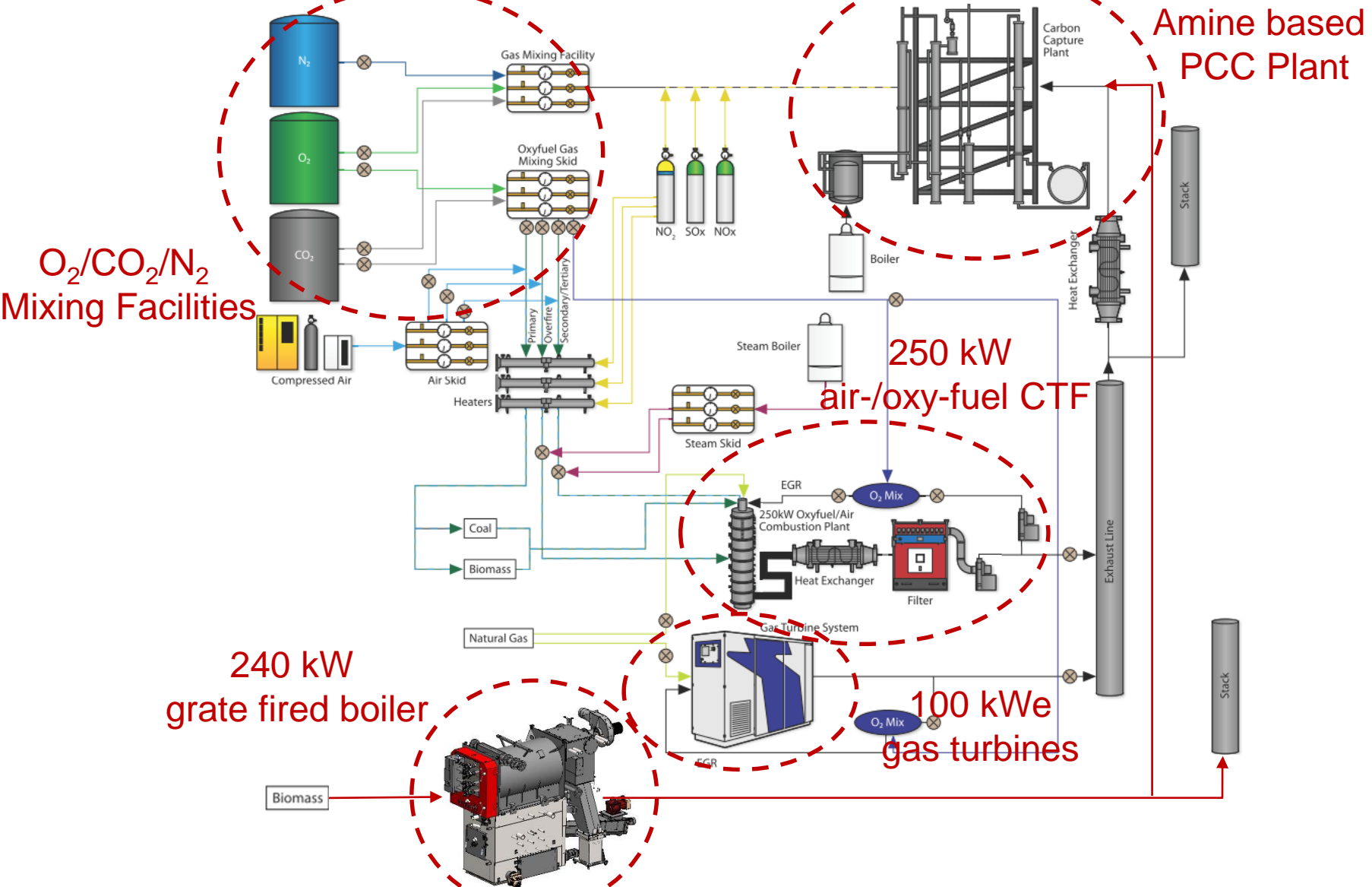




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PACT Core Facilities

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O₂/CO₂/N₂
Mixing Facilities

Amine based
PCC Plant

250 kW
air-/oxy-fuel CTF

240 kW
grate fired boiler

100 kW
gas turbines

Integrated PACT facilities

240kW biomass chip/pellet grate boiler



300kW CHP gas turbines



250kW PF coal & biomass air/oxyfuel test facility



Gas mixing facilities: synthetic /modulated flue/process gas



Sym. EGR

Air/Oxyfuel

Sym. EGR

Synthetic flue /process gas w/o trace gas

Flue gas modulation

Combustion/ gas facilities



1 tonne of CO2 per day capture plant

Post Combustion Capture



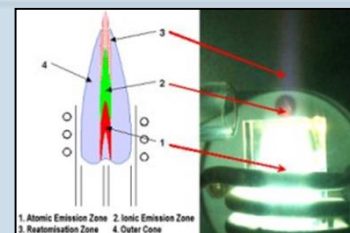
Gas analysers: Stack and FTIR



Solvent analysis



Metal aerosols analysis



Particulate analysis



Online Analytical



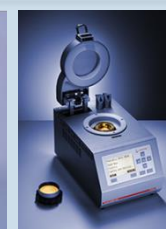
Autotitrator



GC-MS



TG analyser



Petroxy



CHNS Analyser

Lab Analytical

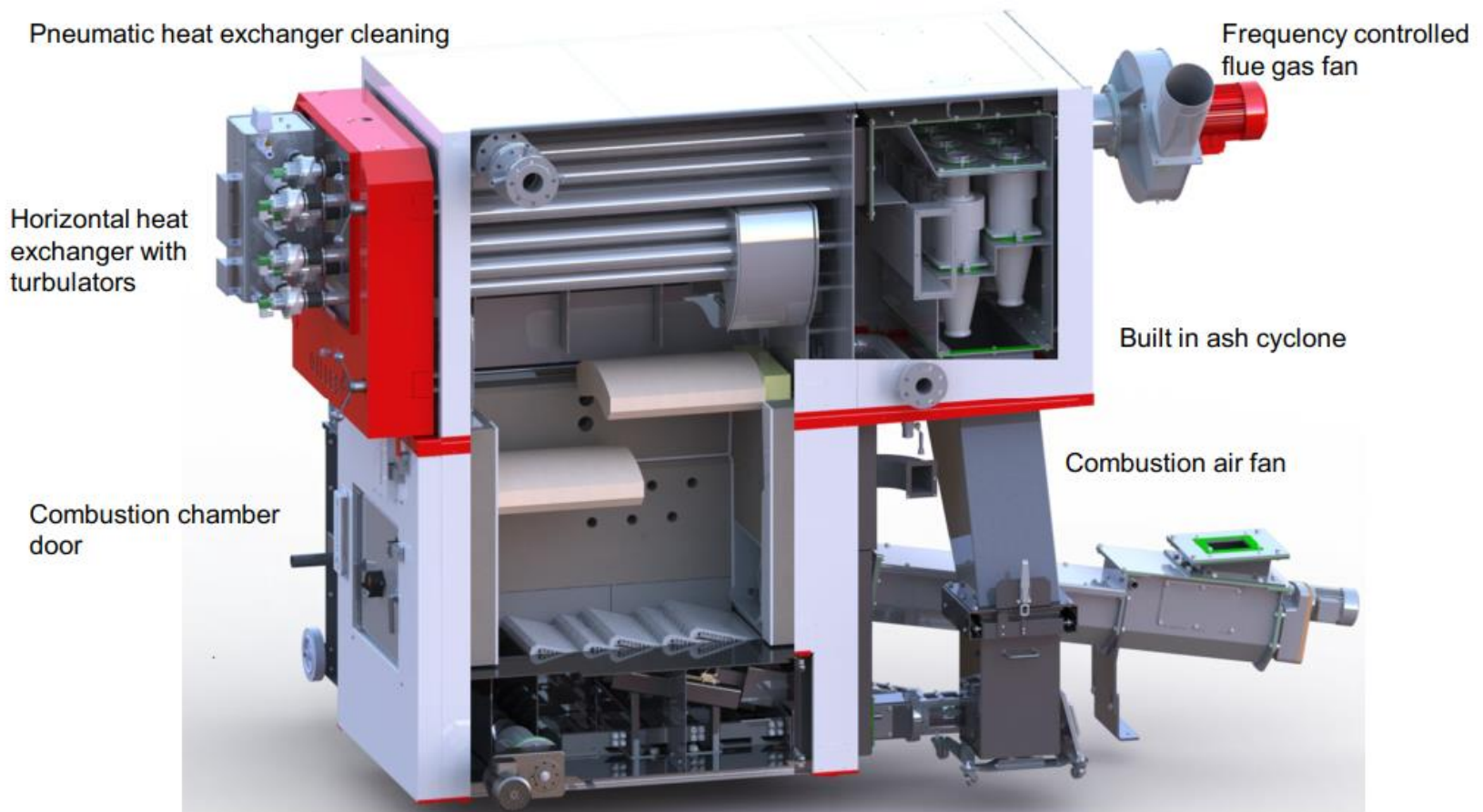


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Grate fired boiler

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- Latest addition to the PACT rigs the 240 kW grate fired boiler
- Integration to post combustion capture plant (PCCP) for solvent research





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Current Fuels Tested at PACT

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Proximate & Ultimate analysis (wt%, ar)

	Willow	Grade A
Moisture	12.0	17.1
Volatiles	73.4	71.3
Fixed Carbon	13.9	11.3
Ash	0.70	0.3
C	43.63	41.81
H	5.06	4.80
N	0.32	0.12
S	0.04	0.02
Cl	0.02	0.03
O	38.23	35.82
GCV (MJ/kg)	17.36	16.86
NCV (MJ/kg)	15.96	15.39

Ash Fusion temperatures (°C)

	Willow	Grade A
Initial deformation	>1500	1490
Softening	>1500	1500
Hemispherical	>1500	>1500
Flow	>1500	>1500



Combustion characterization

- In-furnace temperatures & gas compositions
- Deposition and corrosion probing
- Burnout & metal partitioning between bottom and fly ash streams
- Flue gas composition, metal aerosol and submicron particulates emissions



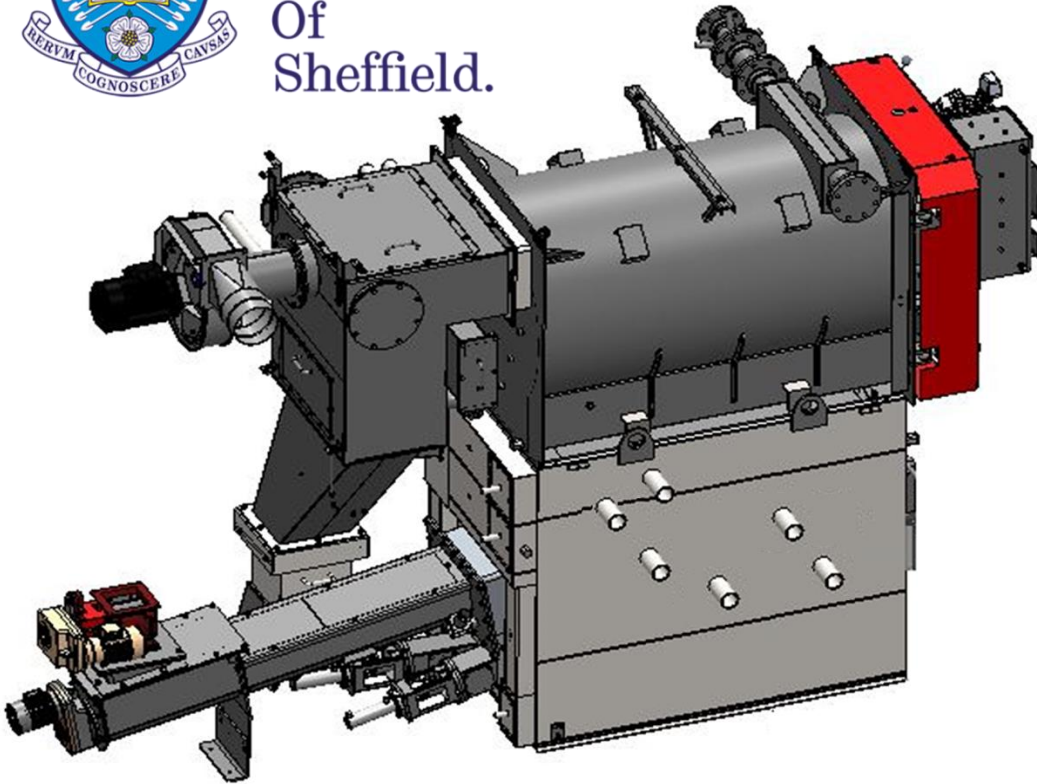
Capture Plant performance: (future research)

- Flue gas and solvent flow rates
- Lean and rich loading
- Absorber temperatures and pressures
- Boiler duty
- CO₂ capture rate
- Emissions (metal aerosols, submicron particles, ammonia)



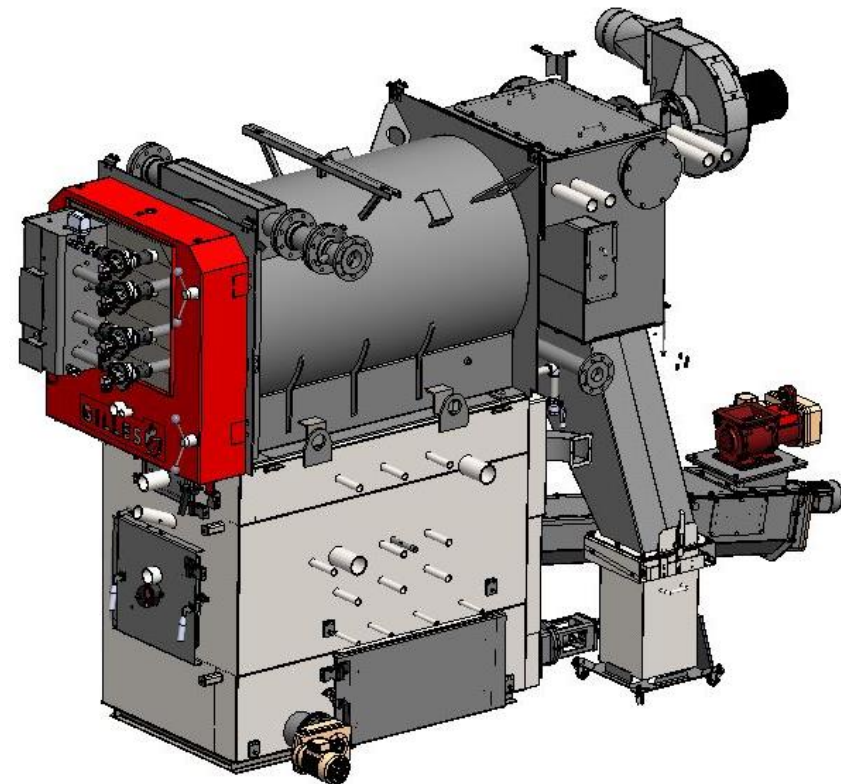
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2" and 3" ports along boiler to enable comprehensive combustion characterisation

- 11 ports in the combustion chamber and overpass to the boiler (in-furnace temperature, gas composition, deposition, corrosion)
- 7 ports before and after the cyclones (flue gas composition, metals, particulate emissions)
- 16 fixed thermocouples

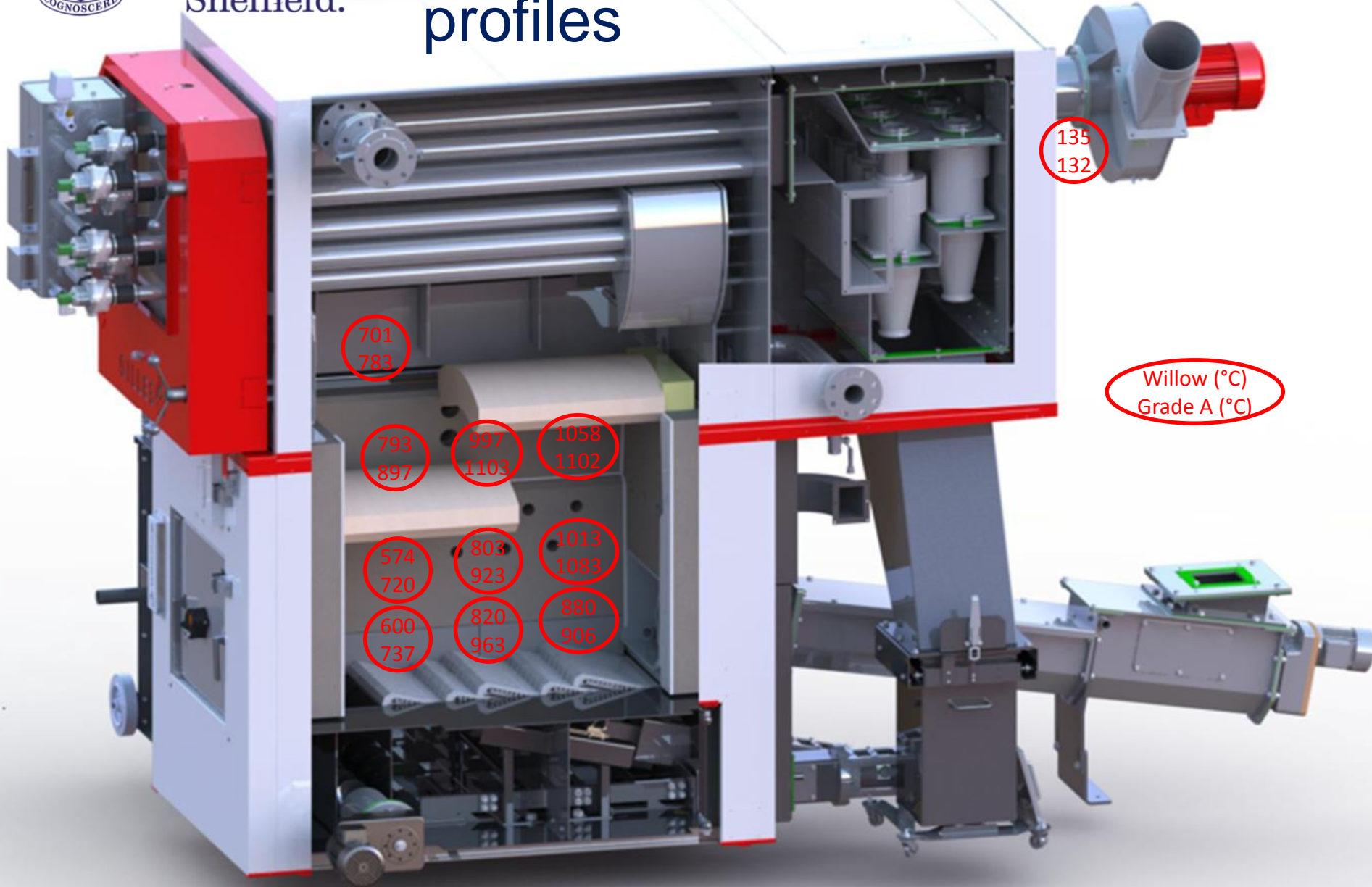




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Temperature profiles

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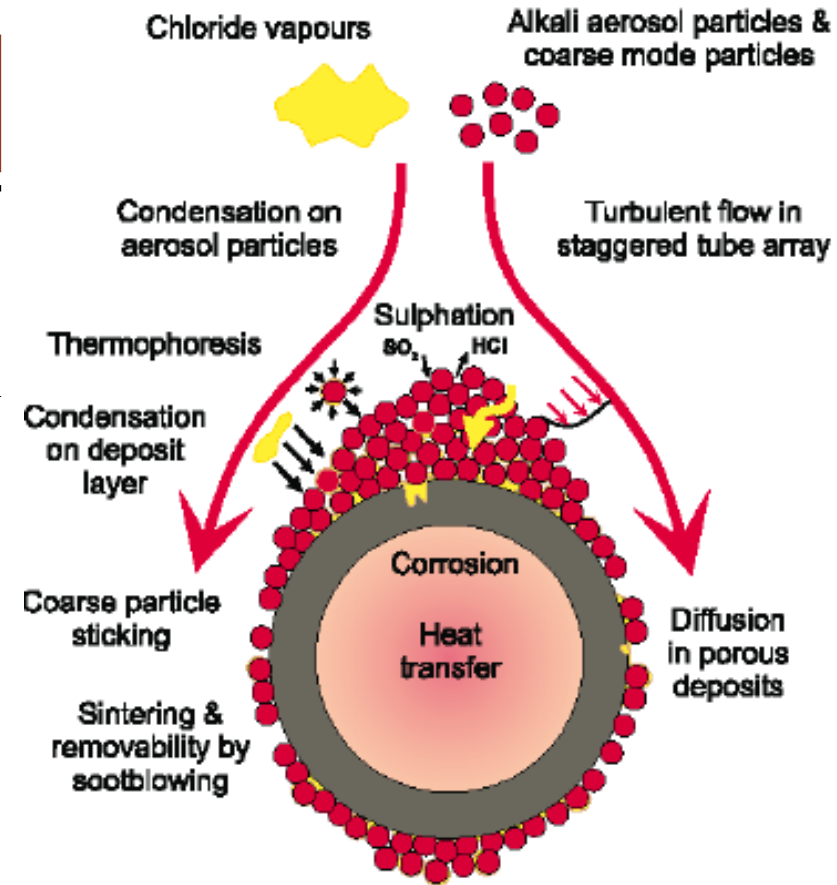
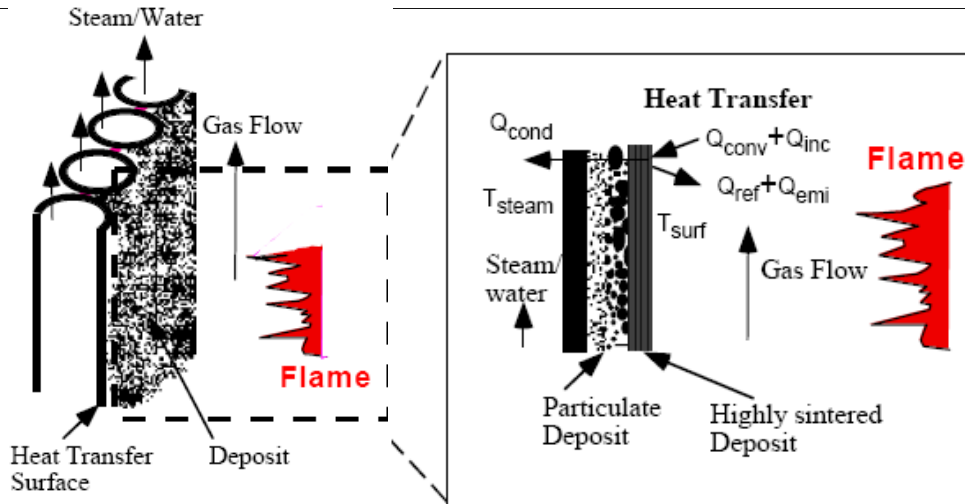
ELSEVIER



Modelling of deposit formation and sintering for the co-combustion of coal with biomass

M.U. Garba, D.B. Ingham, L. Ma*, M.U. Degereji, M. Pourkashanian, A. Williams

CFD Centre, Energy Technology and Innovation Initiative, Faculty of Engineering, University of Leeds, Leeds LS2 9JT, UK



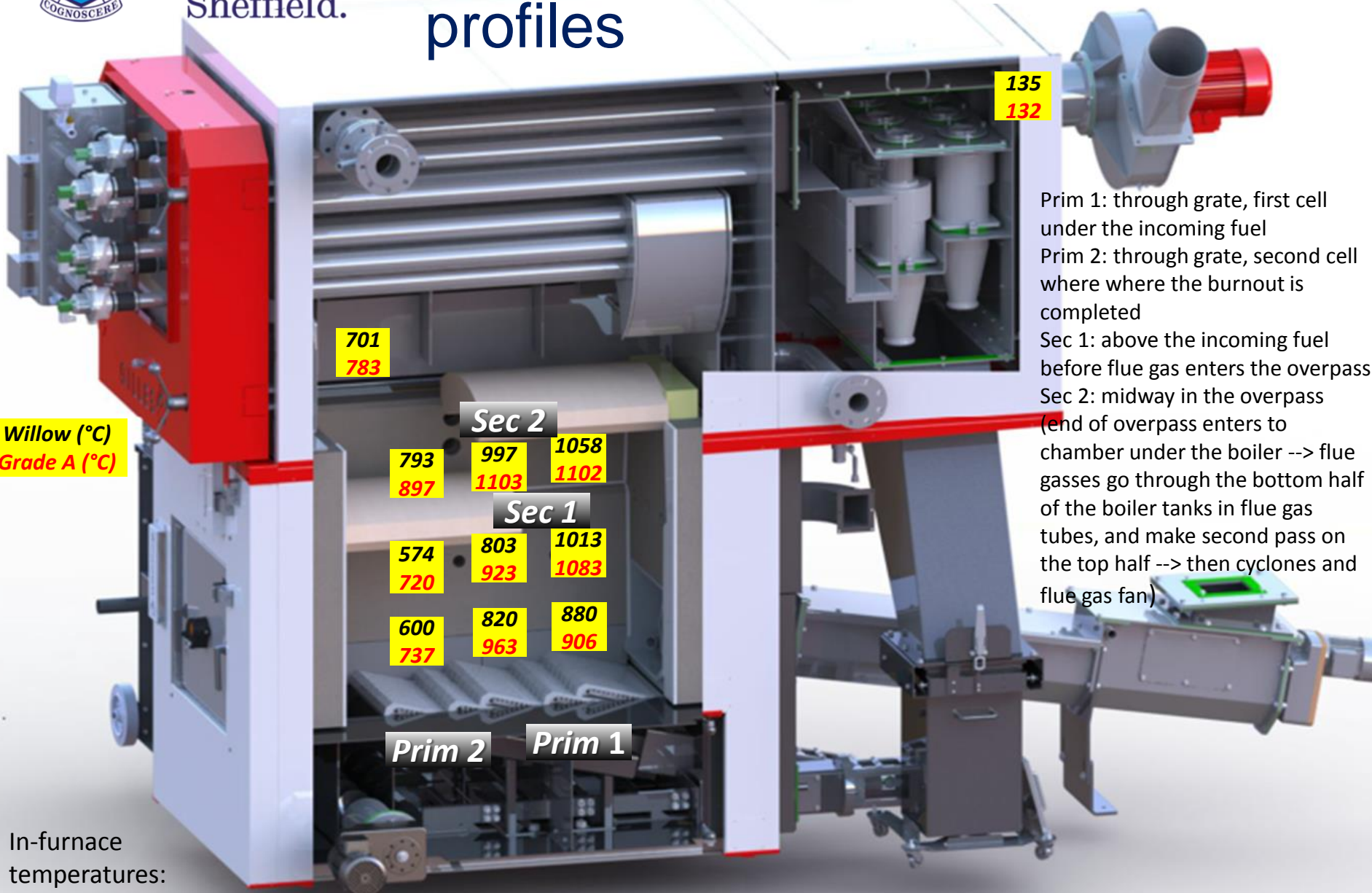
- ❑ Deposition on boiler tubes impacts the overall boiler performance
- ❑ Reducing efficiencies and increasing maintenance requirement



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Temperature profiles

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135
132

701
783

Willow (°C)
Grade A (°C)

Sec 2

793	997	1058
897	1103	1102

Sec 1

574	803	1013
720	923	1083
600	820	880
737	963	906

Prim 2

Prim 1

Prim 1: through grate, first cell under the incoming fuel
 Prim 2: through grate, second cell where where the burnout is completed
 Sec 1: above the incoming fuel before flue gas enters the overpass
 Sec 2: midway in the overpass (end of overpass enters to chamber under the boiler --> flue gasses go through the bottom half of the boiler tanks in flue gas tubes, and make second pass on the top half --> then cyclones and flue gas fan)

In-furnace temperatures:



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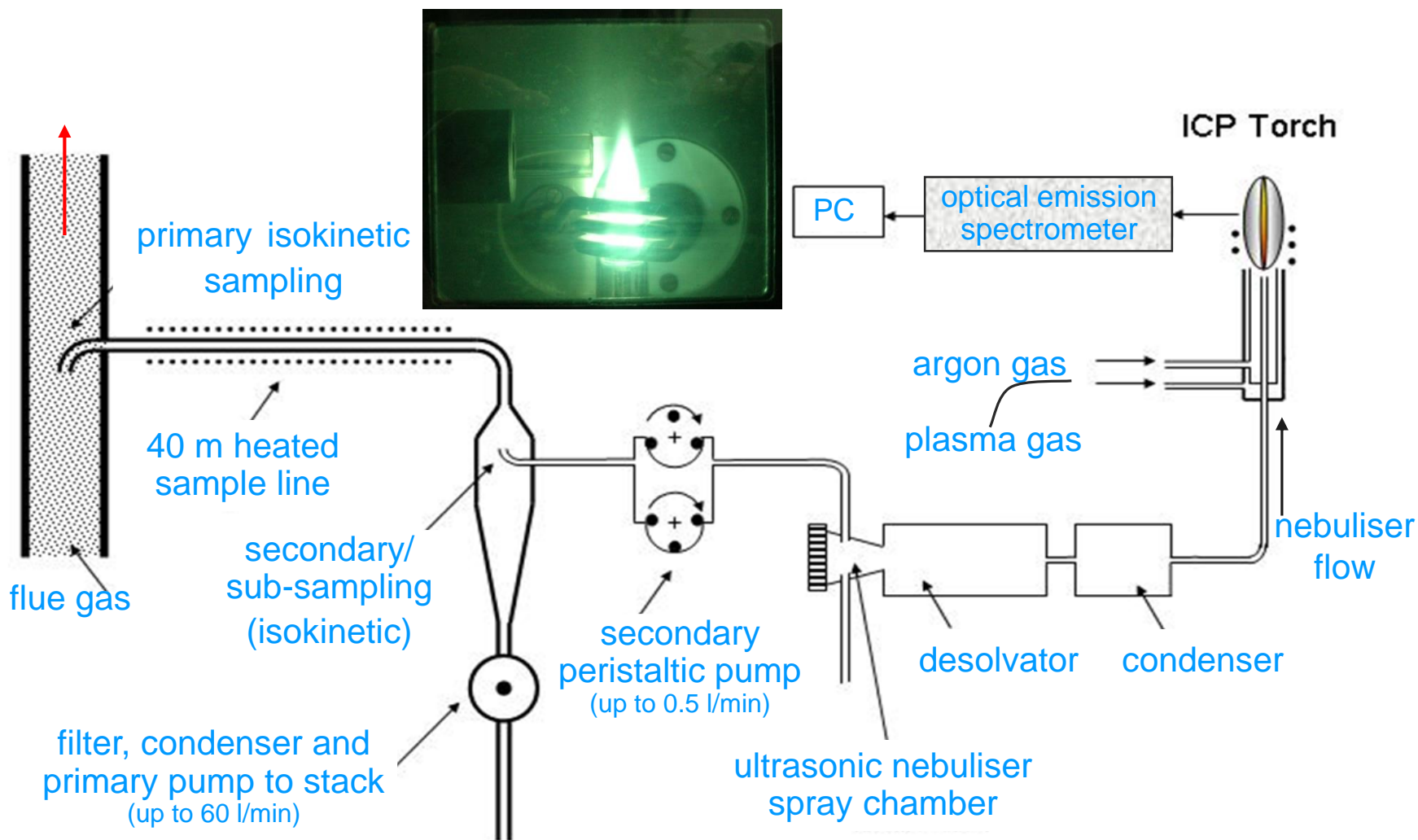
- The continuous metal emissions monitoring laboratory is a self-contained mini mobile laboratory to quantify levels of entrained metal aerosol emissions
- It houses a Spectro Ciros^{CCD} ICP-OES: an inductively coupled plasma – optical emissions spectrometer
- Emissions spectra of non-volatile/volatile elements:
 - ~ over 30 elements – Pb, Na, Zn, B, Al, Br, Ca, Cr, Sc, Cd, Fe, I, K, Li, Co, Cu, Ti, P, Si, Sn, Mg, Ni, Mn, Ag, Tl, S, V, Sb and Hg
- Our tests will focus on elements that:
 - ~ cause operational issues (slagging, fouling, corrosion) **K and Na**
 - ~ are easily vaporised **Hg, Cd, Pb**
 - ~ are toxic (heavy metals) **Hg, V, Cr, Cd and Pb**



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Sample system configuration

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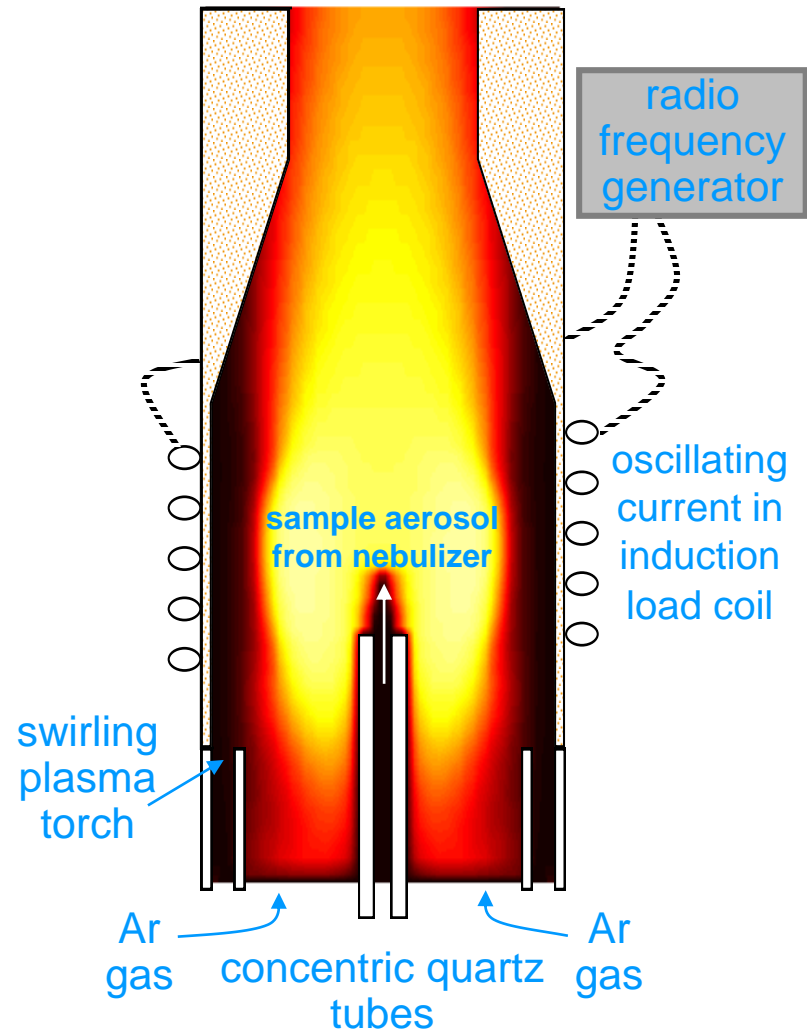


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ICP Torch

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- Custom-built, radial, demountable plasma torch
- Argon plasma heated to 6000K
- The plasma torch excites the sample to higher energy states. On relaxation, from these excited states, causes a release of photons. These photons have specific wavelengths directly corresponding to the transition in energy level, and it is this fingerprint wavelength that is used to identify the specific species present in the sample





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ICP Data from Combustion Tests

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Spectral Line	Lower Detection Limit (mg/m ³)	Upper Line Range (mg/m ³)	Correlation Coeff
Ag 328.068	0.00366	18.488	0.99996
Al 396.152	0.01450	16.500	1.00000
As 189.042	0.09120	18.488	0.99997
B 249.773	0.09440	16.394	0.99987
Ba 455.404	0.00031	18.488	0.99999
Ca 422.673	0.24900	16.500	1.00000
Cd 228.802	0.00306	18.488	0.99997
Co 228.616	0.00352	18.488	0.99996
Cr 267.716	0.00268	18.488	0.99996
Cu 324.754	0.00252	18.488	0.99994
Fe 259.941	0.00344	16.394	0.99999
Hg 253.652	0.10400	15.907	0.99949
K 766.491	0.07330	16.500	0.99993
Li 670.780	0.00192	18.488	0.99996
Mg 279.553	0.00114	16.394	0.99996
Mg 285.213	0.00183	16.394	0.99999
Mn 257.611	0.00052	16.394	0.99998
Mo 202.030	0.01060	16.394	0.99999
Na 589.592	0.03330	18.488	0.99996
Ni 231.604	0.01030	18.488	0.99995
Ni 227.021	0.01830	18.488	0.99996
Pb 220.353	0.05960	18.488	0.99999
Pb 261.418	0.01770	16.394	0.99997
Sb 206.833	0.05810	18.488	0.99999
Tl 190.864	0.13000	16.394	0.99987
V 292.464	0.00280	16.394	0.99996
Zn 213.856	0.00536	18.488	0.99994

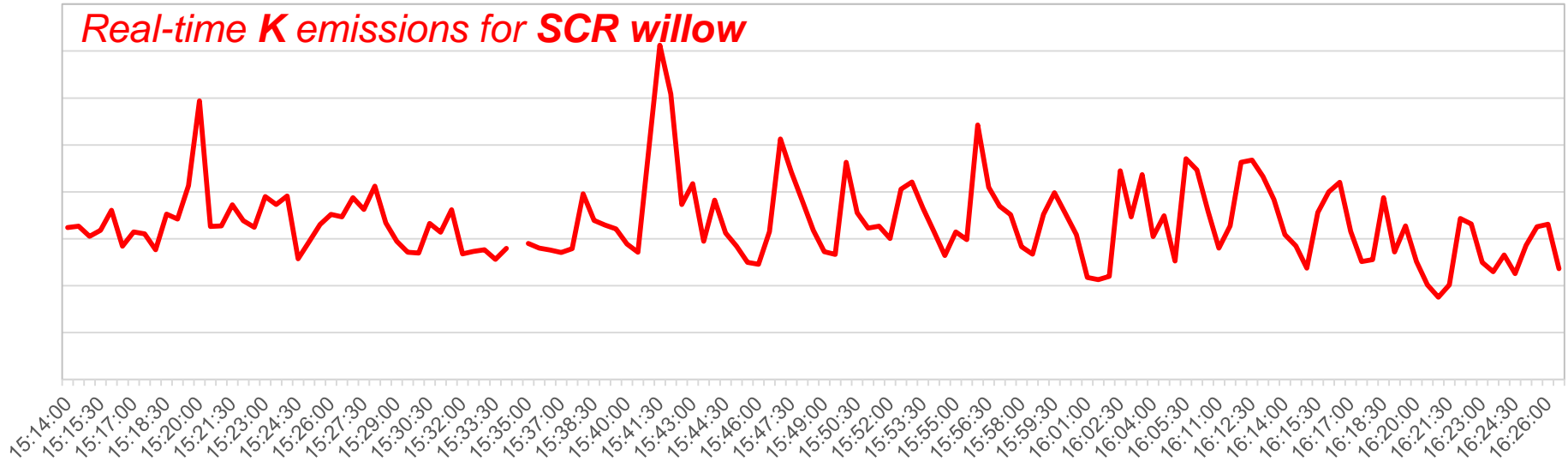


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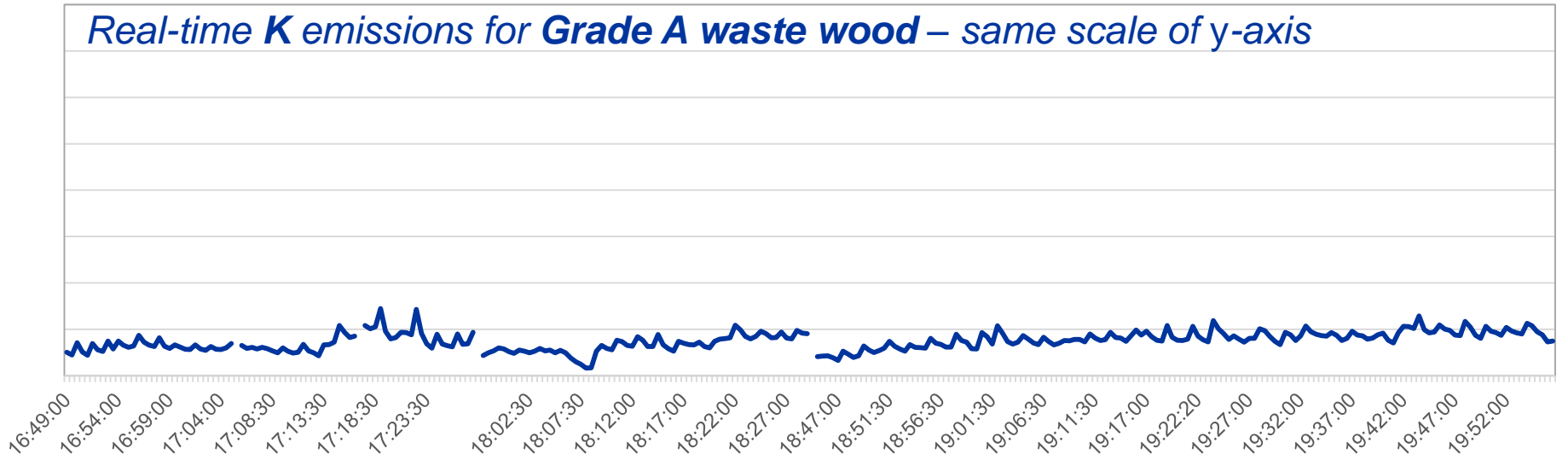
ICP Data from Combustion Tests

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Real-time K emissions for SCR willow



Real-time K emissions for Grade A waste wood – same scale of y-axis



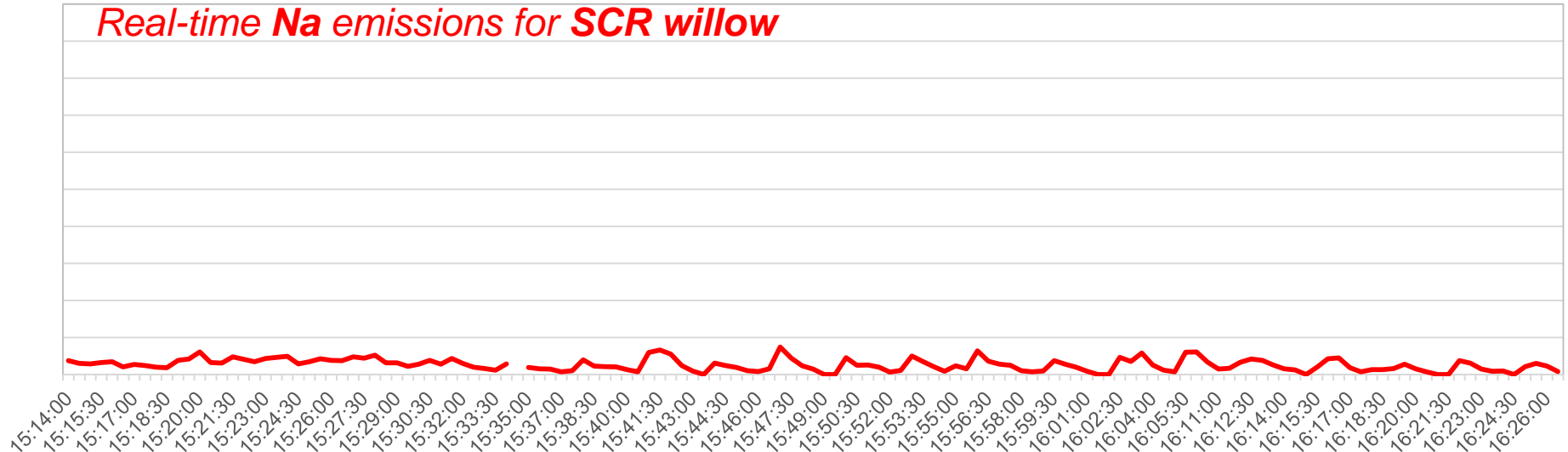


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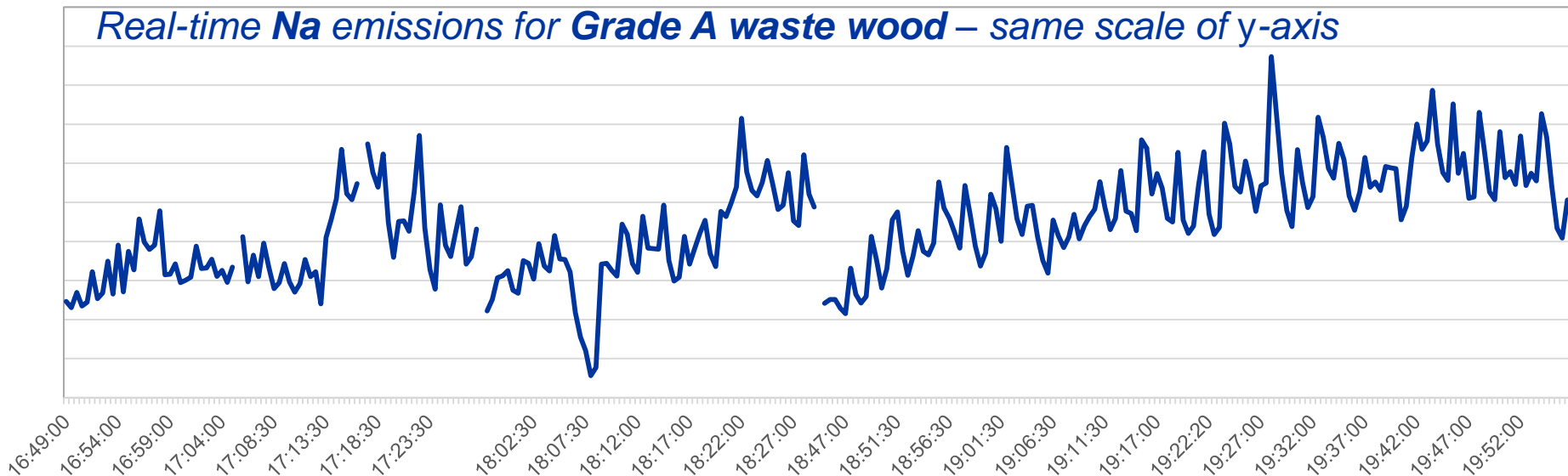
ICP Data from Combustion Tests

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Real-time Na emissions for SCR willow



Real-time Na emissions for Grade A waste wood – same scale of y-axis



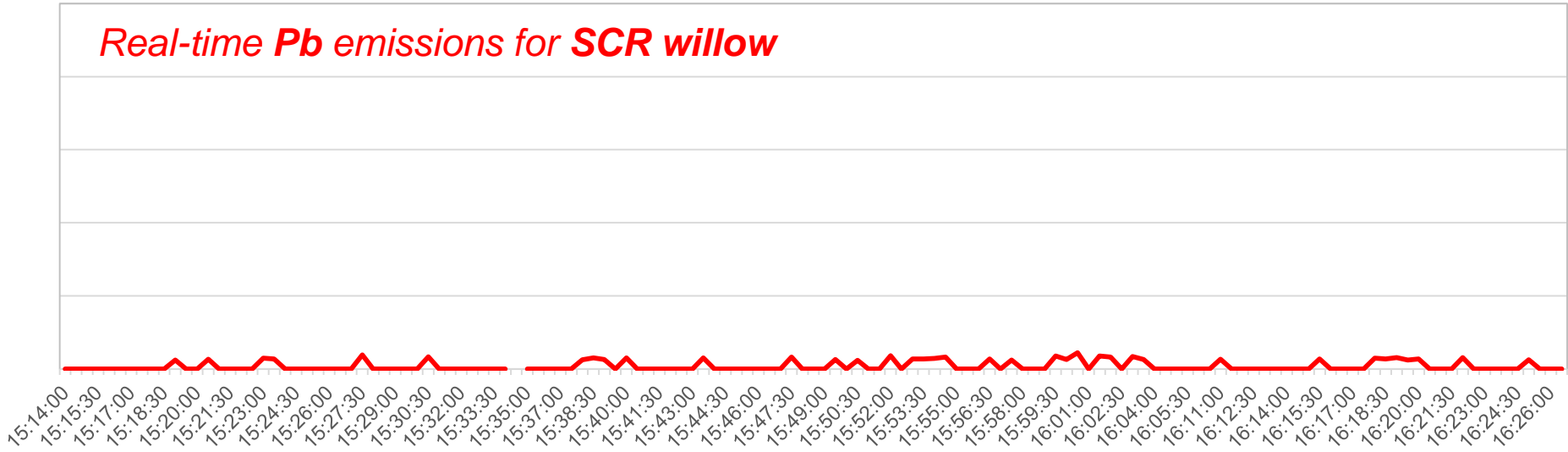


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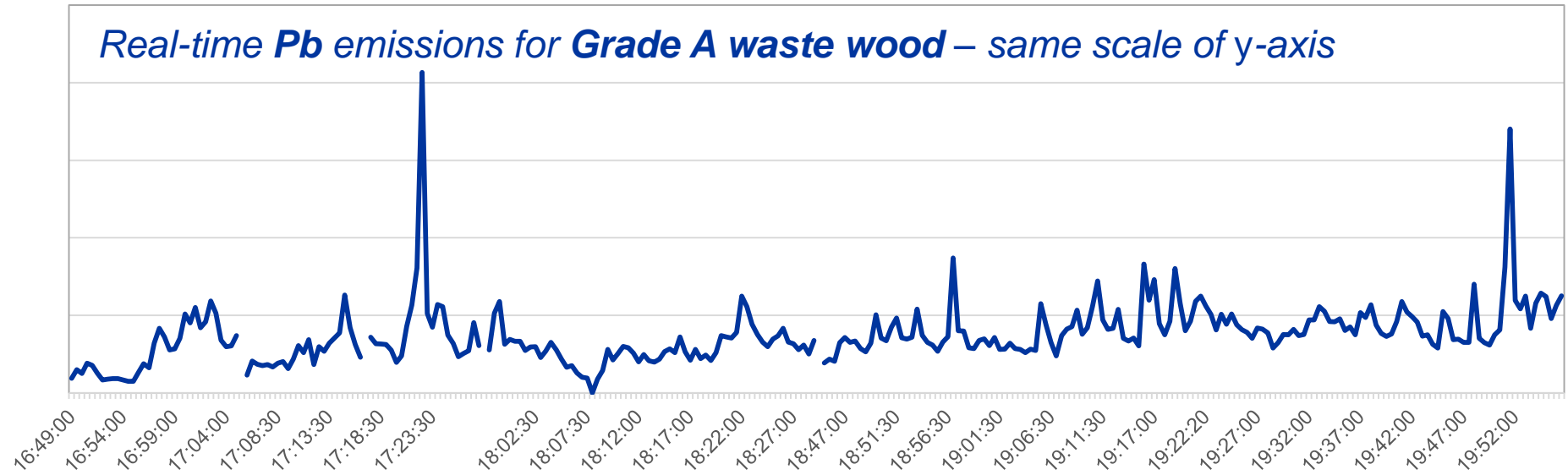
ICP Data from Combustion Tests

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Real-time Pb emissions for SCR willow

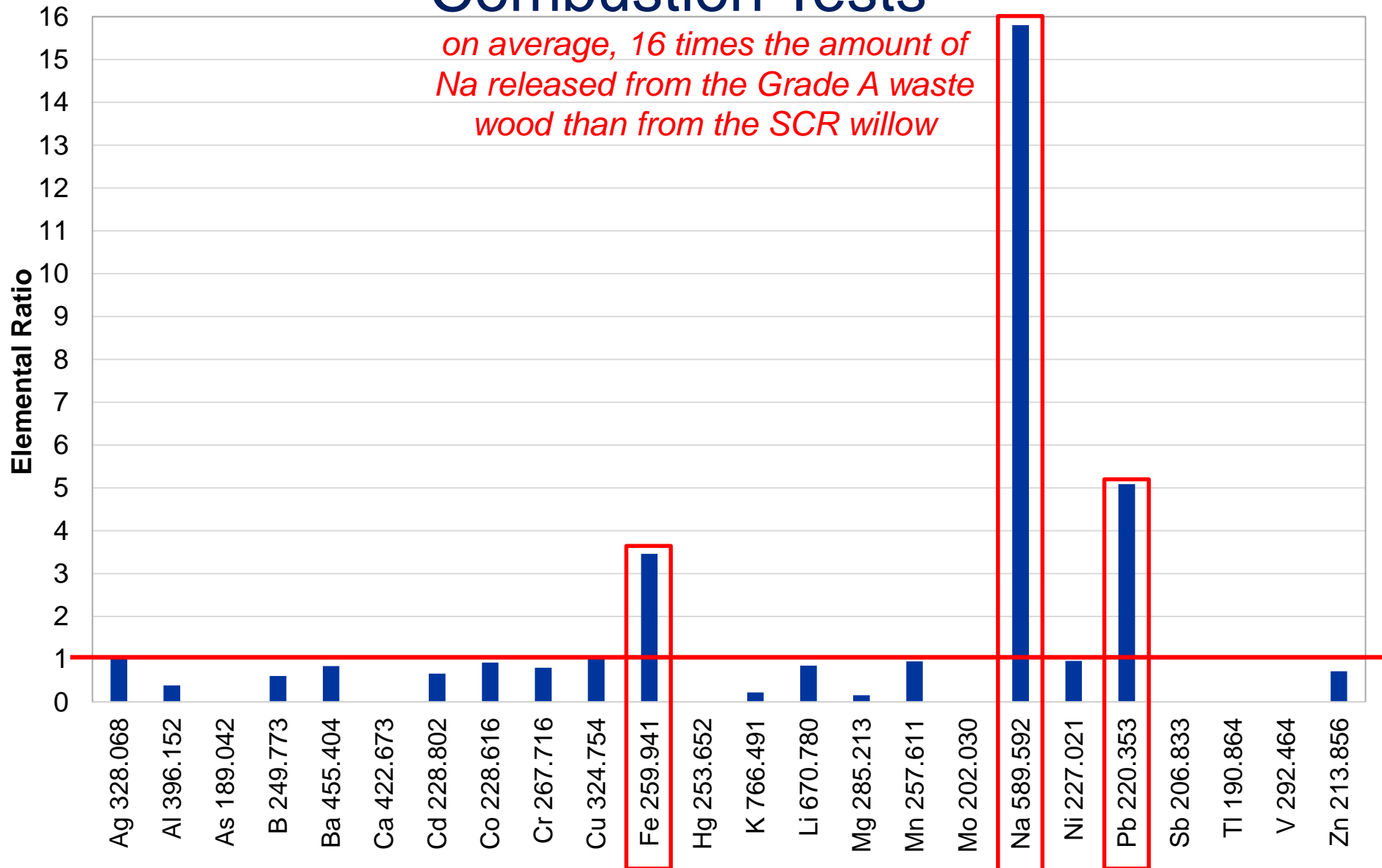


Real-time Pb emissions for Grade A waste wood – same scale of y-axis





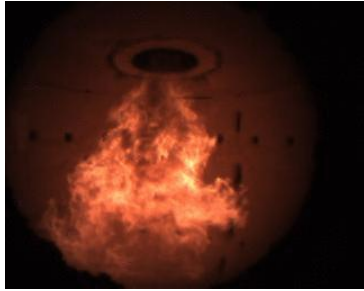
ICP Data from Combustion Tests



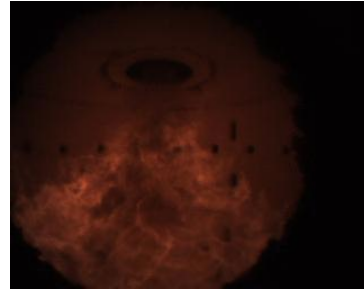
BECCS: fuel and oxidizer switching

Experimental calculation of the oscillation frequency - BIOMASS

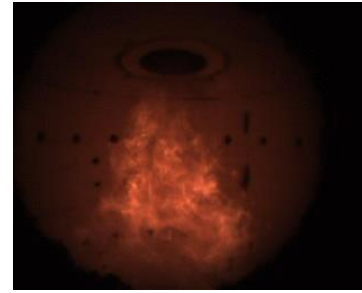
Original flame imaging



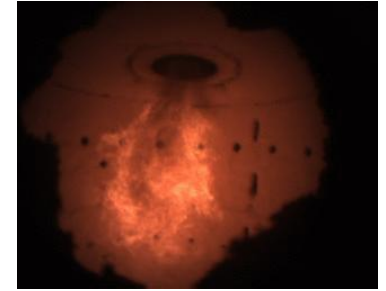
Air



Oxy24

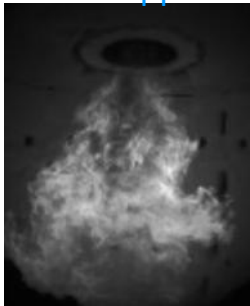


Oxy27

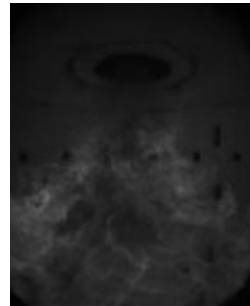


Oxy30

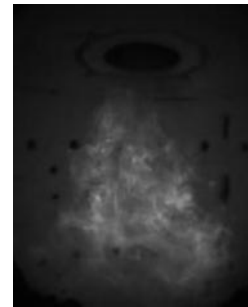
Luminance approach



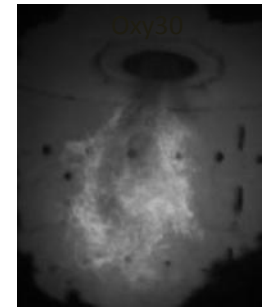
Air



Oxy24

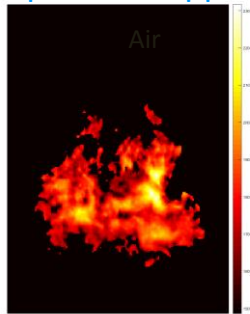


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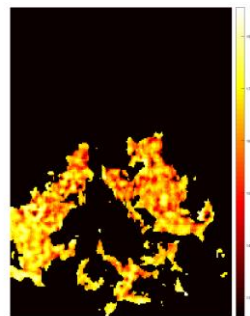


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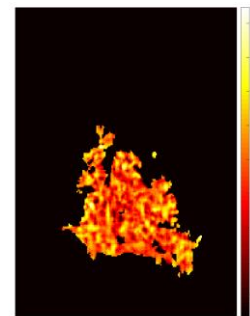
Temperature approach



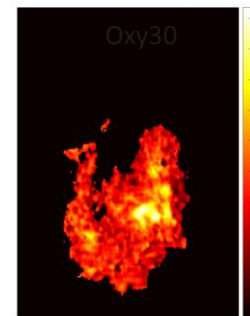
Air



Oxy24



Oxy27

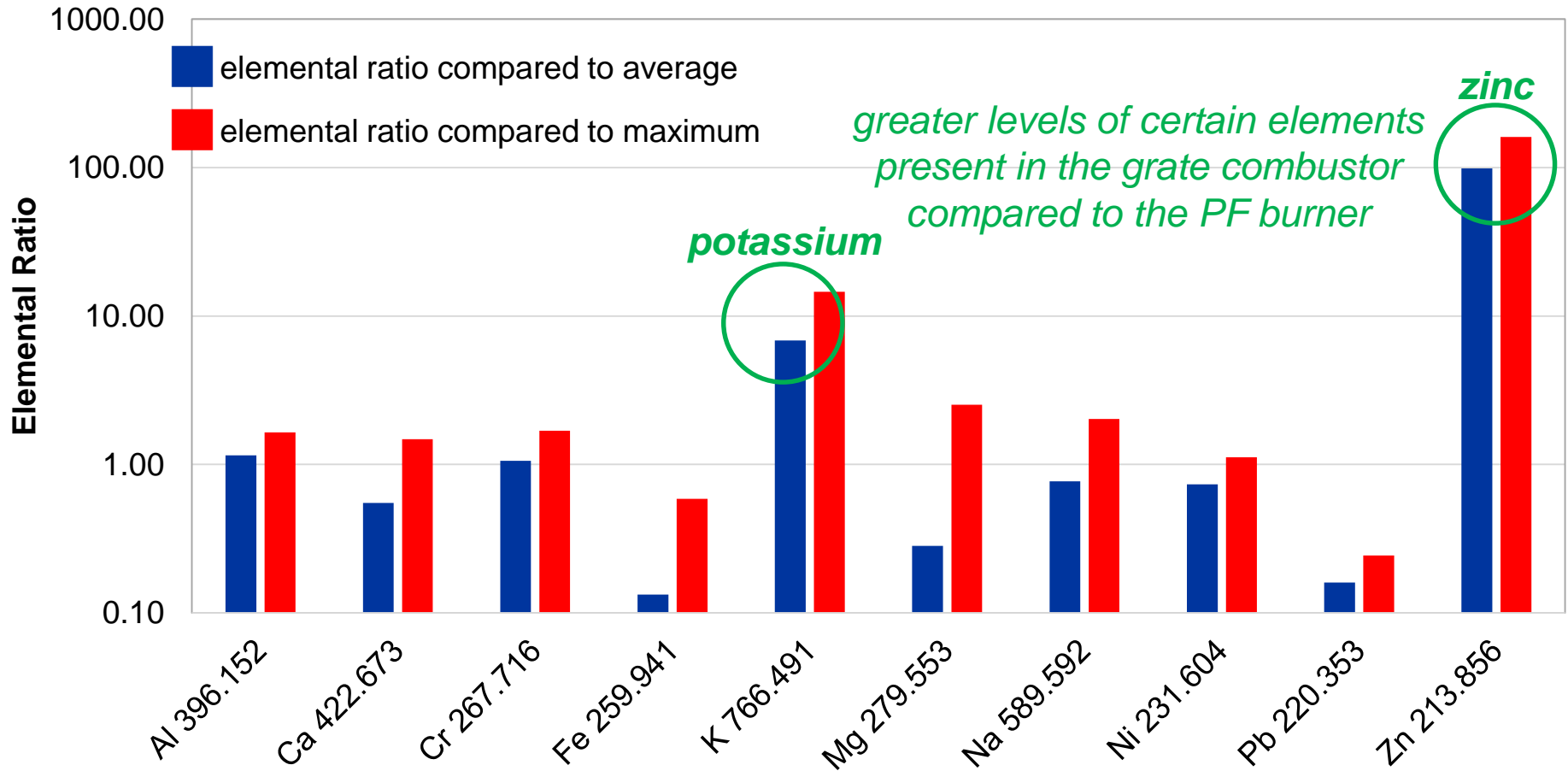


Oxy30



ICP Data from Combustion Tests

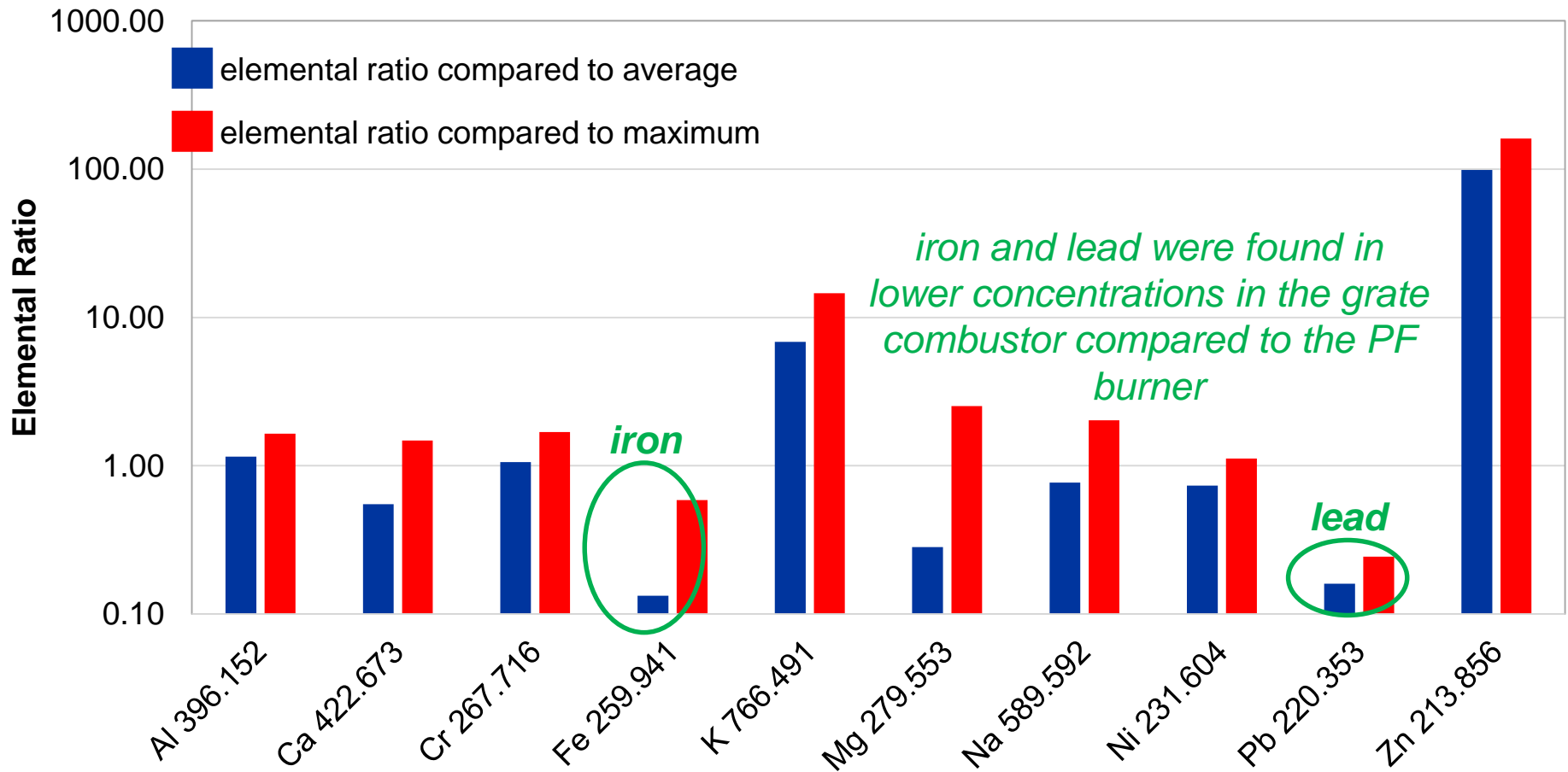
- Comparison of SCR willow combustion in the grate boiler to white wood combustion in a PF burner – elemental ratios





ICP Data from Combustion Tests

- Comparison of SCR willow combustion in the grate boiler to white wood combustion in a PF burner – elemental ratios

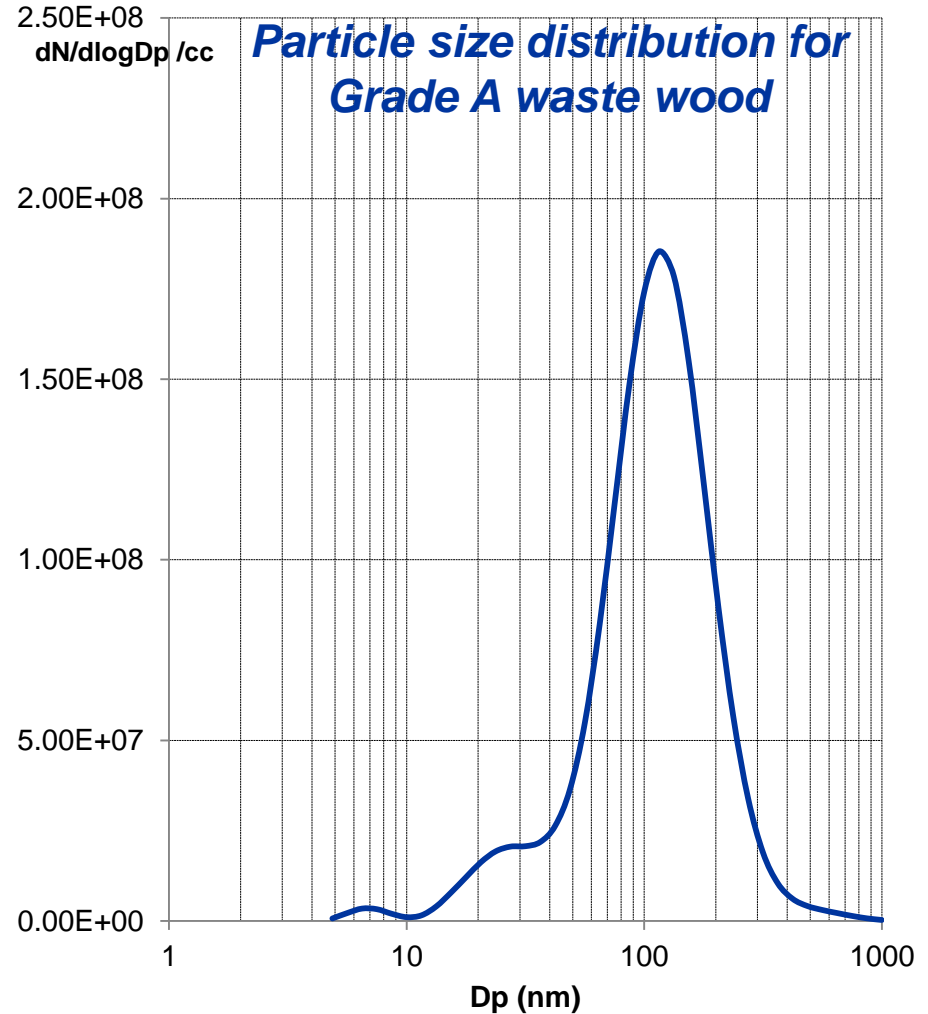
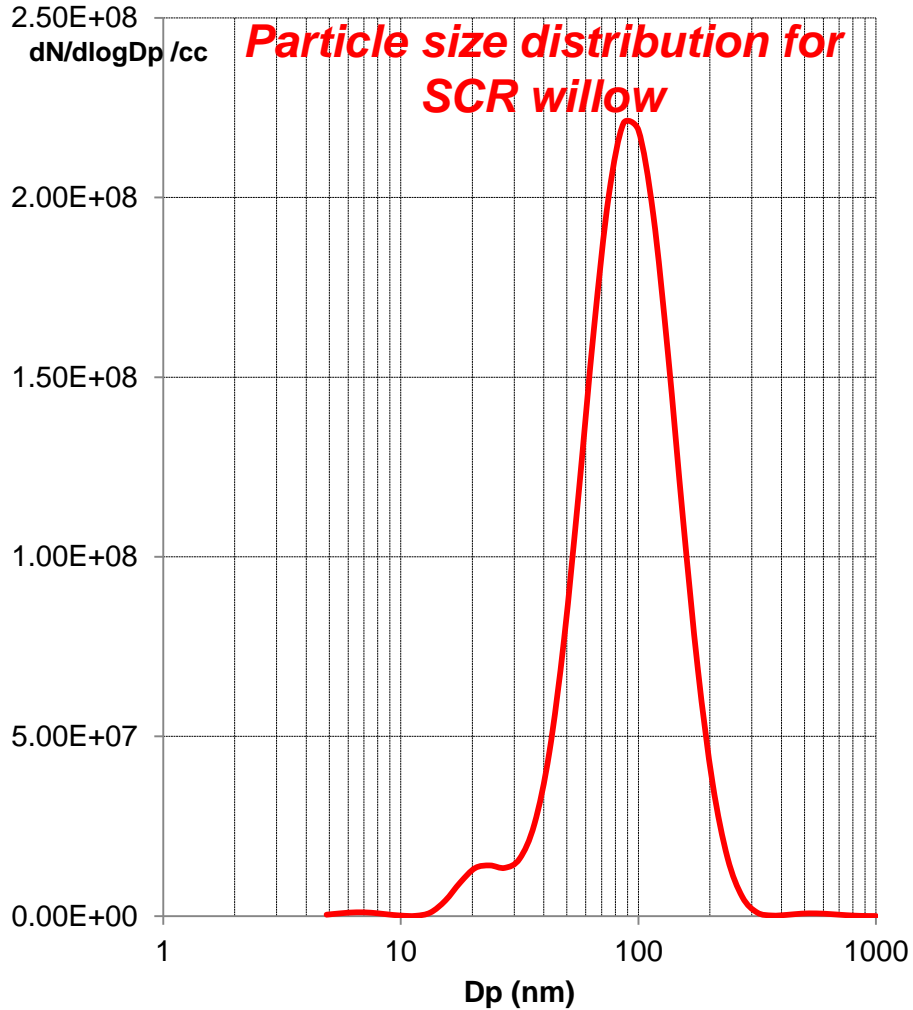




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DMS data – submicron particle size distribution

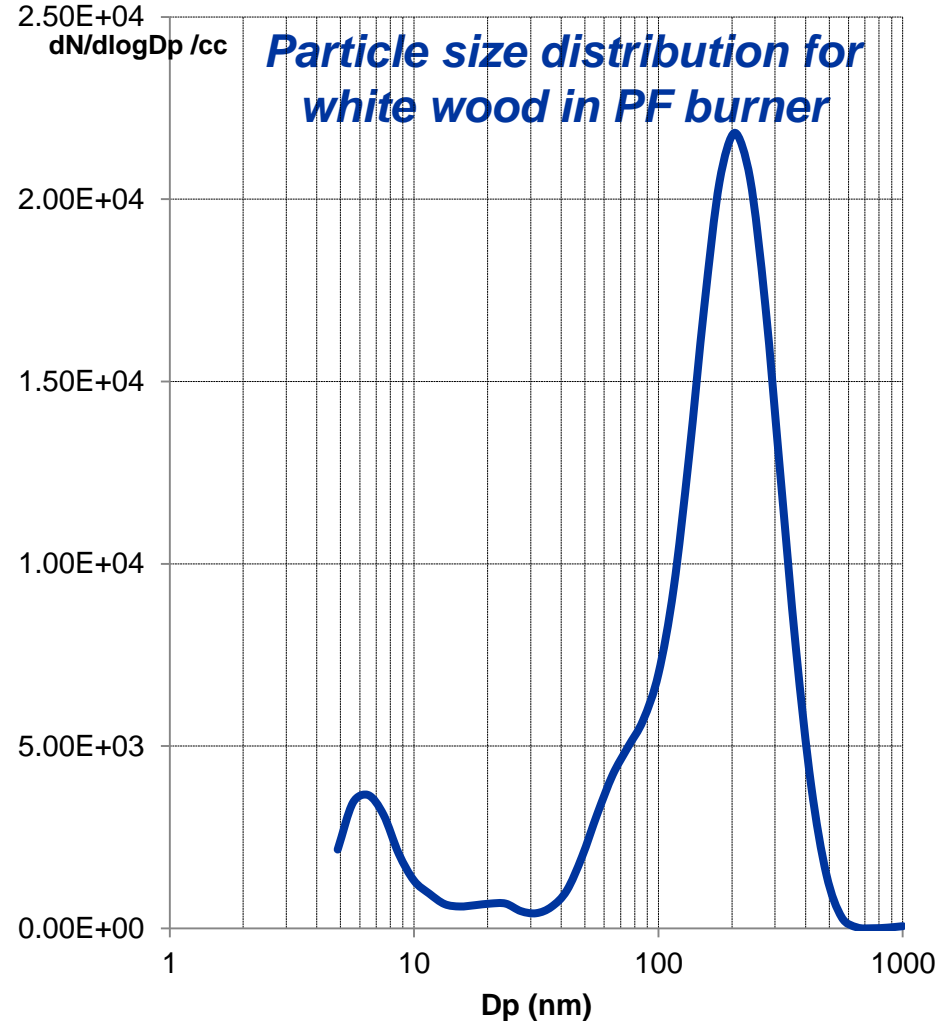
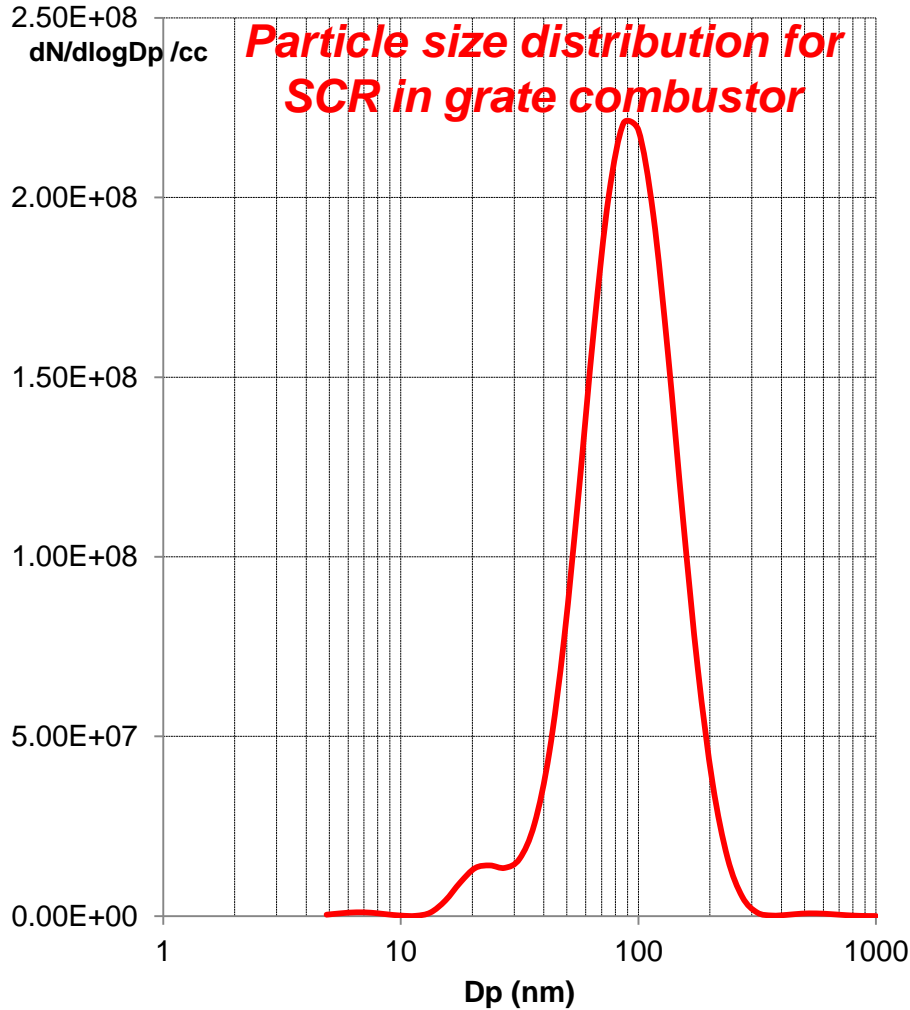




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DMS data – submicron particle size distribution

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DMS data – submicron particle size summary

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	Total Particle Concentration (N/cc)	Geometric Mean Diameter (nm)	Peak Size Concentration
SCR willow in grate combustor	107,637,062	86.5	peak 1: 20-30 nm peak 2: 86 nm
Grade A waste wood in grate combustor	100, 424,977	89	peak 1: 31 nm peak 2: 115 nm
air-fired white wood in PF burner	12,065	106.5	peak 1: 6-7 nm peak 2: 205 nm



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ICP Data Summary

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- Overall, relatively similar levels of different emissions were achieved for the SCR willow and Grade A waste wood combustion tests – the main difference was for alkali metals (potassium and sodium)
- For SCR willow, **potassium** was the most prominent element, with very high levels of entrained aerosol emissions in the flue gas
- For the Grade A waste wood, **potassium**, **sodium** and **zinc** were the dominant elements to come through as entrained aerosols – but were generally much lower in concentration than for the SCR willow with the exception of sodium
- Entrained aerosol emissions alkali earth metals were found in minimal concentrations in both flue gases, despite notable concentrations in the initial fuel samples
- **Mercury** was not detected in either flue gas; only very low levels of other heavy/toxic metal, such as **chromium**, **cadmium** and **lead** were seen for both fuels

Thank you!



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EPSRC

Engineering and Physical Sciences
Research Council

Imperial College
London

Any Questions?

*The work is part of the Opening New Fuels for UK Generation (EPSRC Grant:
EP/M015351/1)*