Biomass Use in the UK and Related Research

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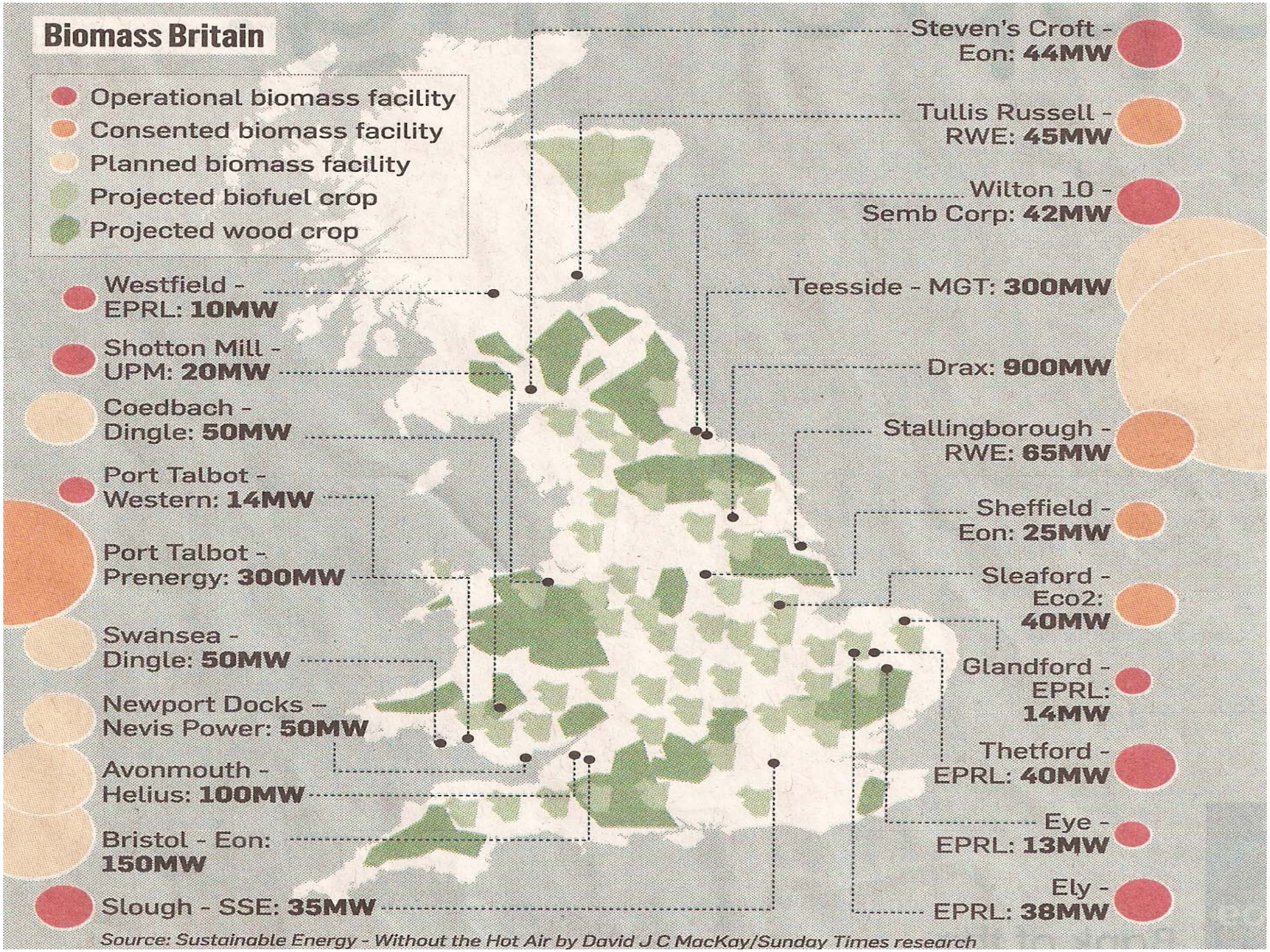
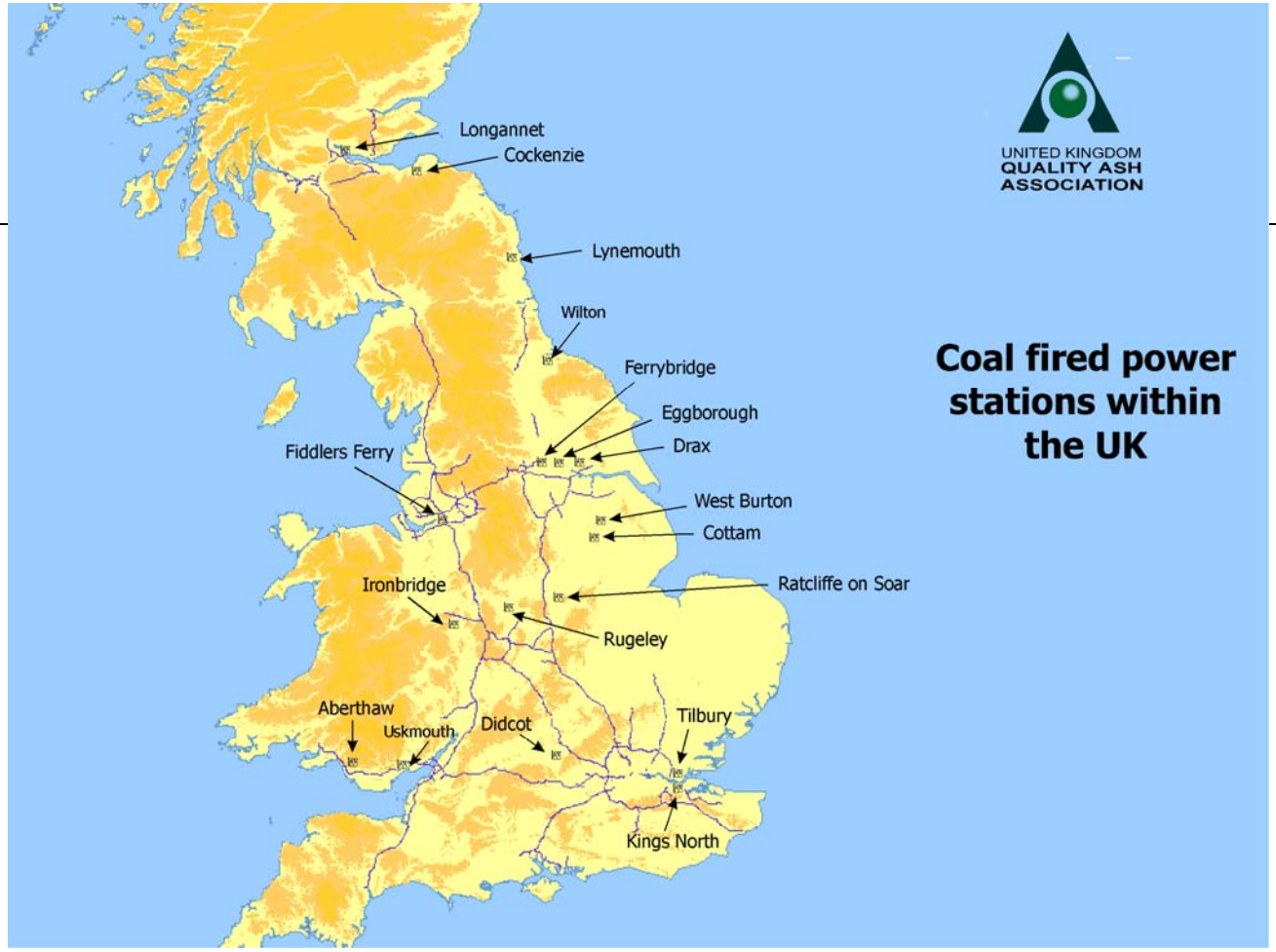


Source: Sustainable Energy - Without the Hot Air by David J C MacKay/Sunday Times research



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"*All sixteen major UK power plants are now co-firing a proportion of biomass, at an average level of 3% (energy basis) making use of a range of fuels including wood (virgin and recycled), olive cake, palm kernal expeller, sewage sludge and energy crops*."

BIOMASS Energy Centre

Feedstock for co-firing in the UK by type, quantity and source

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Feedstock	Quantity burned (tonnes) in 2005	% quantity burned (tonnes) in 2005	Likely country of origin	Mode of transport	Total transport-related emissions (kg CO_2/tonne biomass)
Energy crops (SRC,granulated willow, miscanthus)	4,306	0.3	UK	Road	1.7
Shea residues (meal and pellets)	5,420	0.4	Africa	Ship	55.4
Sunflower pellets	20,331	1.4	Romania	Road & ship	47.1
Sewage sludge and waste derived fuels	49,155	3.5	UK	Road	3.4
Cereal co products and pellets	102,246	7.2	UK	Road	1.7
Tallow	119,828	8.5	UK	Road	1.7
Olive waste (residue and expeller)	283,222	20.1	Greece, Italy Spain	Road & ship	21.2
Wood (sawdust, chips, pellets, tall oil)	377,956	26.8	UK, Canada, Latvia, Scandinavia	Road & ship	1.7 (UK) to 42.9
Palm residues (palm kernel expeller, shell, pellets, oil)	449,657	31.8	Indonesia, Malaysia	Road & ship	106.5 (Indonesia) to 107.4 (Malaysia)
Total mass	1,412,121				
Total energy (PJ)	14.1				

Sources: UK Biomass Strategy, DEFRA, May 2007 & Evaluating the Sustainability of Co-firing in the UK, report to DTI from Themba Technology Ltd, September 2006

Large scale biomass use

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Co-firing – biomass procurement and transportation is a big issue.

Many developments are importing agricultural residues and woods.

Source: Steve Martin, Drax

Research into solid biomass at Leeds

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Characterisation and combustion properties of biomass:

- **Energy crops (v small contribution at present)**
    - Miscanthus; Short rotation willow; Reed Canary Grass; Switchgrass; short rotation forestry.
- **Wood & forestry residues (v large contribution)**
- **Agricultural residues (v large contribution especially co-firing)**
    - Wheat straw
    - Tropical crop wastes

Torrefaction of biomass, and its impact in grindability and combustion properties of biomass.

Biomass Markets

Research Councils UK Energy For a Low Carbon Future

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EPSRC Pioneering research and skills

BCURA

Knowledge Transfer Partnerships

What might we want to understand/ control/modify in biomass?

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Metal/ash/inorganics composition and concentration

Combustion rates and burn-out of the char, emissions

Ease of milling/size reduction

Density – volumetric density and energy density

Yields, growth rates

Agricultural and water inputs

Moisture content and ease of drying

Biochemical composition (lignin/cellulose/hemicellulose)

Examples of Imported biomass studied

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Palm kernel expeller

- Oil extracted from both palm fruit (flesh) and kernel (nut)
- PKE: fibrous remains from the kernel oil extraction process.

Shea residue

- Shea butter extracted from kernel of shea fruit
- Residue: fleshy mesocarp, shell and husk left after removal of butter

Olive residue

- Olive residues: crushed olive kernel, shell, pulp, skin
- Imported as cake, expeller, or pellets

Fuel samples provided by RWE nPower

Imported biomass characterisation

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Parameter	PKE	Shea residue	Olive residue A	Olive residue B	Olive residue C
C (% daf)	51.12	54.24	54.42	54.33	51.38
H (% daf)	7.37	6.58	6.82	7.20	6.32
N (% daf)	2.80	3.48	1.40	1.39	1.45
O (% daf)[a]	38.71	35.70	37.36	37.08	40.85
C/N	21.32	18.21	45.41	45.59	41.33
Moisture (% ar)	7.60	8.42	6.40	4.61	5.19
Volatiles (% ar)	72.12	57.06	65.13	70.68	55.51
Fixed carbon (% ar)[a]	16.18	27.62	19.27	17.17	17.31
Ash (% ar)	4.10	6.90	9.20	7.54	21.99
HHV (MJ/kg) dry basis[b]	20.00	20.37	22.47	20.25	16.10
Ash composition (% dry basis)					
Al_2O_3	0.87	1.29	1.94	0.85	2.74
CaO	11.90	5.51	15.44	9.40	19.49
Fe_2O_3	5.70	2.37	2.14	0.75	5.29
K_2O	21.43	42.57	31.04	32.08	4.41
MgO	11.51	6.83	5.78	2.87	5.25
Mn_3O_4	1.03	0.05	0.05	0.02	0.33
Na_2O	0.41	0.95	0.47	0.33	0.35
SiO_2	16.51	14.40	21.10	10.88	67.40
Total ash components	69.35	73.97	77.96	57.18	105.25

[a] calculated by difference, [b] calculated by method in Friedl et al. 2005

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Ash Fusion Tests

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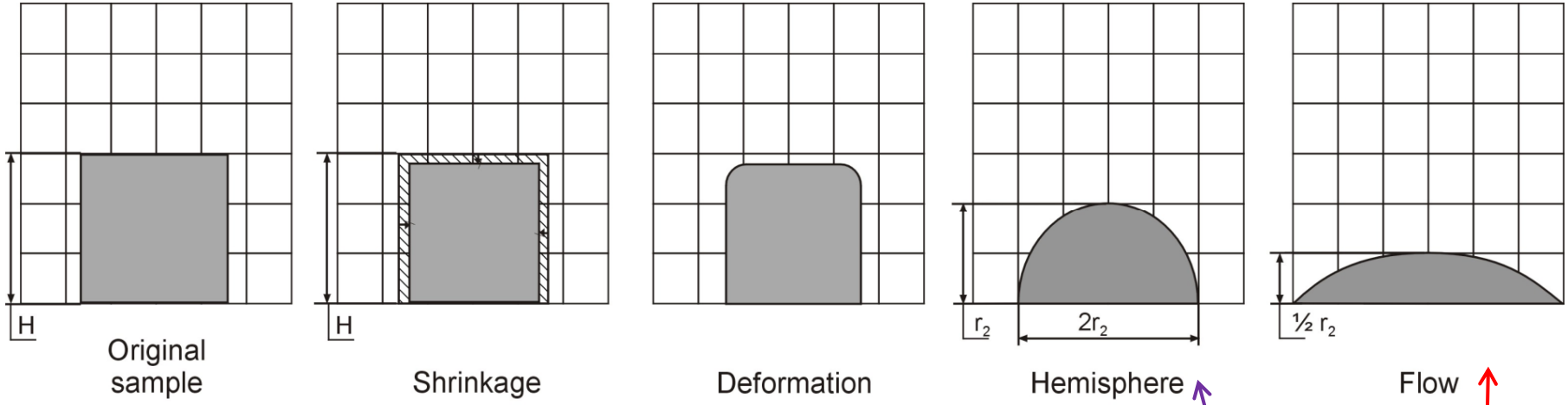

Fuel	Ash Fusion Temperatures (°C)			
	Initial Deformation	Sphere	Hemisphere	Flow
PKE	1070	1130	1140	1180
Olive Pellets	1080	1290	1310	1330
DDGS	Melts at <815°C			

Reducing atmosphere

Slagging and fouling indices

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Fuel	Alkali index (kg alkali/GJ)	Base to acid ratio*	Base percentage
PKE	0.48	2.93	50.94
Shea residue	1.61	3.71	58.23
Olive residue A	1.57	2.38	54.87
Olive residue B	1.27	3.88	45.44
Olive residue C	0.69	0.50	34.79

*TiO_2 not included

Photo courtesy of W. Livingstone, Doosan Babcock

$$AI = \frac{kg\ (K_2O + Na_2O)}{GJ}$$

(Jenkins et al. 1998)

$$R_{b/a} = \frac{\%\ (Fe_2O_3 + CaO + MgO + K_2O + Na_2O)}{\%\ (SiO_2 + TiO_2 + Al_2O_3)}$$

AI>0.34 kg alkali/GJ ⟶ fouling virtually certain! (Miles et al. 1996)

Slagging ⟶ olive B>shea >PKE>olive A>olive C

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Biomass ash softening temperatures

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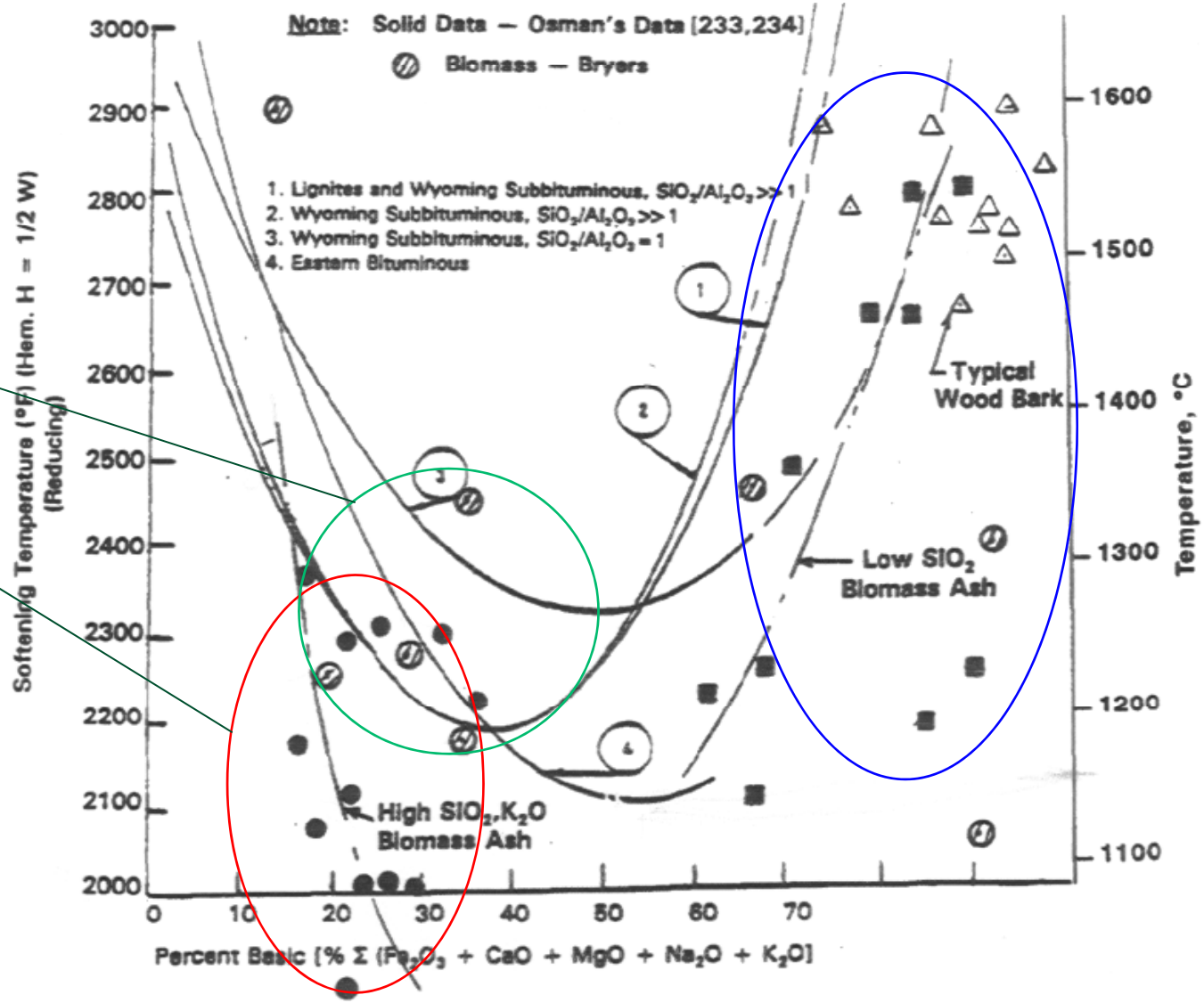
Relationship to basic oxides well established for coal

Woods: Low Si/ low K/ high Ca

Manures: High Ca, high K/ high P

Grasses: High Si/ high K/ low Ca

All except woods have unusually low melting temps



Source: Bryers, 1996

Energy crops

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Can energy crops be tailored for their end use?

- Within Supergen Bioenergy, Rothamsted Research and IBERS hold the Willow and Miscanthus genetic collection.
- Collaborative work is looking at the variation in biochemical and fuel composition as well as thermal conversion properties.
- Within Supergen Bioenergy, Rothamsted Research are conducting agronomy trials of energy crops, and collaborative work is seeking to examine the influence of agronomy on fuel characteristics.

Energy crops – variability and reliability of supply

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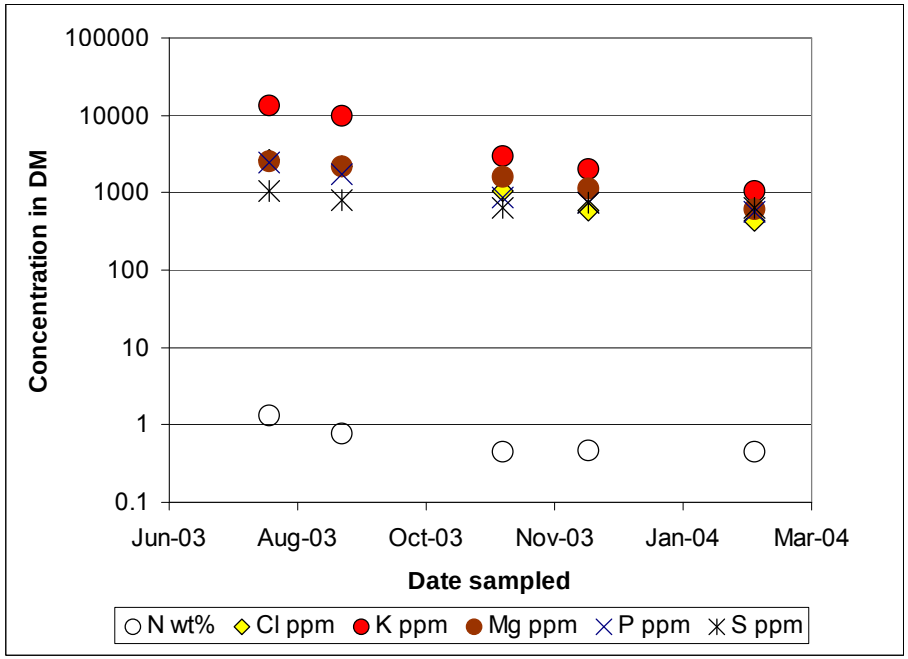

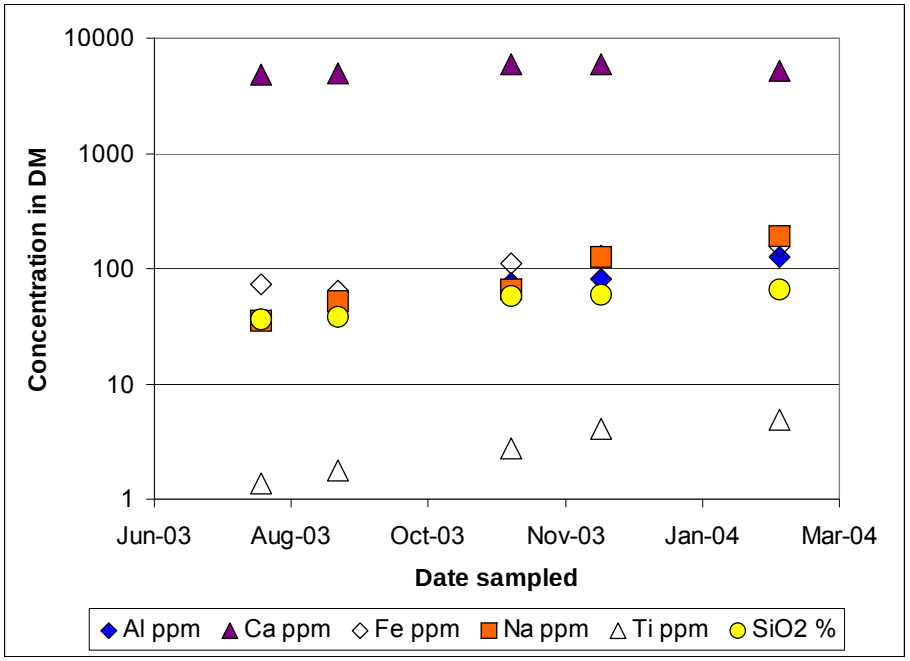

Seasonal variation in metal content (dry) in an energy crop

Both concentration, and relative concentrations of inorganics vary with growing time – ***expect impacts on combustion characteristics***

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Data from Rothamsted-Research

Energy Crops
Fuel quality indicators

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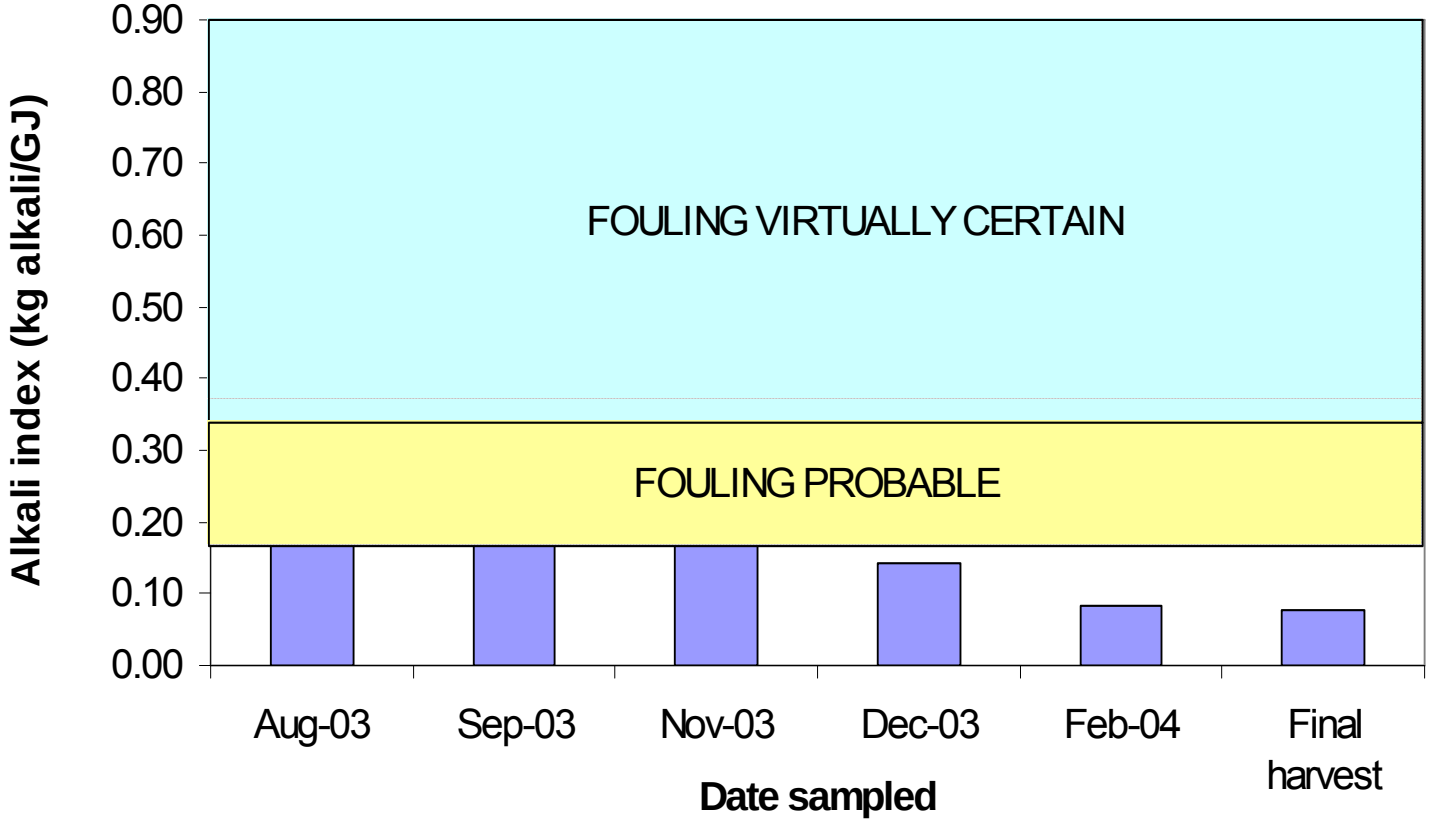

Fuel quality indicators for switchgrass:

Harvest could be moved forward without loss of fuel quality and with a 50% increase in dry matter yield.

Data from Rothamsted-Research

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Miscanthus agronomy and fuel quality

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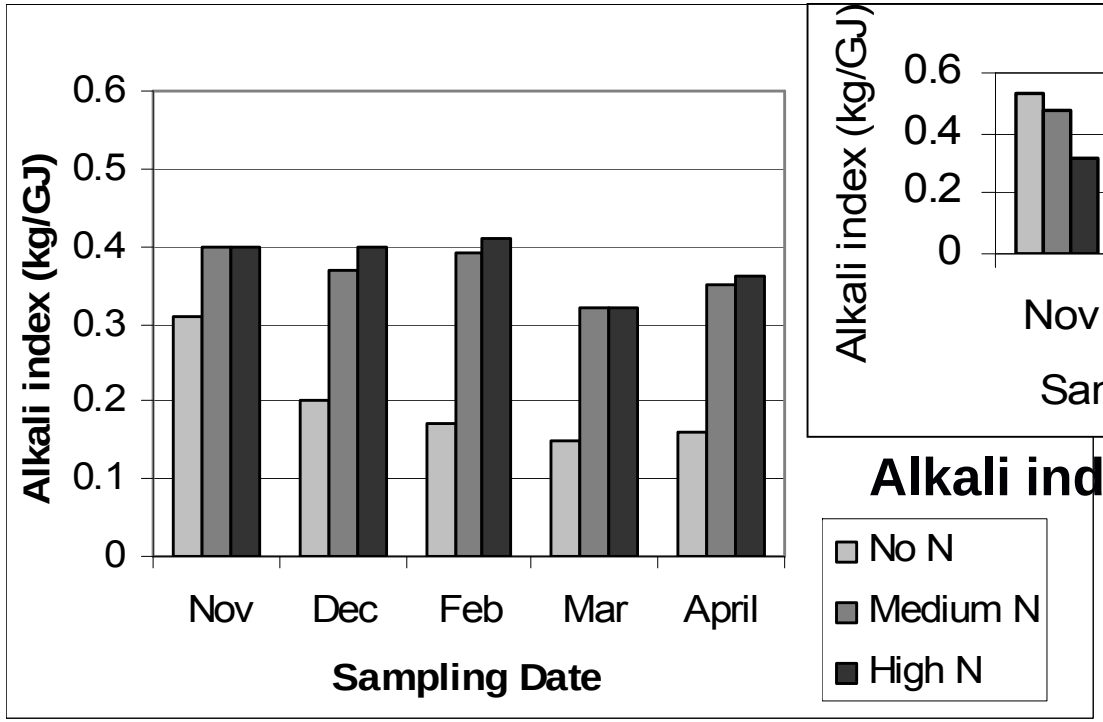
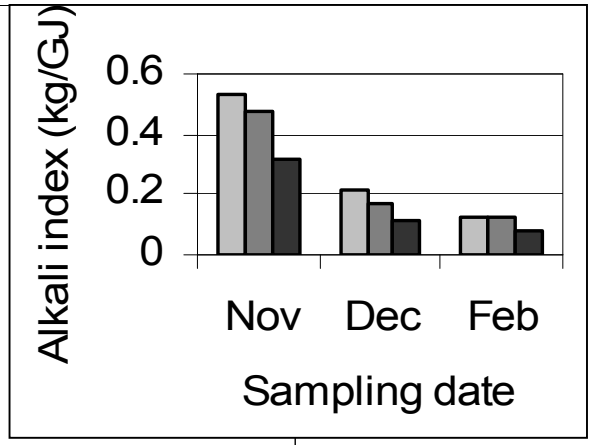
270 Miscanthus agronomy samples characterised and tested for thermochemical behaviour. Certain properties of Miscanthus are influenced by agronomy – for e.g. variation in Alkali index with sampling date for different fertilizer treatments and leaves versus stems:



Alkali index of stems

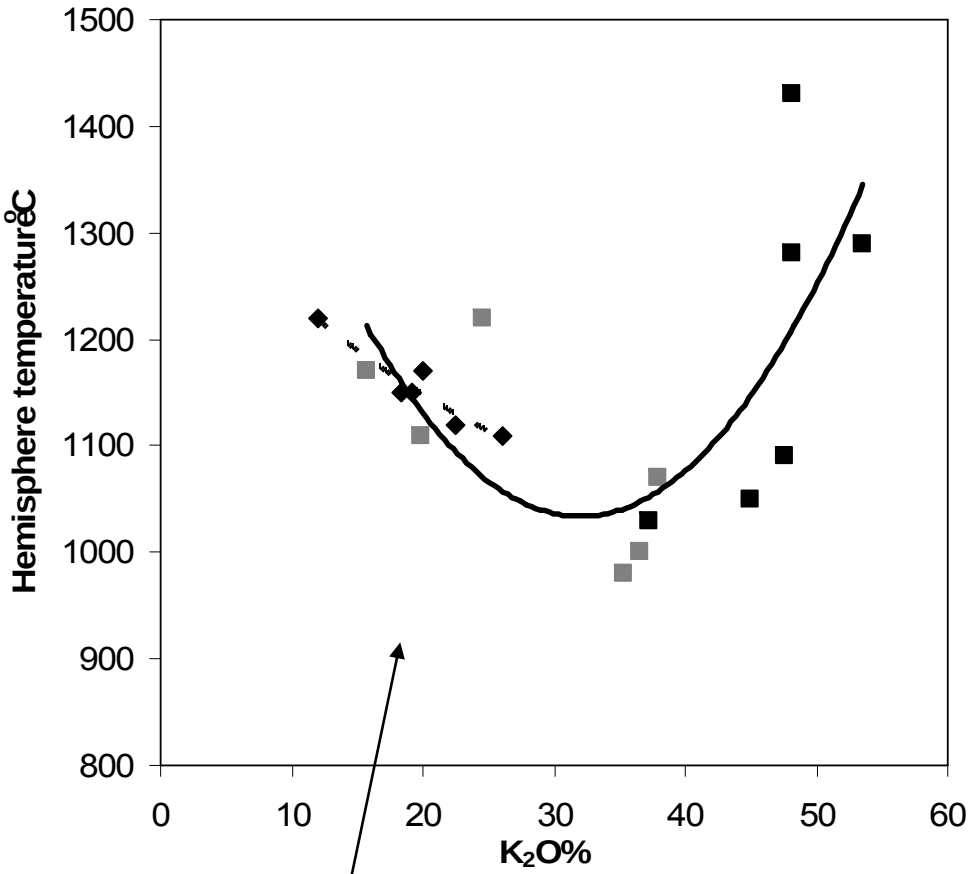


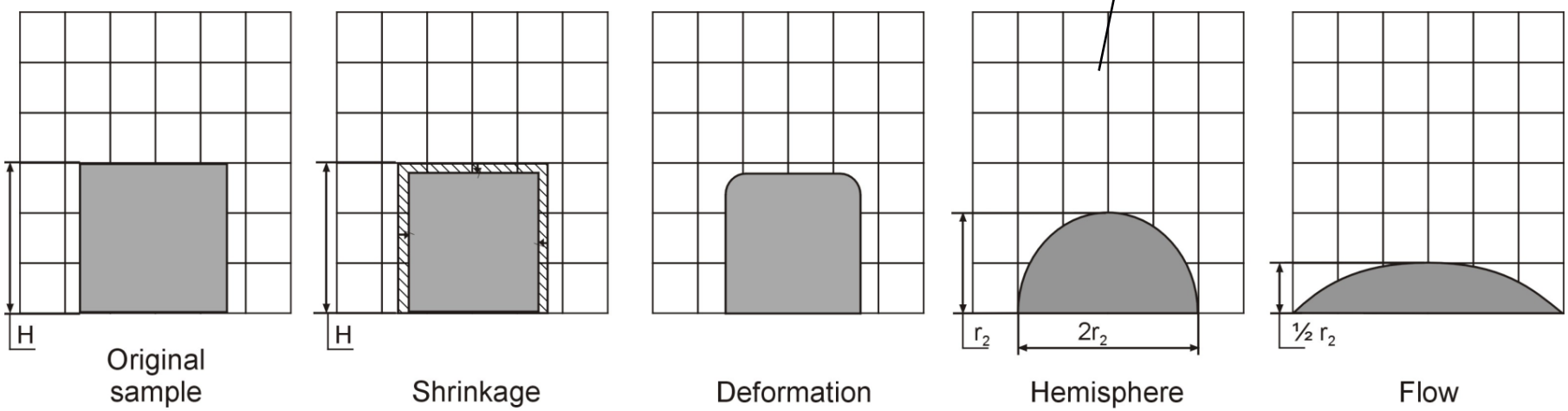
Alkali index of leaves

Baxter X. C., et al. (2009) The Influence of inorganic constituents in Miscanthus Combustion. 17th European Biomass Conference and Exhibition, 29th June -3rd July, Hamburg

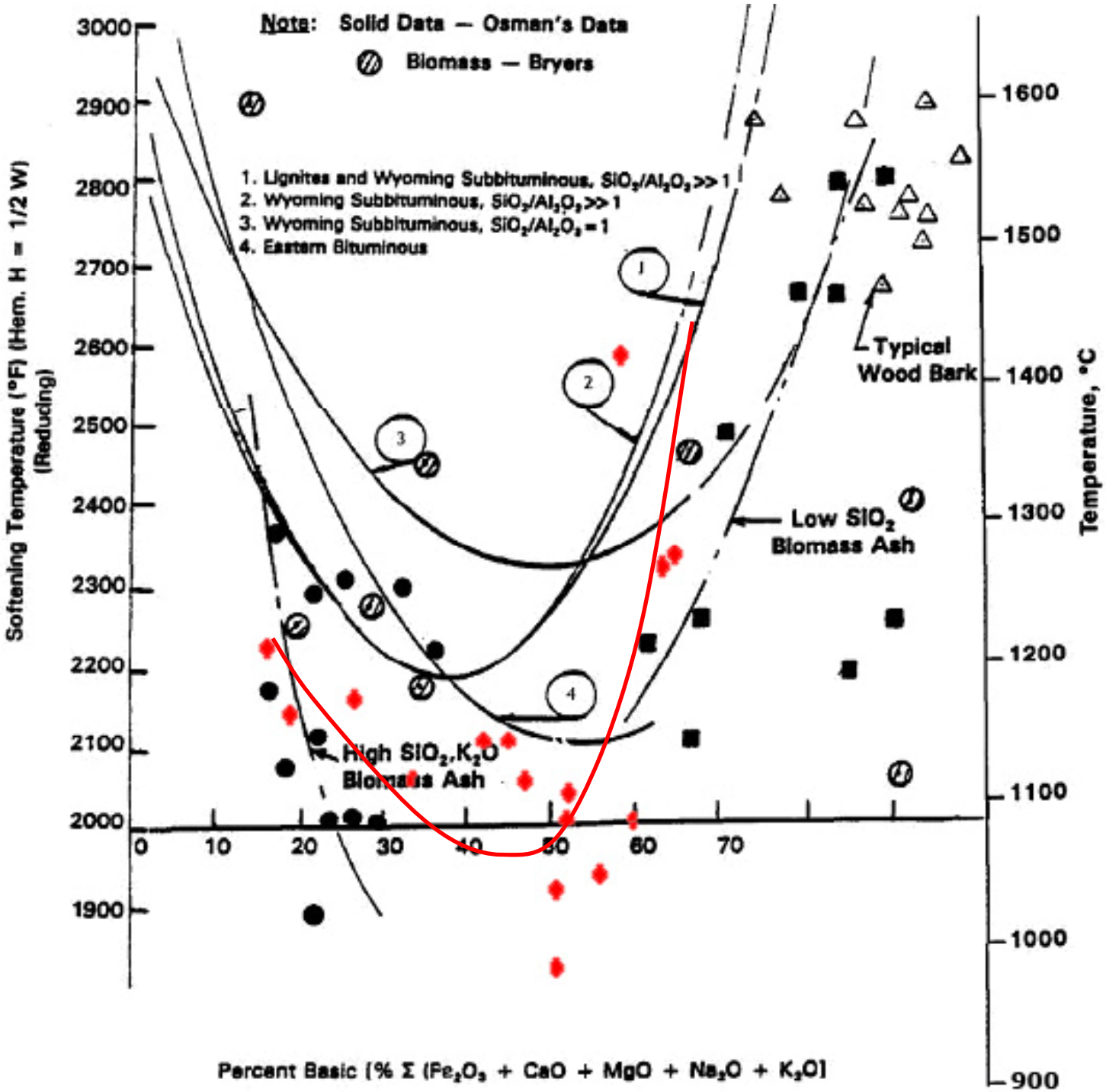
Ash Fusion Tests

Ash melting behaviour of Miscanthus varies with both time of harvest and fertiliser treatment and with leaves (diamonds) versus stems (squares)





Ash melting behaviour



Emissions - nitrogen partitioning

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Parameters	PKE	Shea residue	Olive residue A	Olive residue B	Olive residue C
C (% daf)	91.46	89.34	84.30	85.78	86.23
H (% daf)	2.74	3.14	2.50	2.64	3.48
N (% daf)	4.37	2.49	1.10	1.40	1.18
C/N in fuel	21.32	18.21	45.41	45.59	41.33
C/N	24.41	41.92	89.48	71.49	85.57
Moisture (%)[b]	0.26	0.98	0.00	0.81	0.36
Ash (% dry basis)[b]	62.44	32.20	36.78	40.90	73.65
Char yield (% dry basis)[c]	14.76	39.59	26.95	33.06	44.38
Volatile yield (% dry basis)[c]	85.24	60.41	73.05	66.94	55.62
N partitioning					
N (%) in char	9.03	20.67	18.22	17.32	12.22
N (%) in volatiles	90.97	79.33	81.78	82.68	87.78

[a] calculated by difference

[b] from combustion in STA-MS (hr 10°C min^{-1} to 600°C)

[c] from char preparation (hr 10°C ms^{-1} to 1000°C)

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Char-N conversions

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*DTA with MS detection

Masses monitored:

m/z 14: N_2^{2+} and CO^{2+}

m/z 27: HCN + tail end of m/z 28 signal

m/z 28: $^{12}C^{16}O$

m/z 30: NO + $^{12}C^{18}O$

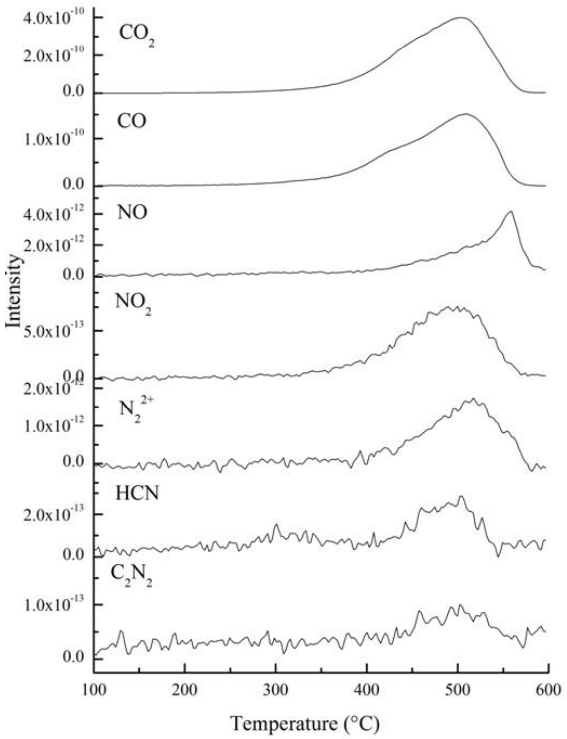
m/z 43: HCNO

m/z 44 : $^{12}C^{16}O_2$ + N_2O

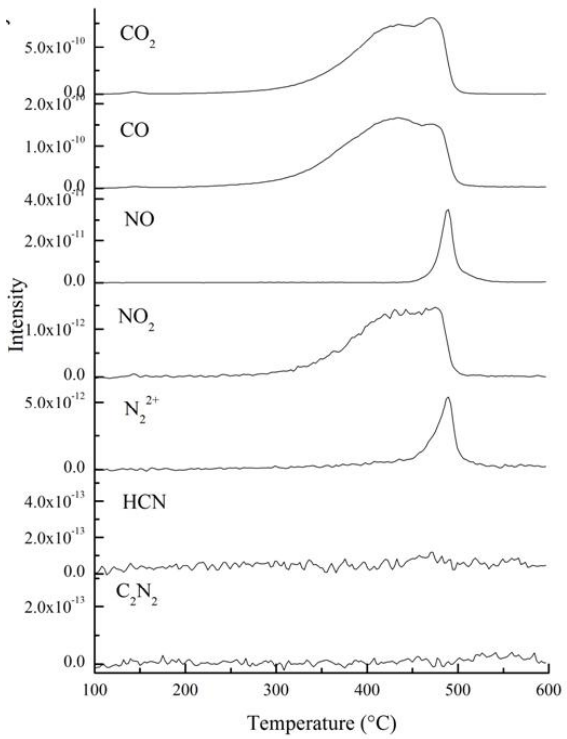
m/z 46: NO_2 + $^{12}C^{18}O^{16}O$

m/z 52: C_2N_2

PKE char



Shea residue char



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Char-N conversions

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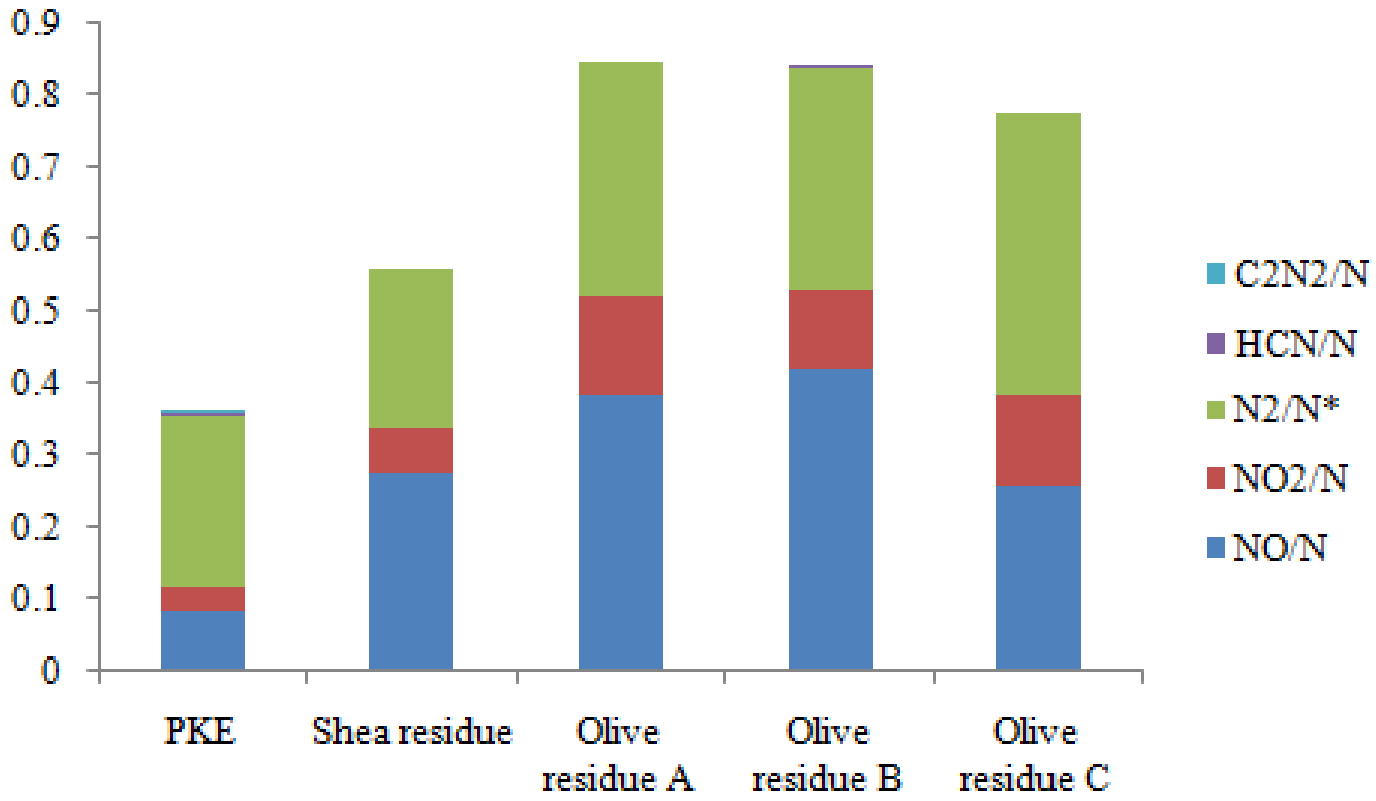

* from N_2^{2+} signal and m/z 14:m/z 28 ratio=0.154

Data on N-partitioning, and fundamental rate/yield data helps inform the CFD combustion group – particularly in biomass combustion mechanism development

CFD modelling work

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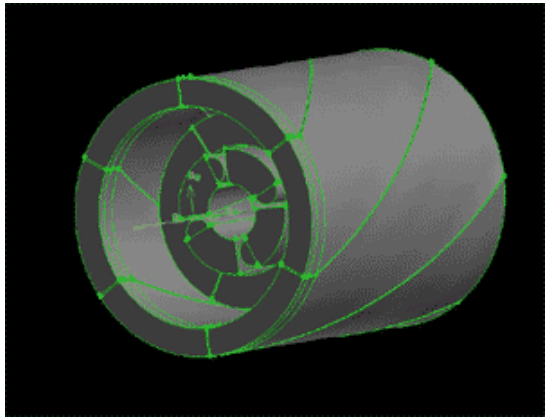
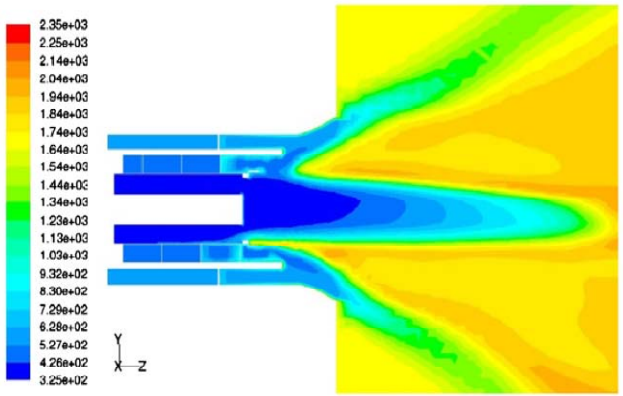
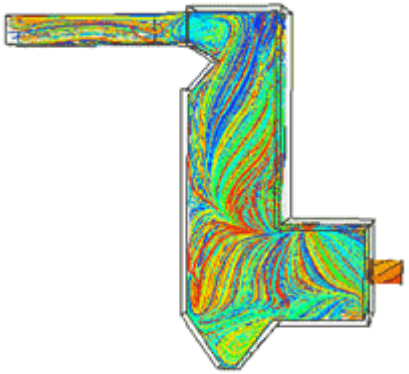
Co-firing and Oxy-coal combustion

- Combustion of large particles
- Deposition
- Biomass combustion mechanism
- Particle flow

Prof. M Pourkashanian







Torrefaction

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The Process:

- Mild temperature pyrolysis (200-300°C) treatment of solid biomass

Yielding an enhanced quality solid fuel with:

- Increased energy content (~20%)
- Reduced moisture and low re-absorbtion of moisture
- Increased friability/brittle nature

- **The Implications:**
  - Higher value product (higher thermal efficiencies)
  - Reduced transport costs
  - Increased storage potential (reduced storage costs and considerations)
  - **Potential for biomass feedstocks to be processed in existing fuel handling systems (ball mills/pulverisation)**

Colour Changes

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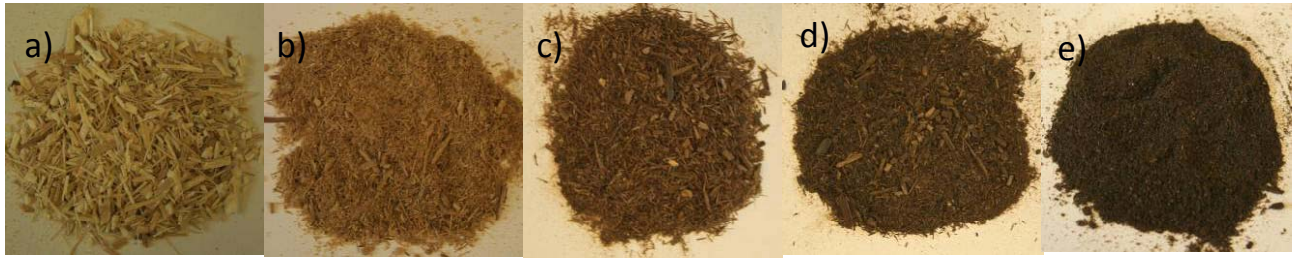
Images of a) untreated willow; b) willow C; c) willow B; d) willow A; e) willow D.

A: high T, low t, low d;
B: low T, high t, low d;
C: low T, low t, high d;
D: high T, high t, high d



Images of a) untreated Miscanthus; b) Miscanthus C; c) Miscanthus B; d) Miscanthus A; e) Miscanthus D.

Other work has studied cellulose, xylan, lignin, and other crops such as wheat straw, reed canary grass, switchgrass…

Mass and Energy Yields (Willow)

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Torrefaction Temperature (°C)	Energy Yield (%)	Mass Yield (%)	Energy : Mass
250	94.5	84.1	1.12
270	89.7	76.4	1.17
290	85.5	71.1	1.20

Grindability - Miscanthus

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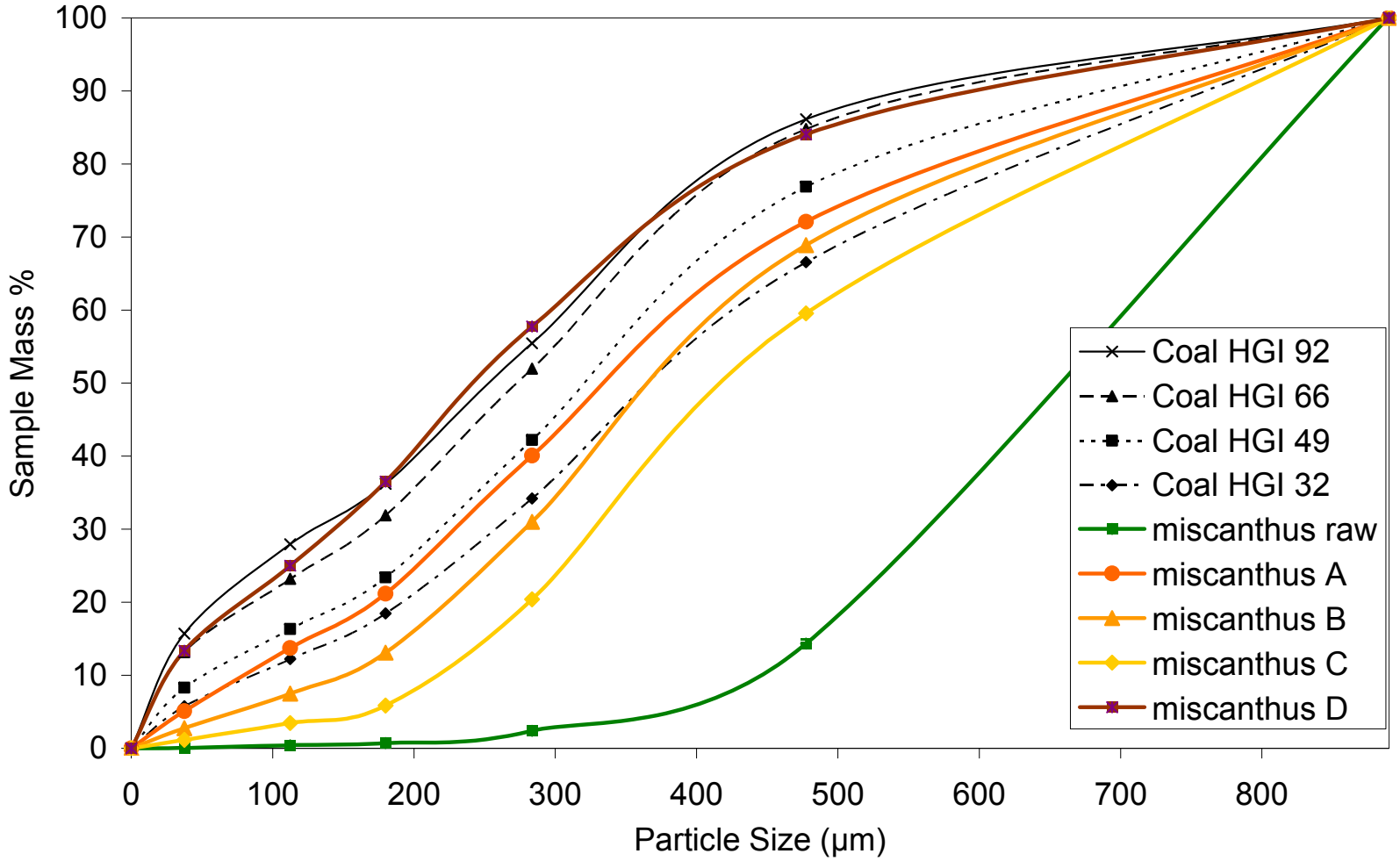

Grindability - Willow

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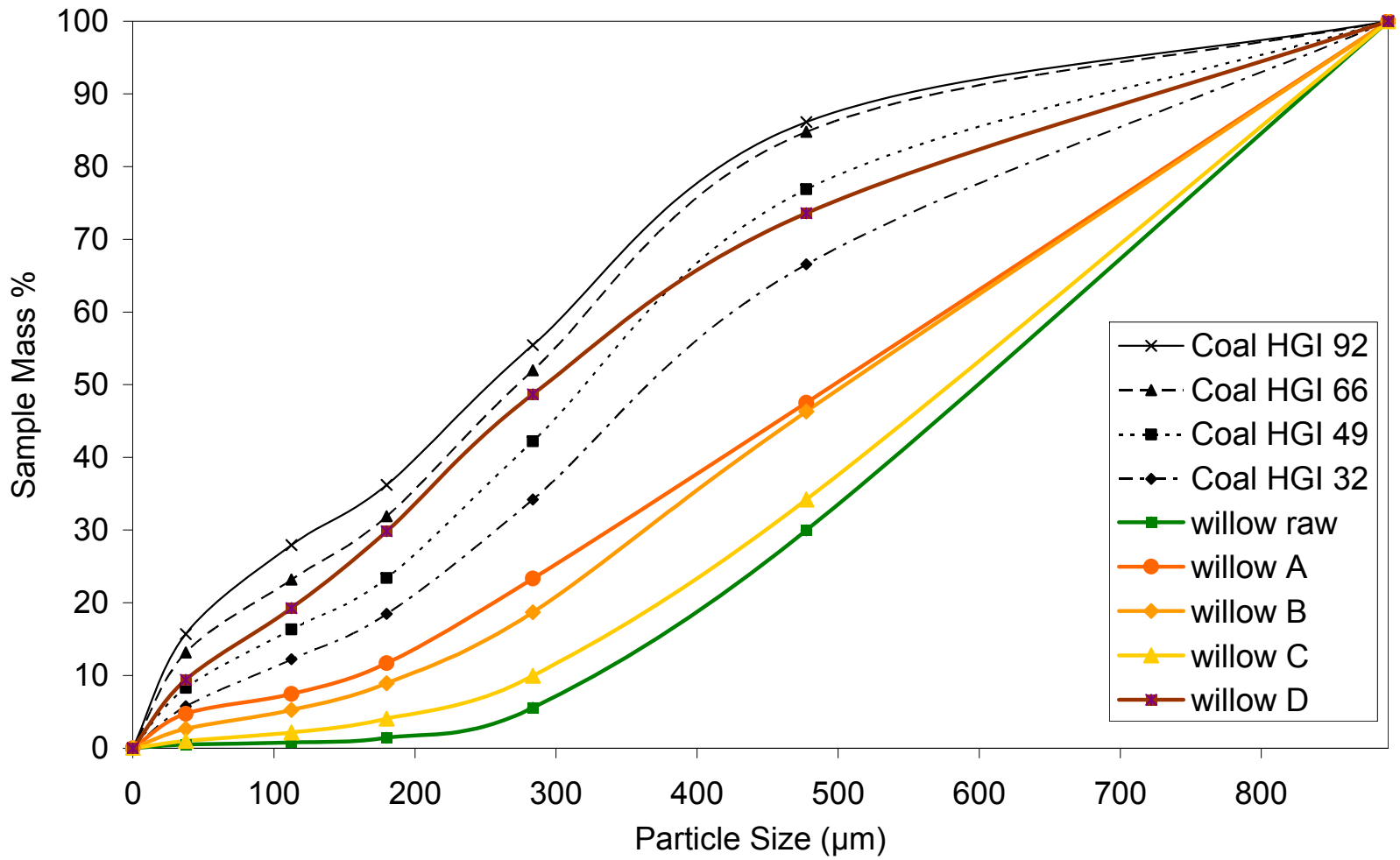

Torrefaction severity and grindability

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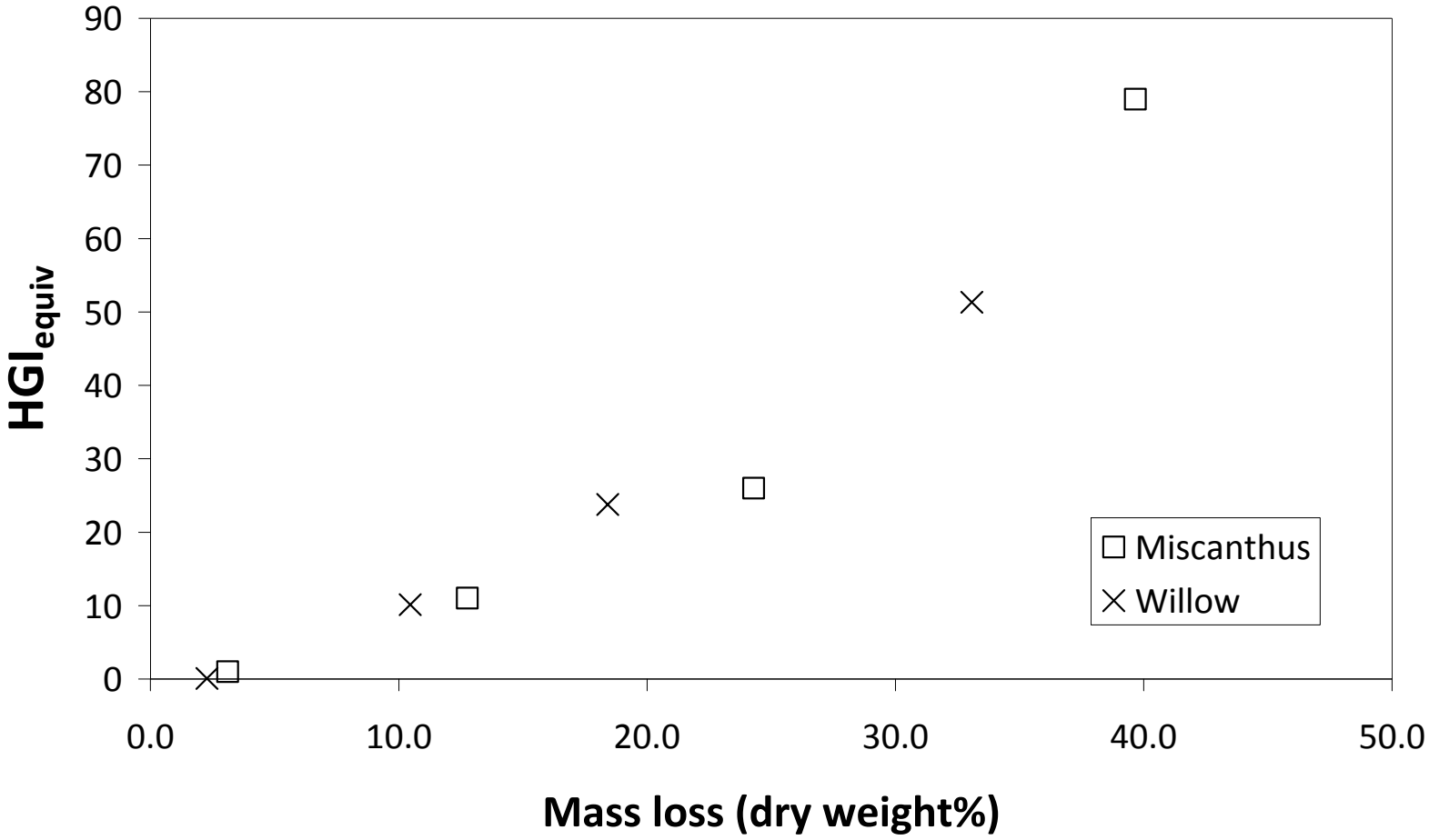

Scanning Electron Microscopy images of untreated willow and torrefied willow residue

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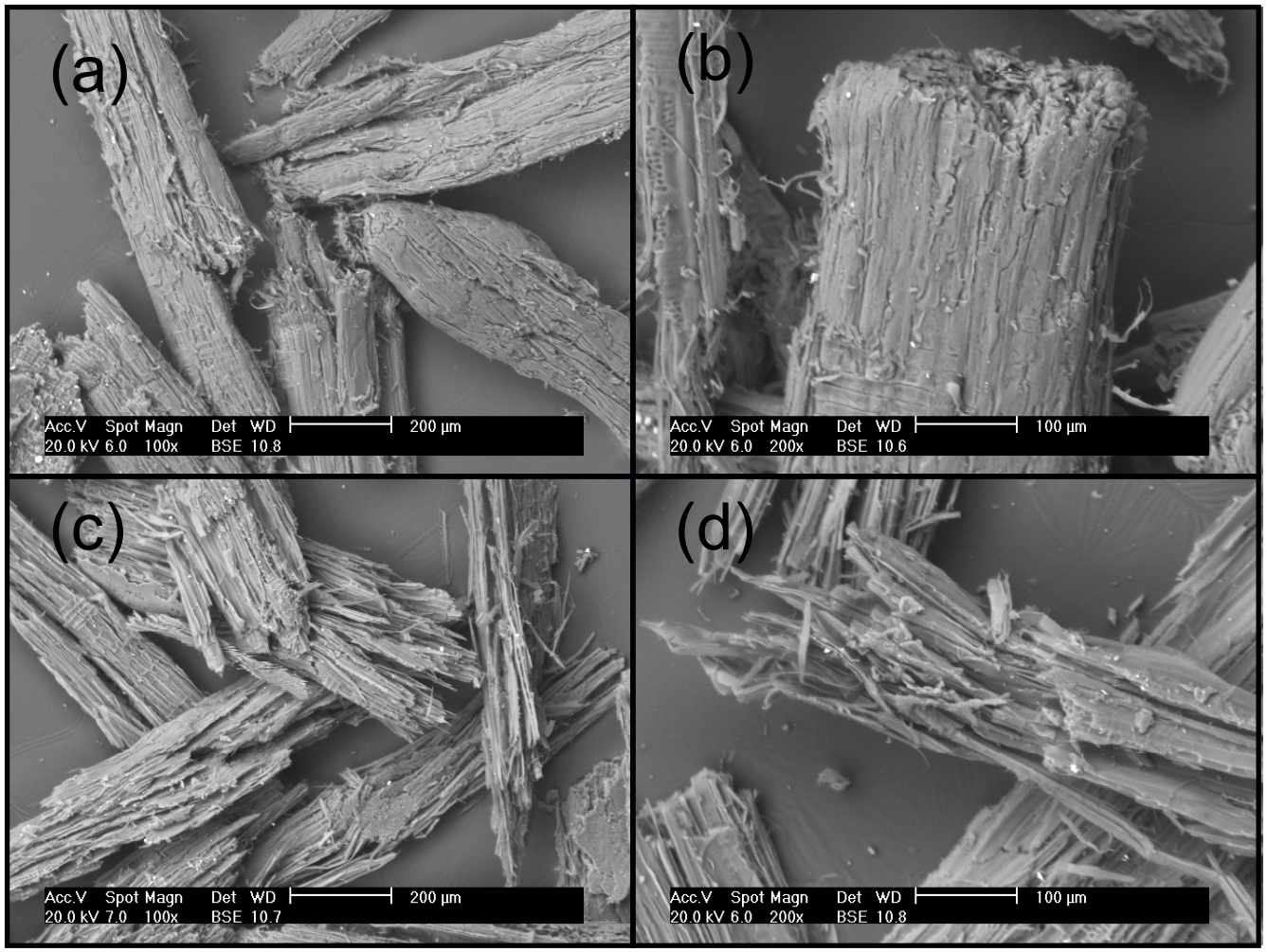

SEM images of [(a) & (b)] untreated willow; and [(c) & (d)] steam torrefied willow (290°C).

Summary

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- The biomass use in the UK involves a wide range of fuels – including imported residues, wood residues, agricultural residues and energy crops.
- These have very different properties in terms of their composition, ash behaviour combustion behaviour and emission propensity.
- Research at Leeds is concerned with developing an understanding of the differences in combustion behaviour:
    - Slagging and fouling
    - Reaction rates
    - Emissions
- Research also concerns modifying the properties of energy crops – what properties are beneficial, and how can these be achieve?
- For woody and herbaceous crops, particle size reduction is an issue for pf power stations, and torrefaction is one area under study for improving the grindability of these biomass.

Acknowledgements

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Funding from the following is gratefully acknowledged:

“Supergen Bioenergy”, RC grant

“Applying Coal Milling Technologies to Thermally Treated Biomass: Proof of Concept.” BCURA Project B92.

“SUSTAINABLE BIOMASS BASED ENERGY SYSTEMS TO 2020 AND BEYOND.” EPSRC platform grant.

“Fundamentals of torrefaction and performance of torrefied fuels” EPSRC research grant.

Contributors:

Dr. Leilani Darvell

Dr. Toby Bridgeman

Prof. Alan Williams

Xiaomian Baxter

Bijal Gudka,

Abby Saddawi

Also Thanks to:

Dave Waldron, Alstom.

Alf Malmgram, RWE nPower

Bill Livingston, Doosan-Babcock

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Pioneering research and skills

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