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# Biomass Residues as Power Station Fuels

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

| 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
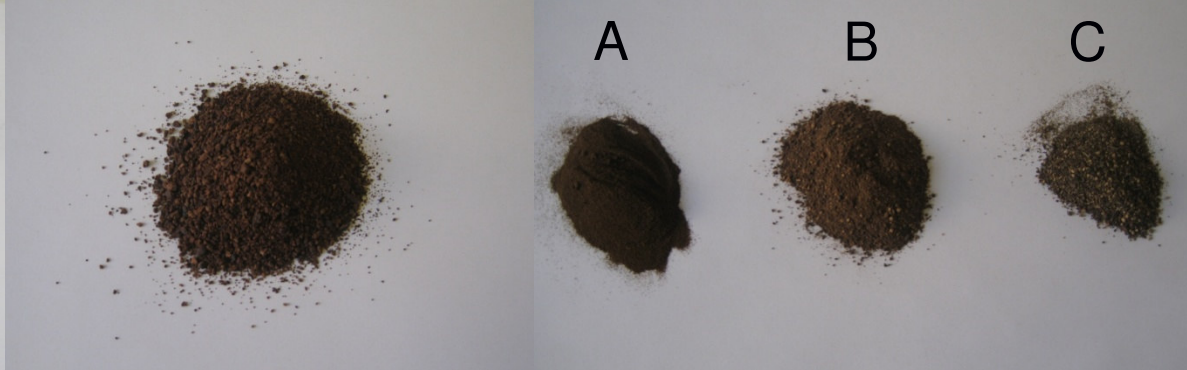
## Palm kernel expeller     Shea residue     Olive residue



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

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

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

Fuel samples provided by RWE nPower

# Aims

To examine the combustion properties of PKE, shea residue, and three different olive residues

To examine the nitrogen partitioning and char-N chemistry during combustion

# Methodology

- **Fuel characterisation:** ultimate, proximate, and metal analyses, ash behaviour (fouling and slagging indices)

- **Nitrogen partitioning**

- **Studies of fuel chars**:

    1. Characterisation: ultimate and proximate analyses

    2. Combustion by TGA-MS: char-N conversion to N-containing species

# Results: Fuel characterisation

| 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 | 19.67 | 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

# Results: Slagging and fouling indices

| 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

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

(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 $\longrightarrow$ fouling virtually certain! (Miles et al. 1996)

Slagging $\longrightarrow$ olive B>shea >PKE>olive A>olive C

# Biomass ash softening temperatures

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
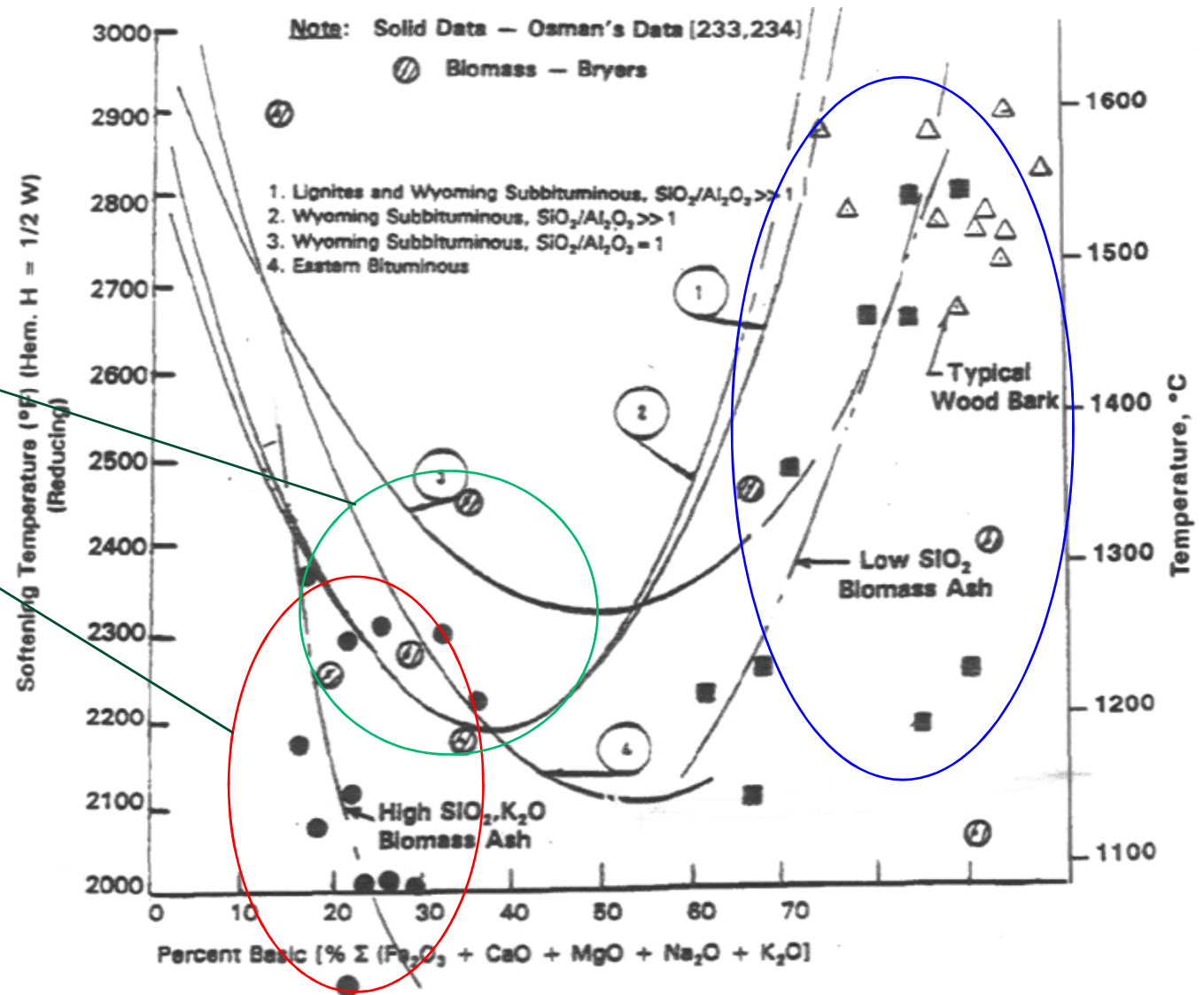
# Results: Fuel chars and nitrogen partitioning

| 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 |
| O (% daf)[a] | 1.43 | 5.04 | 12.10 | 10.17 | 9.12 |
| 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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PKE char                Shea residue char

Masses monitored:

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

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

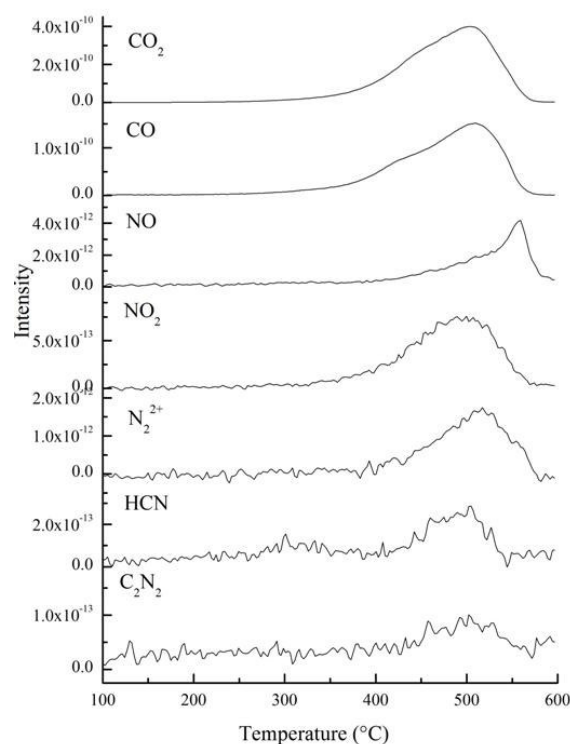m/z 28: $^{12}C^{16}O$

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: $C_2N_2$
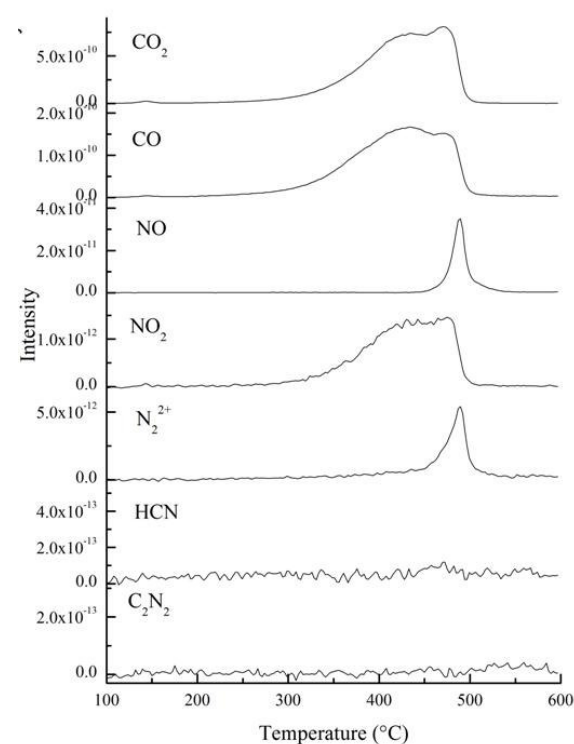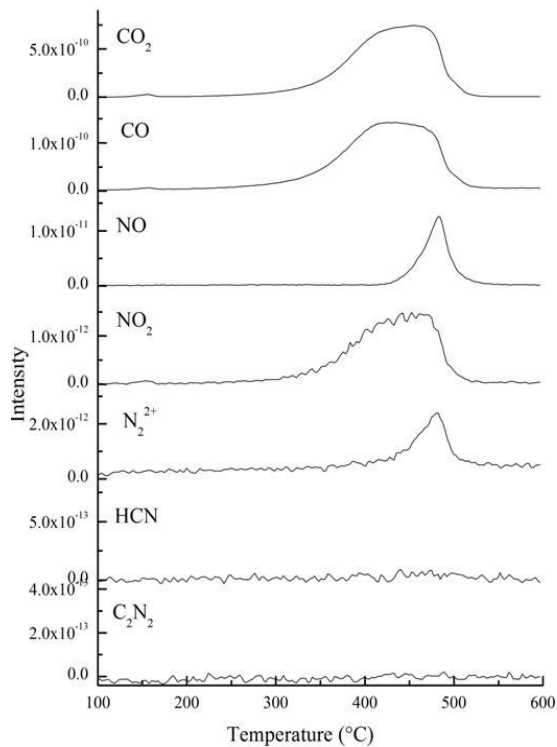
Olive residue A char    Olive residue B char    Olive residue C char
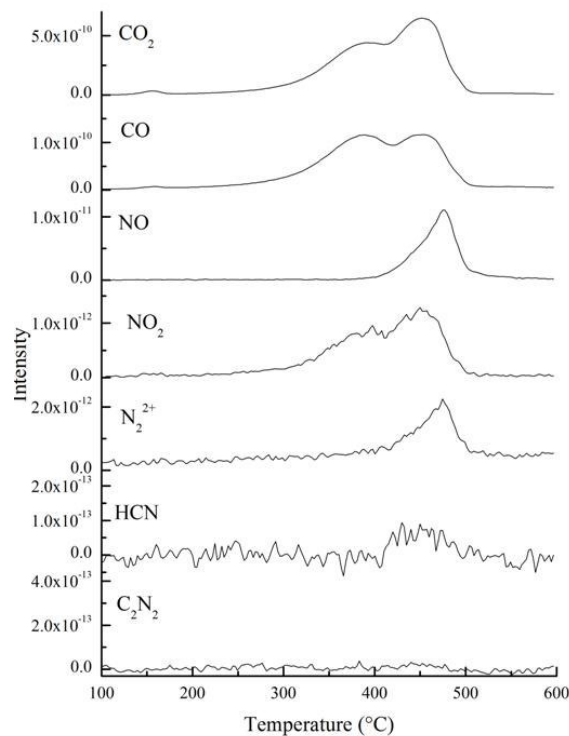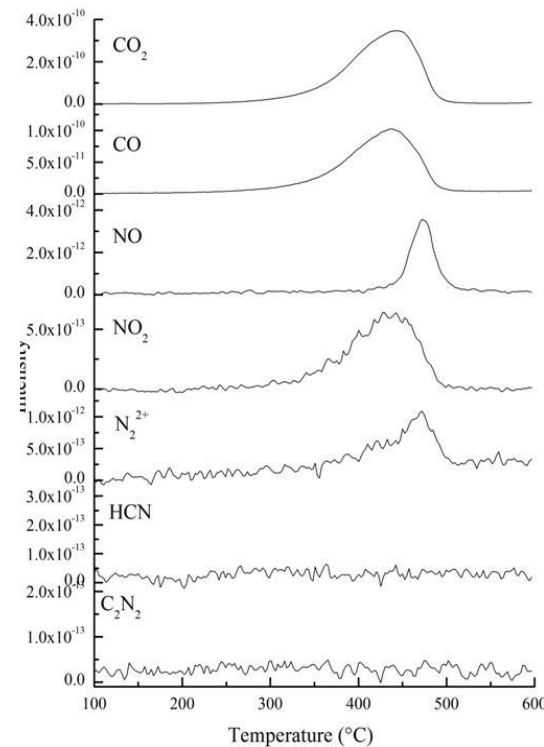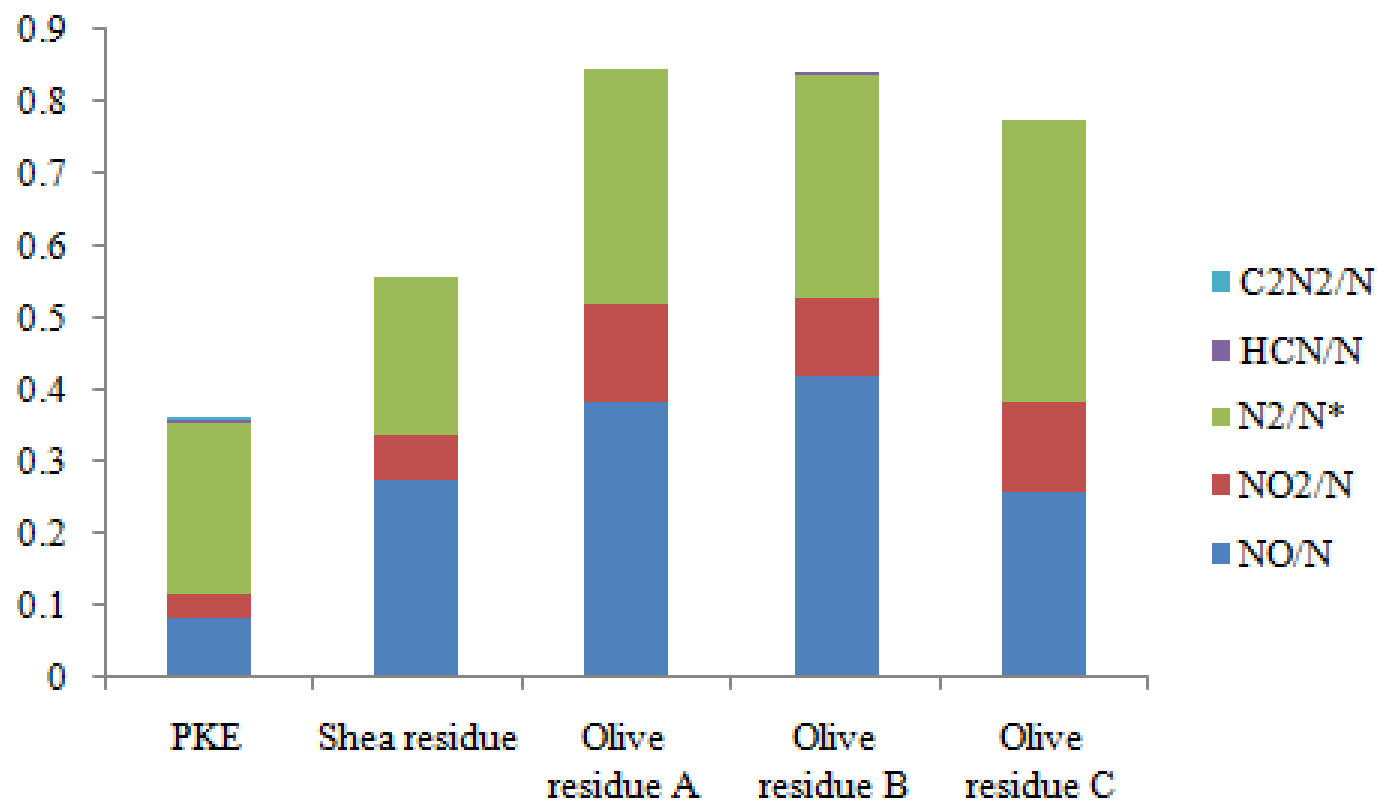
* from $N_2^{2+}$ signal and m/z 14:m/z 28 ratio=0.154

# Conclusions

- All fuels investigated show a high tendency to fouling and slagging, with ash softening temperatures <1100°C

- Most of the N is lost in the volatiles (~80-90%)

- Most of the char-N is released as $N_2$ and $NO_x$ in combustion

- Other species detected: HCN and $C_2N_2$ in small quantities (from PKE and olive residue B chars)

- Similarly to coal, N is retained until near the end of char combustion stage, with NO as a primary product

# Acknowledgements