PRODUCTION OF HIGH QUALITY BIO-COAL FROM EARLY HARVESTED MISCANTHUS BY HYDROITHERMNAL CARBONISATION

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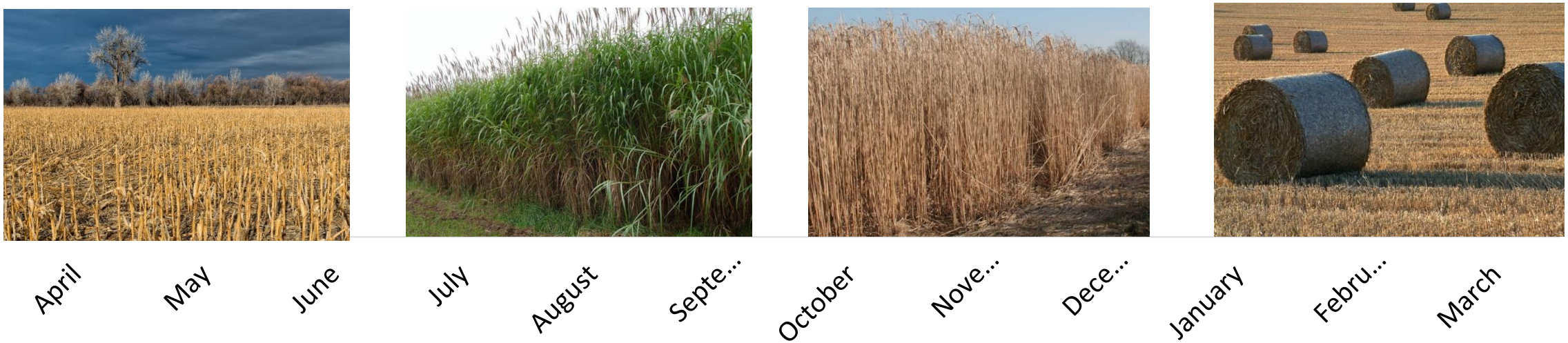
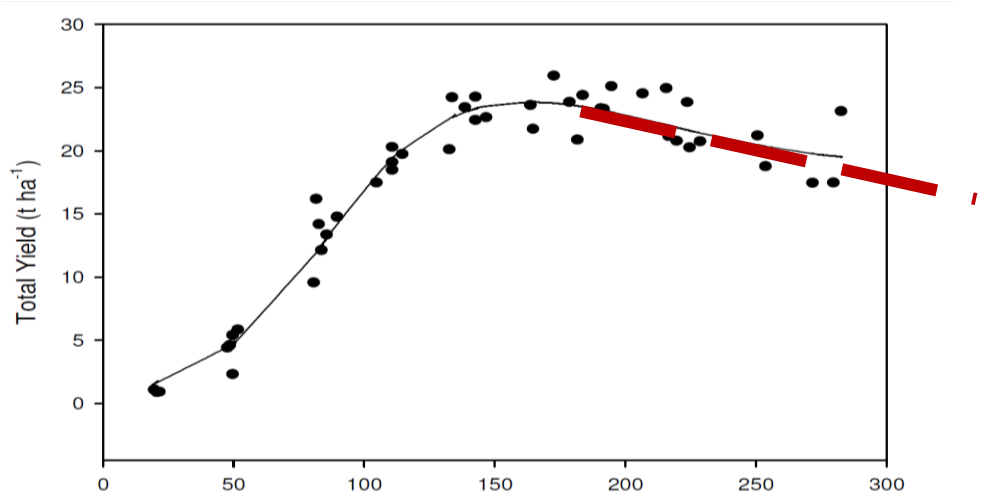
How is Miscanthus conventionally harvested?

- Miscanthus harvested between January and early May
  - To allow translocation of plant nutrients into the rhizome for next year's growth
  - Plant looses leaves improving fuel properties
    - Reduce fuel N, P, K and Cl though the loss of leaves
    - Reduce moisture content (further drying in UK still required)



What is green harvest Miscanthus and why?

- Maximum dry matter yield is achieved during autumn when the crop is green
  - Estimated decline of 30 kg ha^{-1} day^{-1} (db) after senescence [1]
  - Up to 43 % increase in dry matter yield in Europe [2,3]
- Autumn could be the most efficient way of utilising biomass from energy grasses



Miscanthus yield between 1st January and 1st October [1]

[1] Gezen and Riche (2008) *Aspects of Applied Biology 90* 219; [2] Godin et al., (2013) *Industrial Crops and Products,* 48**,** 1-12; [3] Yates et al., (2015) *ETA-Florence Renewable Energies*;

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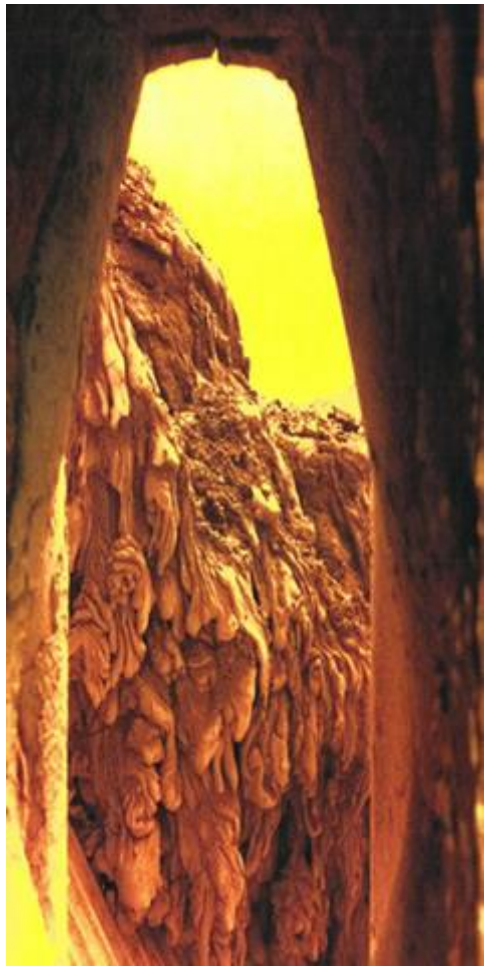
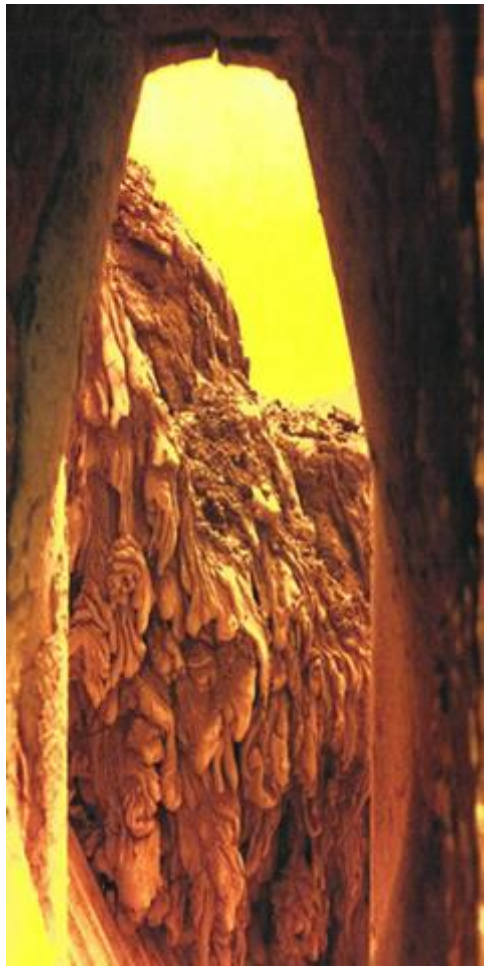
Importance of inorganics

- Alkali metals (K + Na) lower the ash melting temperatures
  - Slagging
- Alkali metals volatilise and deposit on heat exchangers
  - Fouling
- If Cl is present it interacts with K and Na deposits
  - Active corrosion
- Ca and Mg can increase ash melting temperature lowering slagging risk
- Increasing Ca, Si and P can prevent volatilisation of alkali metals, reducing fouling
  - e.g. $KCl_{(g)} + 2CaHPO_4.2H_2O + O_2 = CaKPO_4 + 2H_2O + HCl_{(g)}$



Inorganics and Miscanthus

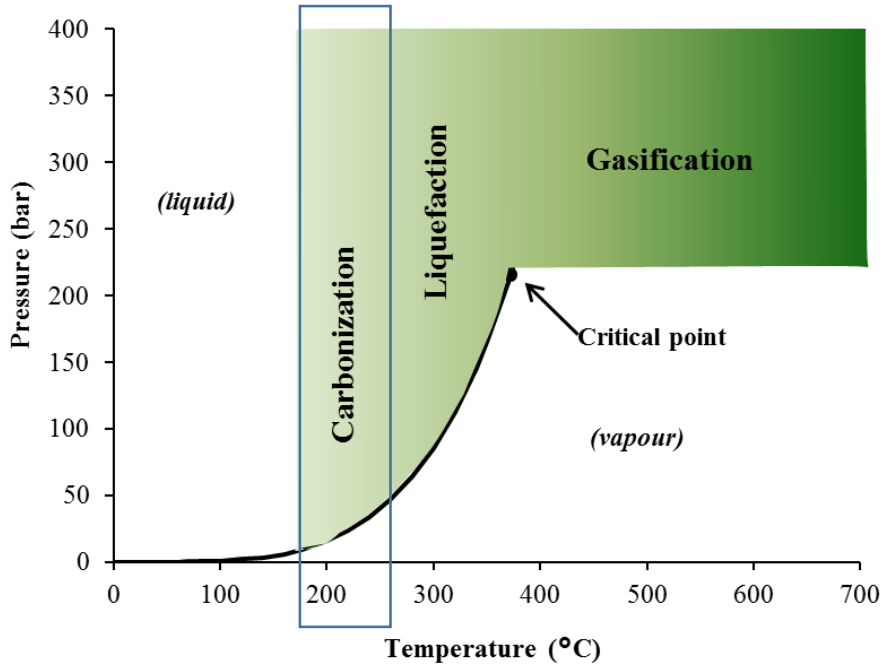
- Green harvested *Miscanthus* high in K, Na and Cl ☹
  - unsuitable combustion fuel without demineralisation
- Loss of leaves reduce Na, K and Cl but often not enough!
  - Reduction often insufficient for safe combustion [4]
  - Loss of biomass
  - Leaf loss returns some nutrients to soil
  - Appears to be offset by N-fertiliser 3-4 years
- Pre-treatment to improve fuel ash chemistry appears pre-requisite
  - For both green and conventional harvested *Miscanthus*



[4] Baxter et al., (2010) *Fuel,* 117, Part A, 851-869

What Is Hydrothermal Carbonisation (HTC)?

- Biomass pre-treatment to convert biomass to coal like fuel
- Initially petrology tool to simulate natural coal formation
- Quickly developing TRL3-TRL6
- Uses subcritical water
  - Typically 200-250°C: 14-40 bar
- Water prevents superheating of cellulose
  - Enables it depolymerisation and reformation
- Physiochemical properties of subcritical water different



Without…..

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Why interest in HTC?

Biomass

- Low bulk density ☹
- High moisture ☹
- Low calorific value ☹
- Hydrophilic ☹
- Difficult to mill ☹
- Slagging and Fouling ☹

Bio-Coal

- Higher bulk density ☺
- Low moisture ☺
- High calorific value ☺
- Hydrophobic ☺
- Easily friable ☺
- Slagging and Fouling ☺

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Experimental design

- Miscanthus harvested November 2015 and March 2016 as whole canes
  - Some sample- leaf and canes separated
  - Remainder homogenised to <5 mm
  - ½ processed ‘as received’
  - ½ processed ‘oven dried’ (for accurate mass yields)
- HTC carried out in 2 litre batch reactor
  - Parr reactor modified to give greater thermal control
  - Quartz Lined
  - Continuous pressure and temp logging
  - 5 bar argon head gas
- 10 % solids loading (approx. 1000 g solid/run)
- 200 ^{o}C and 250^{o}C with 1 hour hold

Fuel Energy Density

Green Harvest Miscanthus

- Unprocessed: HHV 18 MJ/kg (db) (LHV 5 MJ/kg (ar))
- HTC 200: HHV 20 MJ/kg (db) (LHV 18 MJ/kg (ar)[¥])
  - Yield 76 %
- HTC 250: HHV 28 MJ/kg (db)* (LHV 27 MJ/kg (ar)[¥])
  - Yield 48 %

Conventional Harvest Miscanthus

- Unprocessed: HHV 15 MJ/kg (db) (LHV 8 MJ/kg (ar))
- HTC 200: HHV 18 MJ/kg (db) (LHV 15 MJ/kg (ar)[¥])
  - Yield 71 %
- HTC 250: HHV 26 MJ/kg (db)* (LHV 24 MJ/kg (ar)[¥])
  - Yield 49%

*ADSM coal equivalent: subbituminous C high volatile coal

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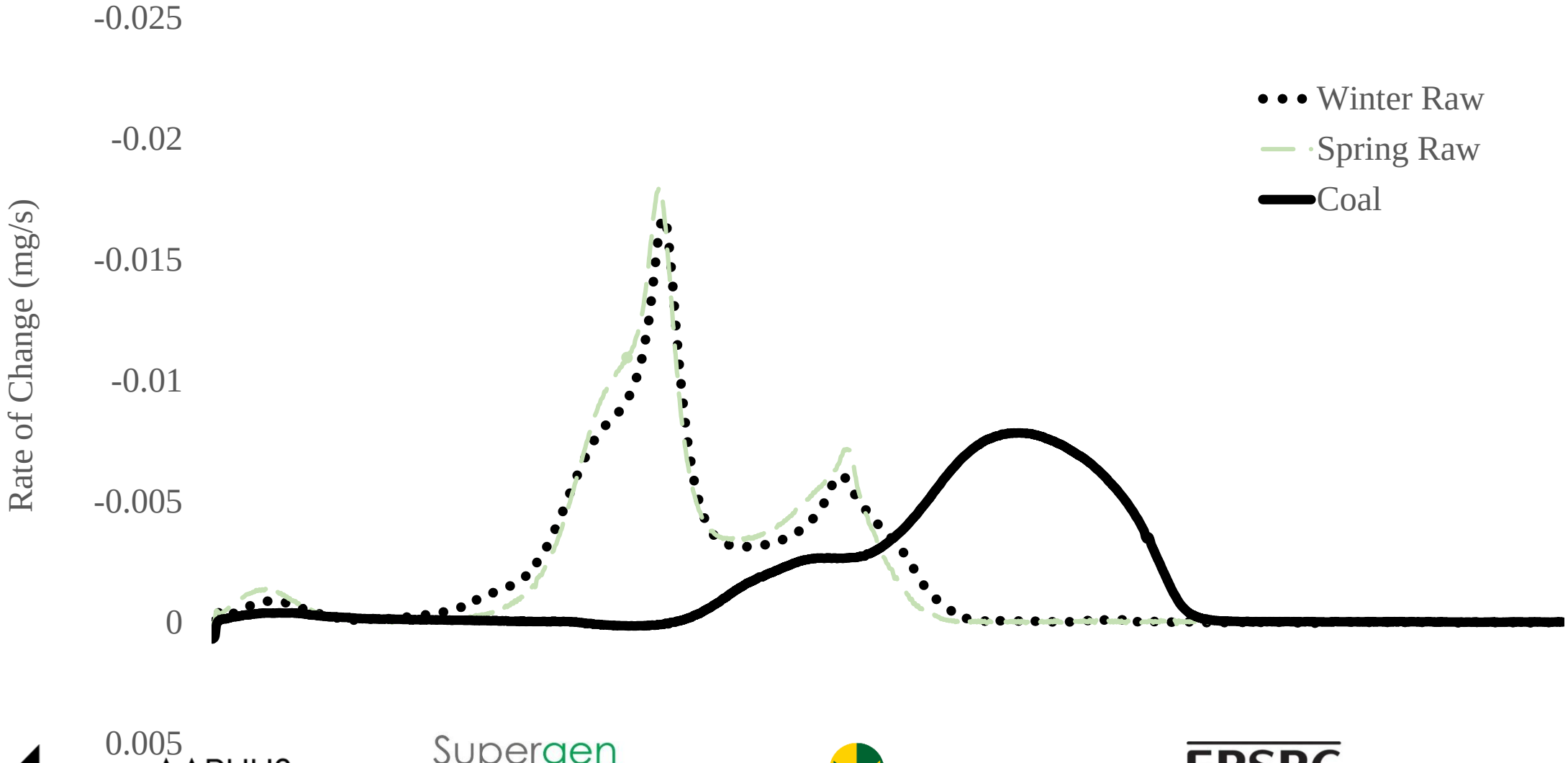
Fuel Burning Properties



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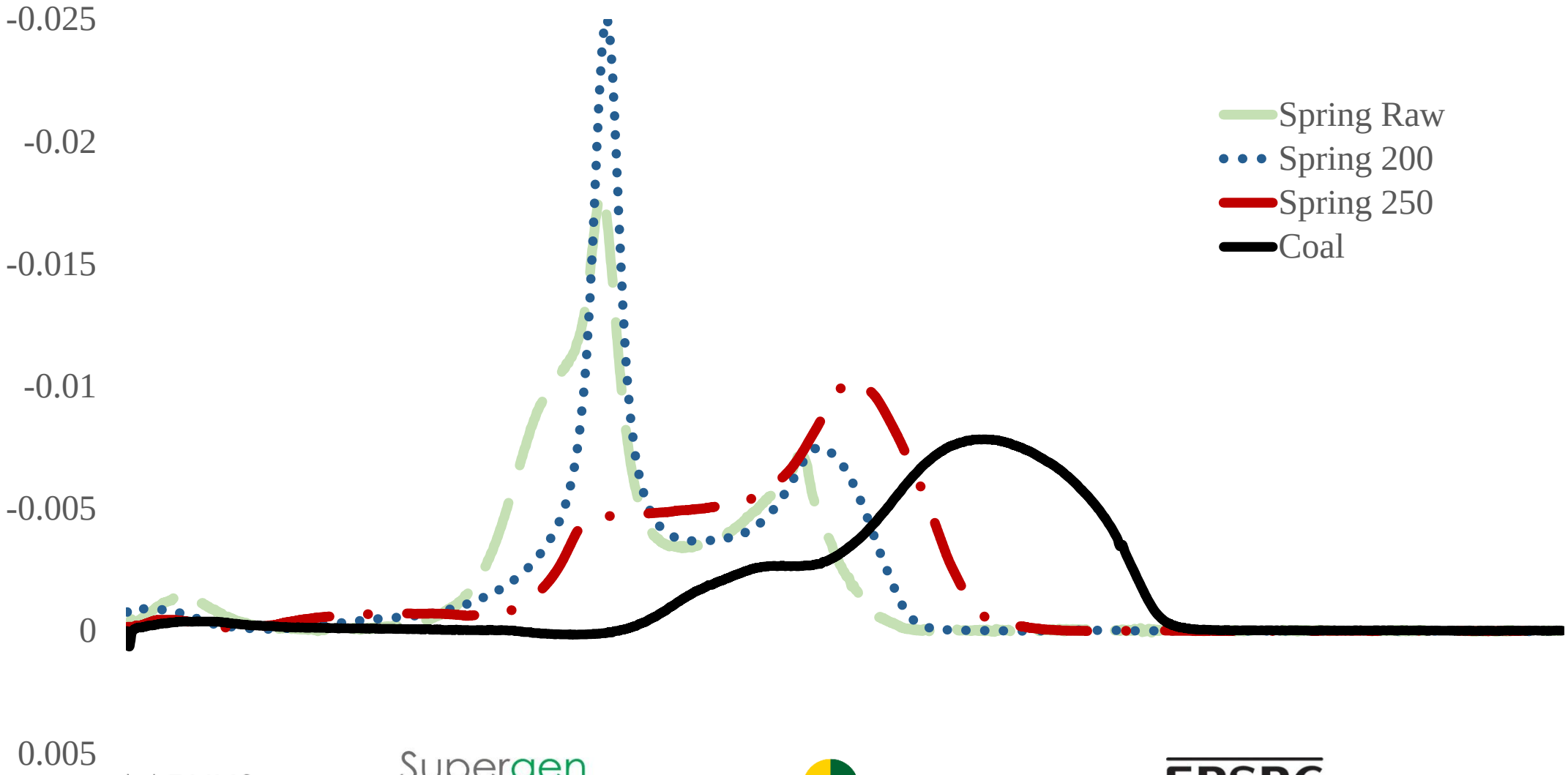

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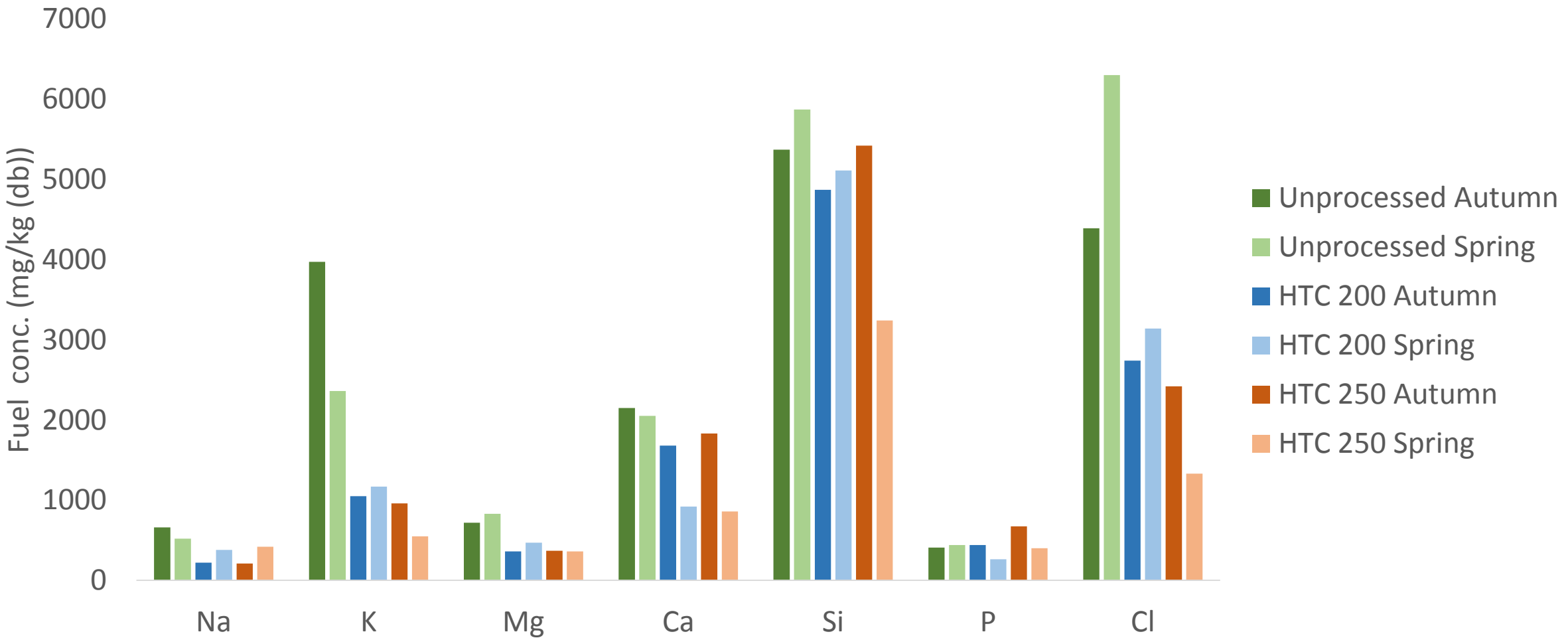
Hardgrove Grindability Index (HGI)

- Pulverised Furnace – 75 % fuel below 70µm for stable flame
  - Coals between 30 and 100
  - 30 = resistant to milling
  - 100 = easily pulverised
  - 15 to 40 represents 50 % reduction in energy requirement

  - Unprocessed Miscanthus: 0 (zero)
  - HTC 200: 25
  - HTC 250: 150

- >70µm act as heat sinks and increase resonance time before ignition
- Larger particles on drying and devolatilisation become entrained
- Flame moves higher in furnace = unstable flame

Influence of HTC on metal content



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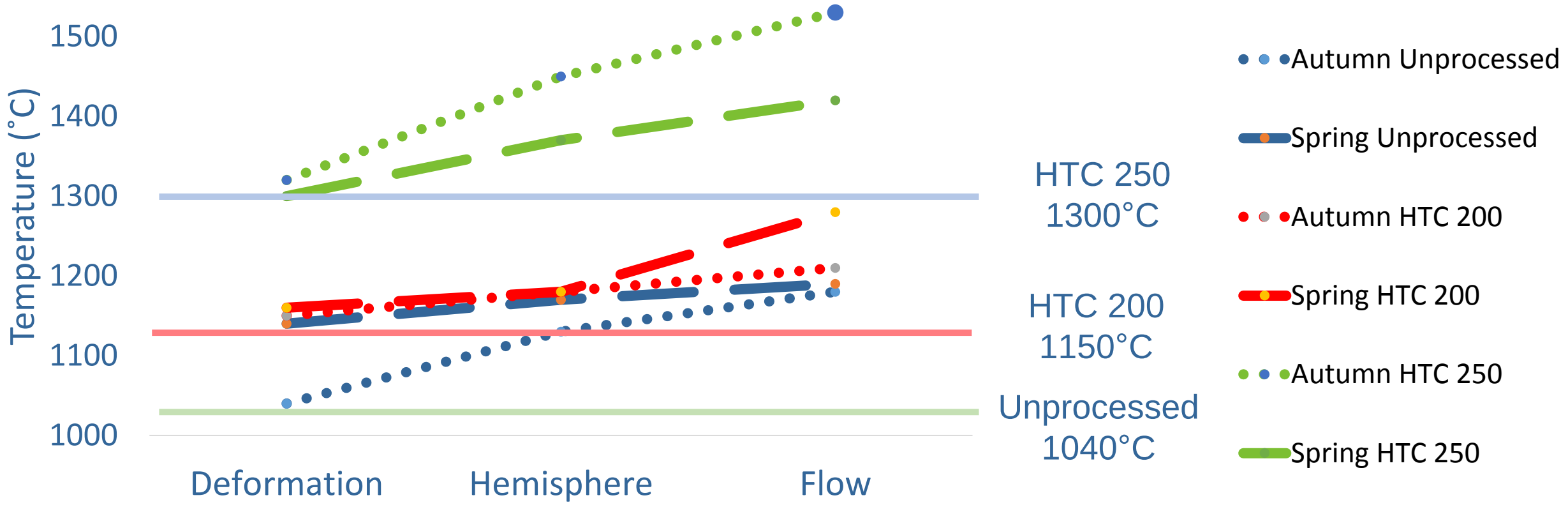

Conclusions

- Weathering of crop in conventional harvesting of *Miscanthus* often insufficient to avoid issues with slagging and fouling.
- Treatment at 200°C reduces energy requirement in grinding, increase flame stability through smaller pulverised particle size and enable safe combustion though alkali metal and chlorine removal
- Treatment at 250°C leads to a significant energy densification, significantly reduces energy requirement in grinding and significant reduces slagging and fouling
- The coal-like combustion profile of HTC 250 will reduce the need for modification of coal fired furnaces and better enable co-combustion with coal
- Hydrothermal treatment of autumn harvested *Miscanthus* could lead to a 40 % increase in yield

Further work

- Now Moved to Aarhus University, Denmark
- Multipurpose pilot hydrothermal reactor
- Scale-up – development of continuous (80 litre) facility more suited to HTC
  - Specifically designed for biomass optimisation
  - Conditions directly comparable to 2l Parr
  - Operational by January (pump on backorder)
  - Production of 100s'kg as opposed to 100 grams!
- Collaborators welcome ☺

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Any Questions?

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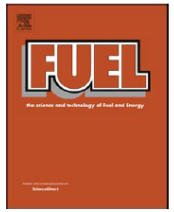

Full Length Article

The potential for production of high quality bio-coal from early harvested *Miscanthus* by hydrothermal carbonisation

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