BECCS

Technical Challenges and Opportunities

BECCS Specialist Meeting
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History of BECCS


- The Term “BECCS”
  - Used for the first time via a paper submitted to the J. Biomass and Bioenergy and Published in April 2003


- UNEP Emissions Gap Report: admitted that BECCS is now a key assumption within most modelling.

- IPCC’S 5th assessment report (Ch.6)

- Risks of Relaying on BECCS (Nature climate Change 2015)

- Paris Agreement (2015)
BECCS

• Large scale use of biomass and CCS inevitable due to Paris Agreement:
  – The Paris Agreement requires a stricter energy savings policy, large scale use of solar, wind and geothermal energy, and application of BECCS.
  – There is a growing and significant dependence on BECCS in future emission scenarios that do not exceed 2°C warming;
    • Over 100 of the 116 scenarios associated with concentrations between 430–480 ppm CO2 depend on BECCS to deliver global net negative emissions in the IPCC Fifth Assessment Report (AR5).
    • The feasibility of this dependence on BECCS is coming under increased scrutiny, (interconnected issues of food production, energy provision, energy system capacity and environmental impacts of large scale bioenergy coupled with large scale BECCS).
    • BECCS artificial “get out of jail” card in IAMs forced into a 2C world (AVOID2)

• How negative is BECCS
  – It was also noted that, because of its potential to deliver negative emissions, BECCS is subject to a higher level of scrutiny across the life cycle than other fuels or mitigation measures This assumption gets to the heart of the basic premise behind the use of BECCS to deliver negative emissions
Technical Challenges (1)

Case Study: Didcot Power Station A

Air Oxy25 Oxy30
Coal

Air Oxy25 Oxy30
Biomass

Temperature [K]
2200
2033
1866
1699
1532
1365
1198
1031
864
697
530
363
Combustion Challenges of Biomass

- 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).
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
What is Biomass

- Cellulose: Hexoses, ~45%
- Hemicellulose: Pentoses, ~29%
- Lignin: Aromatics, ~25%

- Woody Biomass

- Fats and oils

- Lignocellulosic biomass
Biomass Types and its Impacts on milling and combustion

- 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
Biomass Char Combustion Steps

- Type of Biomass Moisture Content Cellulose, Lignin
- Particle Size Heating Rate Time-Temperature History
- Char Properties
  - Intrinsic Reactivity
  - Catalytic Factors
  - Annealing
- Oxidising Environment, T
  - Rate of Oxidation Particle Temp
  - Rate of Burn-out Carbon-in-Ash

Pollutant Formation

- Loss of Volatiles
- Biomass Storage
- Air Supply
- Heating-Up Devolatilisation
- Volatiles NH₃, HCN
- Chars
- Fine Particles
- NOₓ
- SOOT (BC)
- Organic Compounds (OC)
- Ash
- Combustion Products: Gaseous and Particulate Pollutants

CO$_2$ impurities from the utilisation of biomass for power

• The potential of CO$_2$ impurities from the utilization of biomass for power.
• Volatiles comprising hydrogen and light hydrocarbons.
• Biomass fuels contain higher levels of alkali metals in comparison to coal and could form a class of CO$_2$ impurities
• Trace metals contained in fuel may be released to the gas-phase on combustion and propagate into the CO2 stream.
• The main species being chlorides, sulfates and hydroxides of potassium and sodium.
Deposition in the downstream of bag precipitator
Deposition/slagging

• Majority of the solid fuel ash SI are based on the assessment of the fusion behaviour of alumina-silicate coal ashes. Therefore application to biomass ash systems, which are chemically very different, can be problematic.

• In general terms, the use of biomass ash melting curve data, if available and the results of the Ash Fusion Test, are preferable.

• For most biomass materials, K tends to be the dominant alkali metal (generally released by volatilisation). The fouling indices we are developing specifically for the assessment of biomass is based on the total alkali metal content of the fuel on a mass or heat content basis.
Numerical slagging index (NSI) results for evaluation of slagging potential of biomass combustion in boilers

- Chemical reactions occurring within the deposits (oxidation, sulphation & chlorination) processes, can alter the nature of the deposit material (increase the deposit mass)

Publication: To be presented in International Combustion Symposium, S. Korea, 2016
Characterization of Ashes from Different Biomass

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ca</th>
<th>Si</th>
<th>K</th>
<th>Na</th>
<th>Al</th>
<th>P</th>
<th>S</th>
<th>Mg</th>
<th>Fe</th>
<th>Zn</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stem wood</td>
<td>25,742</td>
<td>433</td>
<td>8,752</td>
<td>8,106</td>
<td>127</td>
<td>975</td>
<td>929</td>
<td>670</td>
<td>79</td>
<td>446</td>
<td>2,758</td>
</tr>
<tr>
<td>Stem bark</td>
<td>221,064</td>
<td>8,147</td>
<td>70,668</td>
<td>6,217</td>
<td>3,086</td>
<td>25,359</td>
<td>9,710</td>
<td>7,769</td>
<td>924</td>
<td>5,054</td>
<td>18,284</td>
</tr>
<tr>
<td>Branch</td>
<td>163,671</td>
<td>26,673</td>
<td>85,830</td>
<td>5,403</td>
<td>2,541</td>
<td>31,290</td>
<td>11,873</td>
<td>4,461</td>
<td>1,111</td>
<td>4,758</td>
<td>16,032</td>
</tr>
<tr>
<td>Twigs</td>
<td>120,663</td>
<td>58,220</td>
<td>128,051</td>
<td>3,564</td>
<td>1,646</td>
<td>52,197</td>
<td>13,320</td>
<td>3,615</td>
<td>695</td>
<td>1,486</td>
<td>12,511</td>
</tr>
</tbody>
</table>

Chemical compositions of ash sample analysed by an inductively coupled plasma optical emission spectroscopy (ICP-OES).

- An experimental study on ash formation and deposition
  - Biomass ash components that evaporate to over 80% are Na, K, Cl, S, Zn, Pb; other inorganics such as Ca, Mg, Mn, P, Ti are released for 20-50%.
  - Release of minerals from coal however is much less in absolute terms, and also largely determined by the mineral composition (predominantly S and Cl).
  - The deposition chemistry of devolitalised ash elements pose significant challenges for reliable boiler operation.
  - Fuel preparation, quality control and blending will be needed to avoid problems.
### Chemical Composition of Wood Ash, Sugarcane Bagasse and Coal Fly Ash

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Wood Ash</th>
<th>Sugarcane Bagasse Ash</th>
<th>Coal Fly Ash Class C</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>31.8</td>
<td>85.5</td>
<td>40</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>28</td>
<td>5.3</td>
<td>17</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2.34</td>
<td>1.3</td>
<td>6</td>
</tr>
<tr>
<td>CaO</td>
<td>10.53</td>
<td>2.1</td>
<td>24</td>
</tr>
<tr>
<td>MgO</td>
<td>9.32</td>
<td>1.1</td>
<td>5</td>
</tr>
<tr>
<td>SO₃</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Na₂O</td>
<td>6.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>K₂O</td>
<td>10.38</td>
<td>3.5</td>
<td>-</td>
</tr>
</tbody>
</table>

### Heavy metal contaminant (ppm) in biomass ashes and coal fly ashes

<table>
<thead>
<tr>
<th>Heavy Metal</th>
<th>EPA</th>
<th>Sugarcane Bagasse Ash</th>
<th>Wood Ash</th>
<th>Fly ash Class C Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barium (Ba)</td>
<td>100</td>
<td>0.148</td>
<td>0.4608</td>
<td>1.72476</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>5</td>
<td>0.00445</td>
<td>bdl</td>
<td>0.003935</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>1</td>
<td>0.00185</td>
<td>nd</td>
<td>0.000845</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>5</td>
<td>0.0326</td>
<td>0.0328</td>
<td>0.036285</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>5</td>
<td>nd</td>
<td>0.0116</td>
<td>0.010215</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>0.2</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>Selenium (Se)</td>
<td>1</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
</tbody>
</table>

*Heavy metal contaminant (ppm) in biomass ashes and coal fly ashes*
Challengers on Biomass Combustion & Impact on BECCS

- Tar release 
  Cl, S in the tars

- Combustion

- Release of inorganic vapour 
  (K, P, Ca, Cl)

- Oxidation, chlorination, sulfidation 
  K₂O, KOH, CaO, P₂O₅, HCl

- Heterogeneous condensation
  KCl, NaCl

- Homogeneous condensation
  Nucleation, coalescence
  K₂SO₄

- Molten fly ash
  SiO₂, (NaCa)(AlSi)ₓOᵧ

- Re-entrainment

- Inertial impact

- Fly ash

- Scavenging Agglomeration

- Slag deposits

- Aerosols

- Furnace deposits

- Temperature range of eutectic mixture formation for KCl–K₂SO₄–Na₂SO₄ system
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 CO₂ 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 O₂.
- 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 K₂SO₄.
- To date, no estimates or measurements of the composition of CO₂ derived from Bio-CCS in power plant 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
BioCap-UK

University of Sheffield:
- Khalidah Al-Qayim
- Karen Finney
- Jon Gibbins
- Lin Ma
- Bill Nimmo
- Xin Yang
- Katarzyna Stechly
- Janos Szuhanszki
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University of Leeds:
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- Laura O'Keefe
- Patricia Thornley

University of Edinburgh:
- Bill Buschle
- Hannah Chalmers
- Chih-Wei Lin
- Mathieu Lucquiaud
- Juan Riaza

Industrial Panel: Greg Kelsall and Rachael Hall (GE), Ian Hibbitt (BOC), Robin Irons (EON), Chris Manson-Whitton (Progressive Energy), Alfredo Ramos, Penny Stanger (PSI), Scott Taylor (Sembcorp Industries), Stanley Santos (IEA)

Chair: Jim Swithinbank (University of Sheffield)
Multiscaling is the science dealing with modeling and simulation of phenomena and models across multiple time and/or length scales.
Modelling and Power Plant simulation

Laboratory scale

Pilot scale (250 kW CTF)

Full-scale
Pilot-Scale Integrated Experimental Facilities for BIO-Cap Project

Gas Mixing Facilities

250kW Air/Oxy Rig

ICP-OES & DMS 500

Carbon Capture Plant
• Deposition on boiler tubes impacts the overall boiler performance
• Reducing efficiencies and increasing maintenance requirement
2D imaging - Deposit growth

- Growth of deposit monitored by camera
- Deposition over 10 hrs
Focus of Bio-CAP 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)
Focus of Bio-CAP Research

• We are obtaining experimental data on Aerosols from Biomass combustion (high concentration of alkali metals (K), S, Cl, and some heavy metals)
  – Impact of aerosols on melting behaviour of ashes (deposit formation)
  – Impact of Biomass with high Cl-content aerosols (straw) on corrosion problems
  – Impact of metals impurities on solvents performance
  – Nature of aerosols in solvent based capture plant
Continuous, simultaneous multi-elemental online detection of entrained metal aerosols and vapours

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

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
BECCS Workshops and conference

• BIOCAP Dissemination activities

FINE PARTICLE FORMATION AND EMISSIONS IN BIOMASS COMBUSTION

Kuopio 2010