Institution: University of Leeds

Unit of Assessment: 15 – General Engineering

Title of case study: Case 2. Improving Co-firing Efficiency for Sustainable Biomass Energy

1. Summary of the impact (indicative maximum 100 words)

Over the past 10 years there has been a massive expansion in biomass use for power generation, particularly in the UK and Europe. Research at the University of Leeds has been crucial in addressing many of the challenges inherent in moving from coal to biomass including milling, combustion characteristics, deposition and corrosion enabling adoption of biomass for power generation. The research has impacted: (1) company strategy and industry practice for the use of biomass and key technology choices; (2) society, health and environment via CO_2 reduction and emission reduction; (3) national energy security through an increased fuel inventory; (4) UK Government and EU policy as expert members of advisory groups.

2. Underpinning research (indicative maximum 500 words)

The research has underpinned four main areas: fundamentals of biomass combustion; biomass supply and combustion of energy crops; impact of inorganics on combustion properties and ash behaviour; torrefaction of biomass and impact on biomass handling and combustion.

Biomass research at the University of Leeds began in 2000 with an EPSRC project (GR/N03129/01, **Jones**, £98,098) which established that a key nutrient, potassium, had a profound impact on the behaviour of biomass in combustion. This was not only related to fouling and slagging, which was known but not completely understood to a predictive level, but on the rates of combustion. Later funding [EPSRC Advanced Research Fellowship, GR/S49018/01 and GR/S49025/0, **Jones** (2003-2007); Platform Grant (EP/D053110/1, 2006, **P Williams**, 2006-2011, £439,578); SUPERGEN Bioenergy consortium (GR/S28204/01 & EP/E039995/1, **Jones**, 2003-2011, £2.9m & £6.3m respectively)], established this catalytic effect experimentally in high temperature flames and produced a model to predict volatilisation of potassium during combustion [1]. The modelling effort, led by **Pourkashanian** and **A. Williams**, incorporated this into CFD models of test furnaces and boilers to predict deposition [2, 3]. The location and nature of expected deposition informs boiler operators on soot blowing regimes and boiler outages. There also developed international engagement of research work in the power sector [2]. Work under British Coal Utilisation Research Association (Grant B79, **Jones**, 2006-2007, £50,000) and EPSRC (EP/F061188/1, **Pourkashanian**, 2008-2011, £360,582) also examined co-firing optimisation and the formation of NOx [1, 3] – an important consideration when converting to biomass since firing strategies can result in either increasing or decreasing NOx. Decreasing the total amounts of NOx produced can eliminate the need for expensive NOx reduction equipment.

The body of research has thoroughly characterised the types of fuels used in industry (agricultural residues, forestry residues and energy crops) for their thermal conversion behaviour (pyrolysis, torrefaction, combustion) and their predicted performance for different technologies [e.g. 4, 5]. The work stems from very fundamental (including *ab initio* modelling, measurements of reaction rates, establishing the fate of different key elements, such as nitrogen and potassium) [e.g. 1], to more applied studies of behaviour at large scale utilisation, including milling behaviour and development and application of CFD modelling of large boilers and furnaces.

The torrefaction of biomass has been an additional topic of research at the University of Leeds since 2005 funded by, British Coal Utilisation Research Association (Grant B92, **Jones** and **A Williams**, 2008-2009, £59,396), EPSRC (EP/H048839/1, **Jones**, 2010-2014, £600,020), and TSB (project number 103758, **Jones**, 2012-2013, £68,408,). This mild pyrolysis process produces a very attractive fuel for co-firing or full biomass boiler conversions. Work includes optimisation of the process for UK energy crops and residues, the fundamental reactions occurring, and the combustion behaviour of the resulting fuel. It has been established how certain biomass or torrefied biomass mills and combusts in comparison to coal [6]. The expected combustion behaviour and measured rates have been utilised to predict performance of the fuel in a large scale boiler. TSB funded work (project number 103758) with SSE and Energy Environmental Ltd involved a large scale co-firing trial of torrefied biomass with coal at Uskmouth Power Station on 22 February 2013, and led to an improved understanding of CO_2 reductions, as well as milling and combustion performance. The operation of the coal mill remained normal on the torrefied biomass and coal mix, and unlike normal biomass, no accumulation/flooding with torrefied biomass were observed during or after the trial. Similarly, no significant deviation was observed in NOx, SOx and dust emissions. Results indicated there is a potential for significant capital cost savings over a traditional biomass conversion by using a torrefied biomass fuel. Significant cost savings can be made in the milling and the associated pulverised fuel transport facility compared to a traditional biomass conversion.

Key Researchers:
JM Jones (Lecturer, 14/08/1995 - 31/07/1999, Senior Lecturer, 01/08/1999 - 31/07/2004, Reader, 01/08/2004 - 29/02/2008 and Professor, 01/03/2008 - present)
M Pourkashanian (Lecturer, 18/05/1989 - 30/11/1992, Senior Lecturer, 01/12/1992 - 31/07/1998, Reader, 01/08/1998 - 31/12/1999 and Professor, 01/01/2000 - present)
A Williams (Livesey Professor, 1973 - 30/09/2001, Research Professor, 01/10/2001 - 30/04/2011, Professor, 01/05/2011 - 31/10/2013)
PT Williams (Research Fellow, 07/11/1983 - 30/09/1986, Lecturer, 01/10/1986 - 31/07/1992, Senior Lecturer, 01/08/1992 - 31/07/1997, Reader, 01/08/1997 - 31/07/2001, Professor, 01/08/2001 - present)

3. References to the research (indicative maximum of six references)

[1]. **JM Jones**, LI Darvell, TG Bridgeman, **M Pourkashanian** and **A Williams** (2007) “An Investigation of the thermal and catalytic behaviour of potassium in biomass combustion”, *Proceedings of the Combustion Institute*, 31, 1955-1963, DOI:10.1016/j.proci.2006.07.093

[2]. MU Garba, DB Ingham, L Ma, R Porter, **M Pourkashanian**, HZ Tan and **A Williams** (2012) “Prediction of potassium chloride sulfation and its effect on deposition for biomass-fired boilers”, *Energy and Fuels*, 26, 6501-6508, DOI: 10.1021/ef201681t

[3]. **A Williams**, **M Pourkashanian** and **JM Jones** (2001) “Combustion of pulverised coal and biomass”, *Progress in Energy & Combustion Science*, 27, 587-610, DOI: 10.1016/S0360-1285(01)00004-1

[4]. T G Bridgeman, L I Darvell, **JM Jones**, **PT Williams**, R Fahmi, AV Bridgwater, SC Thain, IS Donnison, T Barraclough, I Shield and N Yates (2007) “Influence of particle size on the analytical and chemical properties of two energy crops”, *Fuel*, 86, 60-72, DOI: 10.1016/j.fuel.2006.06.022

[5]. LI Darvell, **JM Jones**, B Gudka, XC Baxter, A Saddawi, **A Williams** and A Malmgren (2010) “Combustion properties of some power station biomass fuels”, *Fuel*, 89, 2881-2890, DOI: 10.1016/j.fuel.2010.03.003

[6]. **JM Jones**, TG Bridgeman, LI Darvell, B Gudka, A Saddawi and **A Williams** (2012) “Combustion properties of torrefied willow compared with bituminous coals”, *Fuel Processing Technology*, 101. 1–9, DOI:10.1016/j.fuproc.2012.03.010

Papers 1, 2 and 6 best represent the quality of the underpinning research. Through the research in Paper 1 it was established that potassium is the single most important inorganic influencing biomass thermal conversion and provided fundamental understanding of this. This is significant because it enables control over the combustion or pyrolysis characteristics of a biomass resource. It led to further development of industrially important work which linked this to impacts in efficiency versus deposition in boilers and furnaces through the approach developed in Paper 2. The research in Paper 6 is part of a series of papers concerning the expected performance of torrefied biomass in large scale coal combustion units. This paper gives key performance parameters concerning reaction rates and nitrogen partitioning, which are critical in the decision-making process of coal plant conversion since they impact on combustion efficiency and NOx formation.

4. Details of the impact (indicative maximum 750 words)

Context

In the UK, electricity generation through biomass co-firing began in 2002 and grew to approximately 28 MWe by 2005 (DTI, 2005). More recently there have been several strategic investments by the UK's power generation industry to replace coal with biomass, driven by legally-binding domestic targets in CO_2 reduction and government incentives so that in 2011 co-firing was delivering over 525 MWe; this is projected to more than double by 2020 and the same is true in Europe as a whole (National Renewable Energy Plans). Conversions to biomass will result in approximately 70% reduction in GHG emissions compared to coal. And increasing incentives could "*employ up to 18,000 jobs in the UK by 2020 in the biomass electricity sector alone"* (Bioeconomy Consultants NNFCC, 2012).

The move to biomass has required changes in policy and practice at nearly every stage in the energy cycle, from fuel procurement and logistics to handling (including milling), burner design, and firing and emission control strategies. Research from the University of Leeds underpins a number of technical challenges the industry has overcome and has also informed policy, in particular the development of energy roadmaps, these impacts occurring during the eligible period as a result of dissemination and direct beneficiary engagement via collaborative R&D, consultancy, CPD and expert advisory roles and capacity building.

Impact on Industry Practice

Technical innovations in the fields of biomass combustion, boiler efficiency, plant operation and emission have benefited the UK's two largest electricity generators Drax Power and Eggborough Power, who between them generate 11% of the country's electricity.

A combination of biomass combustion collaborative research [A] (EP/H048839/1, Jones, 2010-2014) and consultancy between 2010 and July 2013 has "*been extremely valuable*" to **Drax Power Ltd** [B]. Impacts include:

- Widening the fuel portfolio so that Drax is able to use larger volumes of lower grade fuel (i.e. from agricultural and forestry) sources; "*providing significant savings on fuel costs of up to £15m per annum*". [B]
- Allowing "*full sustainability to be achieved, opening up new markets to the industry and better managing the world's resources on a global scale*" by completing a "*superb analysis of options in the supply chain*". [B] "*The outcomes of the KTP project with Drax have directly contributed to the overall strategy of Drax Group PLC by supporting the establishment of new supplies of biomass that when burned will ultimately reduce its CO_2 emissions from power generation by burning more biomass and will diversify the business away from the current almost total reliance on fossil fuel supplies for power generation*". Improved market research capability through the KTP has resulted in an estimated reduction in biomass cost of £2m p.a. [A].
- Solving engineering issues allowing the use of biomass; "*slagging and fouling to be managed and corrosion to be reduced to the four yearly outages normally only seen with coal*." [B]

Drax Power, which invested £50 million in 2009 to allow co-firing of up to 12.5% biomass and CO_2 reductions of up to 1.8 million tonne/p.a., plans conversion of half of their units to biomass over the next three years. Despite recent changes to government policy on biomass subsidies, Drax remains committed to this expansion the CEO describing it is a "*sound investment strategy*" [C].

Eggborough Power Ltd announced plans in November 2012 to fully convert to biomass, an investment of "*hundreds of millions of pounds*" [D]. Consultancy for Eggborough in the field of biomass combustion between February and July 2013, particularly NOx formation, have been "*fundamental to the success of the project*" [E].

Researchers from Leeds undertook collaborative research [F] with **Energy Environmental Ltd** (EEL) in the field of torrefied biomass handling and combustion (June 2012 to March 2013). EEL, the holding company for a portfolio of companies concerned with viable new environmental technologies, benefited from being able to seamlessly integrate torrefied biomass into the coal feed prior to milling. Commercial scale milling and combustion data showed that torrefied biomass "*offers a low cost alternative for coal-fired power stations*". [G]

A University of Leeds Continuing Professional Development short course on biomass combustion that drew on the underpinning research and the Institution's engagement with industry has helped beneficiaries make fuel supplies more predictable in terms of performance in the boiler [H]. The annual course started in 2009 and has been attended by 203 delegates at all levels of seniority, from new graduates to senior project engineers, managing directors, and senior policy advisors [H] from 95 different UK and international beneficiaries (companies/government departments/NGOs).

Policy

Leeds researchers have participated in many workshops and policy discussions, drawing on the underpinning research in biomass and biofuels utilisation to provide expert advice that has informed the development of UK energy:

- All Party Parliamentary Renewable Transport Fuels Group, 2009. This comprises 20 politicians from the major political parties and aims to highlight the potential of renewable transport fuels in reducing carbon emissions from the transport sector and increase fuel security (Pourkashanian). [I]
- EU-GCC Clean Energy Network to support the long-term strategic EU-GCC energy relationship, 2010 (Pourkashanian). [I]
- British Embassy Mission to France which aimed to gain a broader Franco-British perspective on what is driving and hindering the large-scale development and market adoption of biofuels, Lyons, September 2009 (Jones). [J]
- Energy Technologies Institute's bioenergy strategy, 2008 (A Williams, Jones).
- Royal Society of Chemistry's Energy Roadmap online consultation, 2008 (A Williams).
- East Midlands biomass densification report, Regional Development/Policy Support, NNFCC, 2010 (Jones).
- European Research Area Network (ERANET) Bioenergy, Vienna workshop on Clean Biomass Combustion, 2008 (A Williams).

5. Sources to corroborate the impact (indicative maximum of 10 references)

A. KTP007858 between Drax Power and Leeds University, Final Report, April 2012
B. Letter of corroboration from Principal Scientist, Drax Power, 29th August 2013
C. BBC News, '*Why Drax is investing in biomass technology*', released 17th July 2013, http://www.bbc.co.uk/news/business-23342644
D. The Times, '*Eggborough Power Station takes green route as coal enters its 'slow death'* ' http://www.thetimes.co.uk/tto/business/industries/utilities/article3590052.ece, November 2012
E. Letter of corroboration from Engineering Director, Eggborough Power, 7th May 2013
F. TSB 103758, Technical evaluation of using torrefied biomass from the "Rotawave" process to economically reduce carbon output from coal-fired power generation. Final Report, March 2013
G. Press release from EEL, March 2013
H. CPD corroboration – evaluation summaries for 2011-2012, and list of delegates and company details for the CPD Biomass Combustion course from 2009-2013.
I. Invitations to join All Party Parliamentary Group (2009) and EU-GCC Clean Energy Network (2010) as expert member.
J. Mission to France programme and delegate biographies.

All websites successfully accessed on 22nd October 2013.