IEA Bioenergy

Task 34 Pyrolysis

PyNe
28

ISSN 2040-2759

December 2010

Welcome: Task 34

By Doug Elliott, Task 34 Leader

The IEA Bioenergy Task 34 for Pyrolysis has been approved for the new triennium from 2010 to 2012. Current participants in the Task are Canada, Finland, Germany, the UK with leadership provided by the US. This newsletter is produced by the Task to stimulate the interaction of researchers with commercial entities in the field of biomass pyrolysis.

Aims & Objectives

The overall objective of Task 34 is to improve the rate of implementation and success of fast pyrolysis for fuels and chemicals by contributing to the resolution of critical technical areas and disseminating relevant information particularly to industry and policy makers. The scope of the Task will be to monitor, review, and contribute to the resolution of issues that will permit more successful and more rapid implementation of pyrolysis technology, including identification of opportunities to provide a substantial contribution to bioenergy. This will be achieved by the activities listed below:

Priority Topics for Task 34

- Norms and standards
- Analysis – methods comparison and developments
- Country reports updates/ review of state of the art
- Fuels and chemicals from pyrolysis

In this issue of the newsletter you will find short introductory articles from the national team leaders from each of the participating countries summarizing their particular efforts in the field. Also, there are several articles from around the world describing

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Welcome...continued

the latest developments in fast pyrolysis including work in Finland at the METSO pilot plant, in Germany at the University of Rostock, in the UK at York and Southampton Universities, from Canada we have a summary of the work at ABRI-Tech, as well as Agriculture and Agri-Food Canada, from the US there is a highlight of the recently announced fast pyrolysis and bio-oil hydroprocessing demonstration plant funded by UOP LLC and the Department of Energy.

Also included is a write-up of the Task 34-42 co-operation in biorefinery design/LCA and also a summary of the lignin Round Robin completed earlier.

We also have conference reviews for the BIOTEN meeting in Birmingham, UK, and the Thermochemical Conversion Science meeting in Ames, Iowa, USA. Finally, we have discussions on related topics of the recently begun work on hydrothermal liquefaction (pyrolysis in pressurized hot liquid water) in the US and slow pyrolysis work in Finland.

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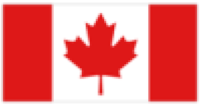

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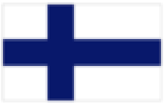

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Bio-oil production, integrated to a fluidized bed boiler—experiences from a pilot operation

Anja Oasmaa of VTT provides an insight into the Metso pilot plant in Finland

> *"The integrated concept is easy and smooth to operate, and has high efficiency."*

Proof-of-concept at Metso's pilot plant

Metso, UPM, Fortum and VTT have developed an integrated bio-oil production concept to provide an alternative to fossil fuels. The consortium has developed a bio-oil production process, in which a pyrolysis reactor is linked to a conventional fluidized bed boiler. The proof-of-concept has been carried out at the 7 tpd pilot: close to 90 tons of bio-oil have been produced from sawdust and forest residues with a reliable process at high availability.

The integrated pyrolysis concept enables high overall efficiency and bio-oil yields. Char, containing side stream and non-condensable gases, is utilized in the adjacent boiler, to produce heat and electricity.

A reliable and flexible technology for the production of bio-oil

Compared to a stand-alone pyrolysis unit with a non-optimal small boiler for the combustion of pyrolysis by products (char and pyrolysis gases), the integrated concept is easy and smooth to operate, and has a high efficiency. It has a considerable advantage from the operator point of view for the pyrolysis to have a steady and smooth flow of input energy (i.e. boiler sand).

The figure below depicts an example of the pilot operation. The quench liquid initially has a high water content, but during the first day, while the feed moisture is also decreased, a constant level of about 25 wt% for the product water is achieved. As a result of the stable pilot plant operation, the product water remains constant for as long as the feed moisture is also constant. After day three, when the feed moisture is gradually increased from 8 to 12 wt%, the product liquid

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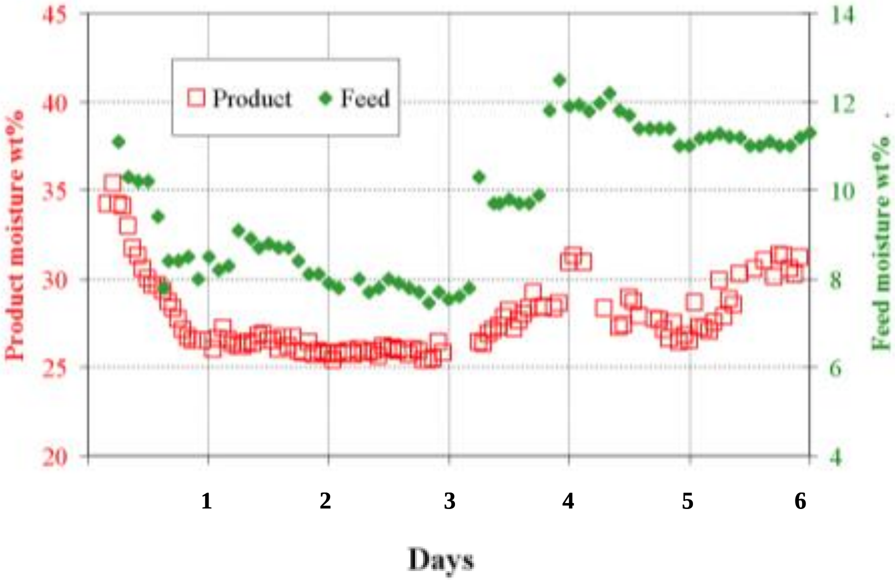

Figure 1: An example of the bio-oil water content during a six day period

Bio-oil production...continued

moisture also increases. A total of three different wood fuels were tested during the shown period.

Fuel preparation is an essential part of the process

The main feedstocks for the pilot plant were forest residues and sawdust. The feedstock was dried at 40-50°C, down to a moisture less than 10% and ground down to a particle size less than 5mm.

Bio-oil is technically suitable for the replacement of heavy fuel oil in district heating plants

Bio-oil was combusted in Fortum's 1.5 MW district heating plant in Masala, Finland. The existing burner was changed to a new bio-oil burner, which is a modified heavy fuel oil burner. A total amount of about 20 tons of bio-oil was combusted during the spring of 2010. One of the main focus topics was the overall functionality of the bio-oil receiving, storing and pumping system. The receiving system and oil tank were located outside the building. The system operated well regardless of the outside temperature, which varied from -20°C to +10°C during the test period.

Another focus was the function of the burner. As a result, a good reliability and satisfactory turn-down-ratio of 1:3 was achieved. Flue gas emissions were close to those of heavy fuel oil - at 4% O_2, CO emissions ranged from 0 to 10 ppm, and NOx from 300 to 400 ppm. Organic compounds were under 5 mg/m^3n and particulate emissions were in the range of 150-200 mg/m^3n. No significant odours affecting the neighbourhood took place.

A new test period at Fortum's district heating plant will be carried out during the autumn of 2010. Once the replacement of heavy fuel oil in the boiler has been demonstrated, the focus of the work will turn to the replacement of light fuel oil in the boiler.

Acknowledgement

This article was produced in conjunction with J. Lehto, Metso Power; P. Jokela, UPM; J. Alin, Fortum and Y. Solantausta, VTT.

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Table 1: Metso's Pilot feedstock analyses

		Forest Residue	Pine
Moisture, as received (DIN 51718)	wt-%	10.9	10.8
Sulphur, dry basis, (CEN/TS 15289)	wt-%	0.03	ND
Ash, dry basis (CEN 335)	wt-% (db)	1.5	0.6
Volatiles, dry basis (DIN 51720)	wt-% (db)	80.2	83.1
Carbon (C), dry basis (ASTM D 5373)	wt-% (db)	51.1	50.7
Hydrogen (H), dry basis (ASTM D 5373)	wt-% (db)	6.0	5.9
Nitrogen (N), dry basis (ASTM D 5373)	wt-% (db)	0.4	0.1
Higher heating value, dry basis (DIN 51900)	MJ/kg	20.6	20.3
Lower heating value, dry basis (DIN 51900)	MJ/kg	19.3	19.0
Lower heating value as received (DIN 51900)	MJ/kg	16.9	16.7

Figure 2: Fortum's Masala site burning bio-oil. The light fuel oil tank is at the front

Pilot Scale Biorefinery

An overview of an integrated pilot scale biorefinery project in Hawaii

Sustainable Transport Fuels from Biomass and Algal Residues via Integrated Pyrolysis and Catalytic Hydroconversion

This project will leverage two commercially proven core technologies into an integrated platform—pyrolysis of biomass from Ensyn Corporation and hydroconversion from UOP.

Project Description

UOP proposes to conduct a pilot-scale operation of a fully integrated process to convert high-impact biomass to fuels, including gasoline, diesel, and jet-range hydrocarbon. Feedstock producers will provide feed and information for detailed life cycle assessment and growth potential. The feeds will be converted to fuels via integrated pyrolysis and hydroconversion. Refiners and engine manufacturers are also team members to demonstrate fungibility of the fuels within the refinery, determine fuel properties, and accelerate qualification and acceptance as liquid transportation fuels.

UOP is currently working with the US Department of Energy (DOE) to develop pyrolysis oil upgrading technology that will improve stability of the products and remove highly reactive components that will allow more cost effective downstream processing of the pyrolysis oils. The unit will include rapid thermal processing (RTP™) technology developed by Ensyn Corporation to convert the biomass to pyrolysis oil. The RTP technology has been used commercially since 1989 and is currently used to process biomass and other feedstocks in seven North American units.

The production of pyrolysis oils is envisioned taking place near areas of biomass resources in order to transport a higher energy density product to the refinery where upgrading to fuels will take place. The stabilization of pyrolysis products will allow longer term storage of feedstocks at the

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Figure 1: The UOP Integrated Biorefinery will convert a variety of biomass feedstocks to fungible liquid transportation fuels.

Pilot Scale Biorefinery...continued

refinery. Once at the refinery, the pyrolysis oils will be processed using modified hydroconversion technologies to produce liquid transportation fuels.

Potential Impacts

As a result of this project, UOP anticipates deploying the technology on a commercial scale. Each commercial application would have 4 RTP units and 1 Upgrading unit to produce 50 million gallons of fuels annually, with the potential to create approximately 800 construction jobs and 1000 permanent jobs, including biomass production.

Other Participants

Tesoro, Ensyn, PNNL, CH2M Hill, Ambitech, Michigan Tech University, Ceres, Cargill, Inc., Grays Harbor Paper LP, Targeted Growth Inc., Imperium Renewables, HR BioPetroleum, Mesa Engineering, Countrymark Petroleum, Kern Oil, Honeywell, Boeing, and General Motors.

Overview

Prime:	UOP, LLC.
Location:	Kapolei, Oahu, Hawaii
Feedstock(s):	Agriculture wastes, pulp, paper, wood, energy crops and algae
Size:	1 ton per day
Primary Products:	Gasoline, Diesel and Jet fuels
Capacity:	4 Barrels per day
Award Date:	Early 2010
GHG Reduction:	60% reduction versus fossil fuel equivalent
Anticipated Job Creation:	85 peak construction jobs and an average of 40 sustained per year during the project duration

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Acknowledgement:
The information contained within this article is taken from the UOP Recovery Act Biorefinery Project Fact Sheet which is available on the US Department of Energy website, as follows:

http://www1.eere.energy.gov/biomass/factsheets.html#integrated

Task 34 Pyrolysis meeting

Stratford-upon-Avon, UK
October 16-17, 2010

Doug Elliott, Task 34 Leader gives an update on the recent Pyrolysis meeting

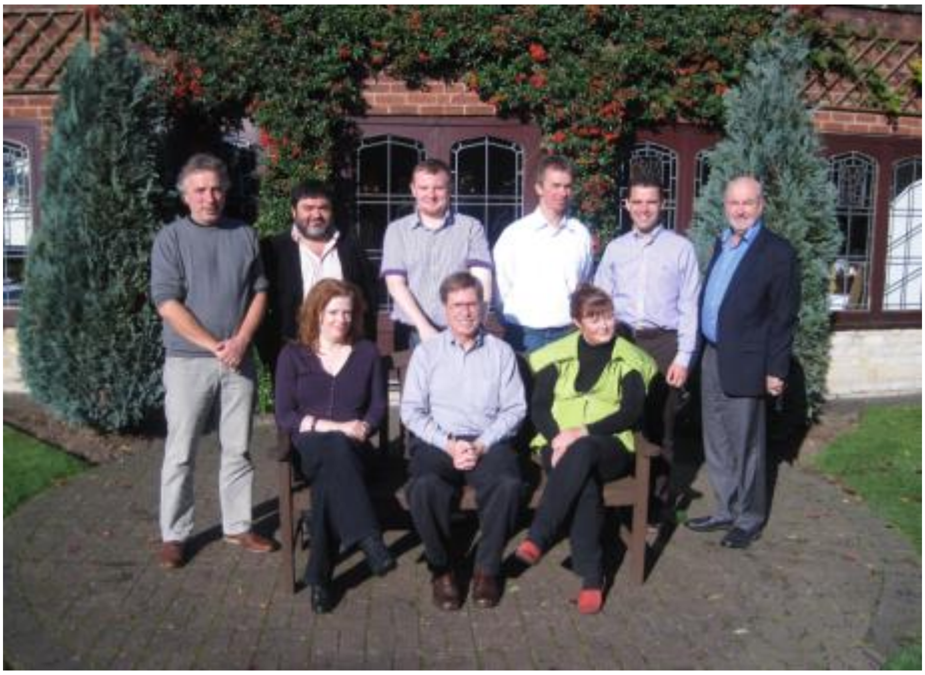

Figure 1: Back row, left to right: Dietrich Meier, Fernando Preto, Daniel Nowakowski, Paul de Wild, Stefan Müller, Tony Bridgwater.
Front row, left to right: Irene Watkinson, Doug Elliott, Anja Oasmaa

> *"The most important outcome of the meeting was the final organization of a Round Robin analysis of bio-oil samples for viscosity and thermal aging."*

All National Team Leaders (NTLs) were present for the recent meeting of the Task 34 on Pyrolysis. The agenda items including Country reports and a proposed publication of that information, norms and standards developments, and organization of a seminar on upgrading bio-oil by catalytic hydroprocessing.

Most of the group also toured the biomass pyrolysis laboratories of Prof. Bridgwater at Aston University in nearby Birmingham, UK. The most important outcome of the meeting was the final organization of a Round Robin analysis of bio-oil samples for viscosity and thermal aging. The list of potential participants includes 23 laboratories in the five participating countries. The bio-oil samples should be distributed by early next year with the expectation that the results will be received by the next Task meeting in April at Hamburg, Germany. The Hamburg meeting is scheduled for April 6-7, 2011 including a tour of the vTI pyrolysis laboratories with a subsequent study tour on April 8 of the nearby PyTec pyrolysis demonstration plant.

The bio-oil upgrading symposium has been tentatively scheduled for September 30, 2011, in Chicago, Illinois, USA immediately following the GTI Thermochemical Conversion Science Conference. The members will then convene in Richland, Washington, USA at the site of the Pacific Northwest National Laboratory for a task meeting on October 3-4.

Doug Elliott
Task 34 Leader

Computational modelling of biomass fast pyrolysis process.

Sai Gu from the University of Southampton, outlines advanced computational models developed in the UK

Researchers at the University of Southampton and Aston University in the UK have been working together to develop advanced computational models to look inside of the biomass fast pyrolysis process. Thermochemical process modelling has been growing into a new era with the combination and incorporation of multiple physico-chemical phenomena into a single model. The development and application of such models in modern day engineering can give a great insight on the process, where simple experiments cannot, and lead the way towards design and process optimisation.

Although there is still reservation about the reliability of models, the huge growth in computational power together with the development of advanced computational algorithms make thermochemical process modelling a credible optimisation solution for the future.

Modelling approaches

The computational model is developed based on the lab-scale fluidised bed systems in Aston University. The key element of the modelling work is the fluidised bed reactors. Fluidised bed is a complex multiphase flow problem. Existing models mainly deal with simple cold bed. We use a new approach to combine the tracking of biomass particle with the hot bed hydrodynamics, so the detailed interaction between biomass and particle and thermal degradation of biomass in the reactor can be observed.

The complete biomass to liquid fast pyrolysis numerical model has a certain advantage over

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> *"We use a new approach to combine the tracking of biomass particle with the hot bed hydro-dynamics."*

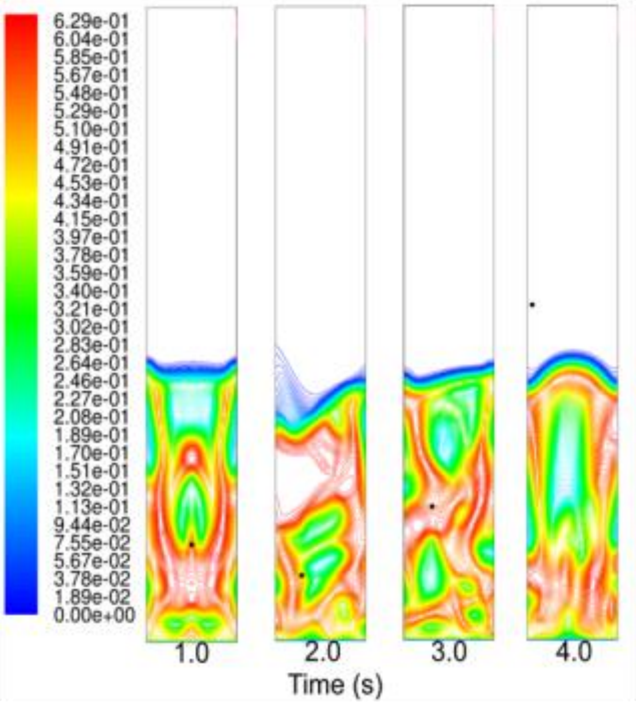

Figure 1: Fluidised bed hydrodynamics with discrete biomass particle (black dot)

Computational modelling of biomass fast pyrolysis process...continued

single particle models and simple fluidised bed hydrodynamic studies. The engineer can extract important information such as bubble distribution, local heat transfer coefficients, intra-particle temperature and product distribution, local particle velocity components, particle trajectories, char and pyrolysis vapours residence time, something that is impossible to obtain with simple fast pyrolysis and hydrodynamic studies.

The effect of biomass particle size and shape as well as shrinkage on the heat transfer coefficients, char residence time and final product yields can be studied and analysed, leading to operational and geometrical modifications of the process and the reactor respectively. Modelling results can greatly aid the scaling of lab-scale equipment to industrial size units and identify possible design limitations or suggest necessary interventions and alterations on the operation of the process. Some of the simulated results are given in Figures 1-4. Detailed results can be found in the references [1-9].

Future work

A complete fast pyrolysis model can be used on the analysis and design optimisation of the equipment that affects the final bio-oil yield. Apart from the bubbling fluidised bed reactor itself, the liquid collection system is an important parameter of the process. The extreme complexity and nature of the pyrolysis vapours make the analysis and simulation of the

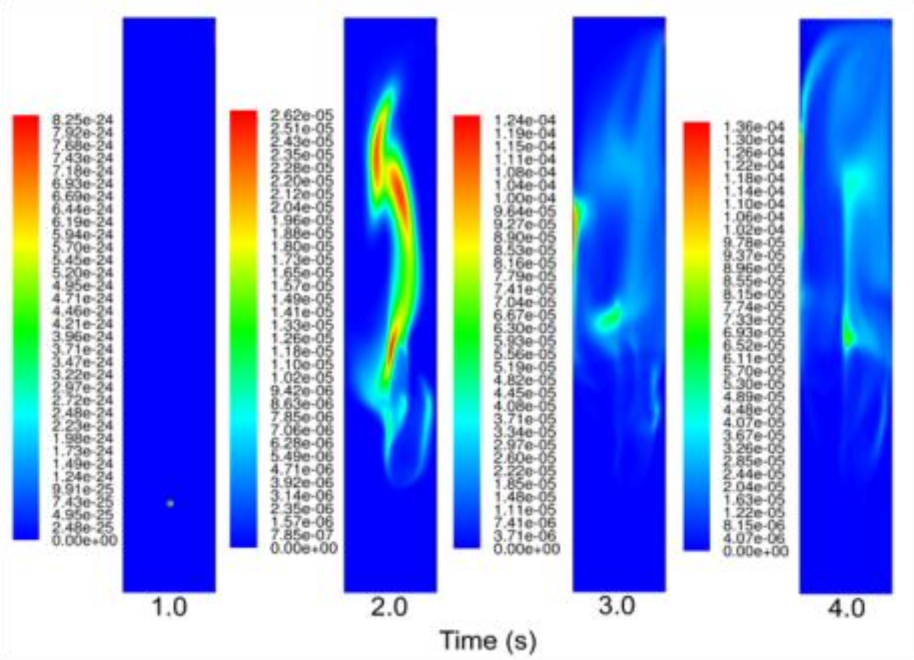

Figure 2: Evolution of pyrolysis vapours from discrete biomass particle

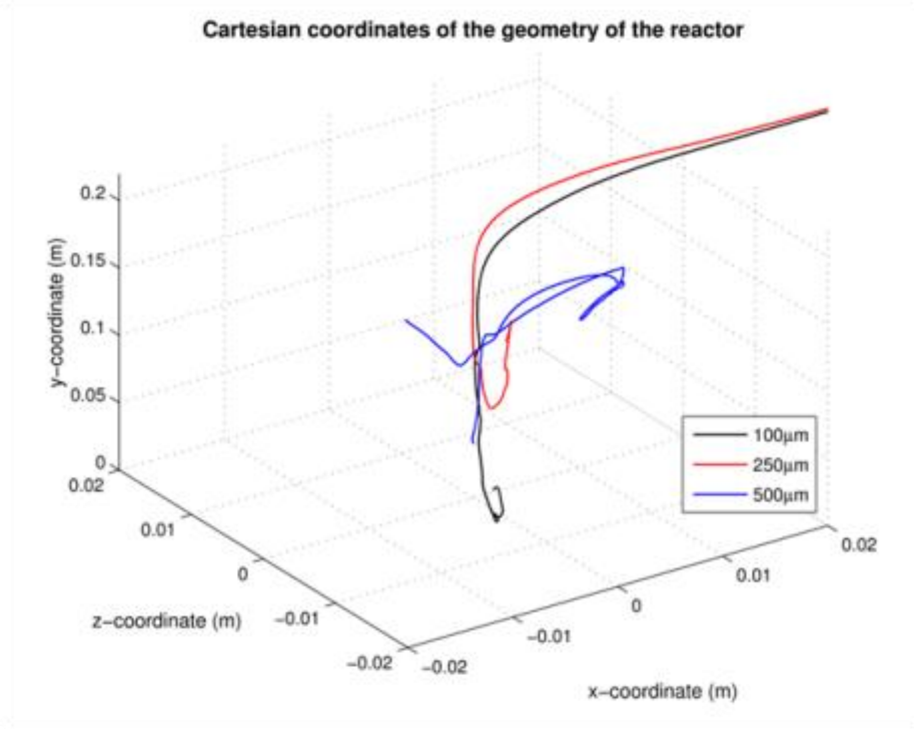

Figure 3: Trajectories of different size char particles

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Computational modelling of biomass fast pyrolysis process...continued

condensation or quenching process extremely complex and difficult. However, the identification of the most important and dominant compounds in the vapour mixture can lead to computational models that would greatly represent the true nature of the problem. The challenge to be faced mainly concerns the calculation of the saturation vapour pressure of pyrolysis vapours present in a mixture of non-condensable gases as well as the heat transfer from the condenser to the gas-vapour mixture. In this way the design and optimisation of the heat exchanging equipment can be achieved, leading to a more uniform final bio-oil product. We are making progress building a complete fast pyrolysis model including reactor and liquid collection.

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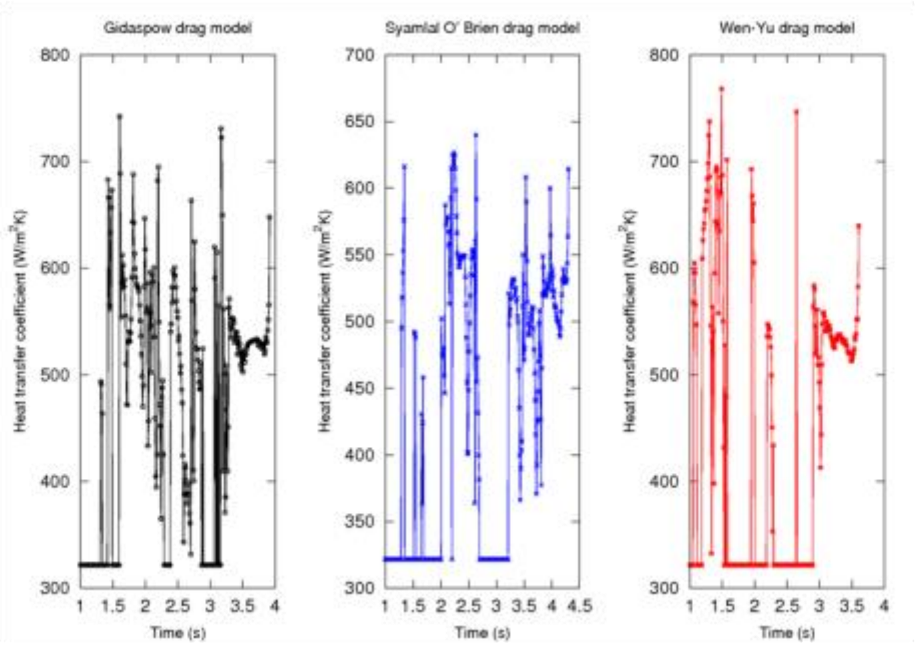

Figure 4: Instantaneous local heat transfer coefficient. Comparison of different drag models for granular flows.

References

[1] Papadikis K, Gu S, Bridgwater AV, Computational modelling of the impact of particle size to the heat transfer coefficient between biomass particles and a fluidised bed, Fuel Processing Technology, 91(1) 68-79 (2010).

[2] Papadikis K, Bridgwater AV, Gu S, A CFD approach on the effect of particle size on char entrainment in bubbling fluidised bed reactors, Biomass and Bioenergy, 34(1) 21-29 (2010).

[3] Papadikis K, Gu S, Bridgwater AV, CFD modelling of the fast pyrolysis of biomass in fluidised bed reactors. Part B: Heat, momentum and mass transport in bubbling fluidised beds, Chemical Engineering Science, 64, 1036-1045 (2009).

[4] Papadikis K, Gerhauser H, Bridgwater AV, Gu S, CFD modelling of the fast pyrolysis of an in-flight cellulosic particle subjected to convective heat transfer, Biomass and Bioenergy, 33(1), 97-107 (2009).

[5] Papadikis K, Gu S, Fivga A, Bridgwater AV, Numerical comparison of the drag models of granular flows applied to the fast pyrolysis of biomass, Energy and Fuels, 2010, 24 (3), pp 2133–2145.

[6] Papadikis K, Gu S, Bridgwater AV, 3D simulation of the effects of sphericity on char entrainment in fluidised beds, Fuel Processing Technology, 91 (2010) 749–758.

[7] Papadikis K, Gu S, Bridgwater AV, CFD modelling of the fast pyrolysis of biomass in fluidised bed reactors: Modelling the impact of biomass shrinkage, Chemical Engineering Journal, 149, 417-427 (2009).

[8] Papadikis K, Gu S, Bridgwater AV, Gerhauser H, Application of CFD to model fast pyrolysis of biomass, Fuel Processing Technology, 90, 504-512 (2009).

[9] Papadikis K, Bridgwater AV, Gu S, CFD modelling of the fast pyrolysis of biomass in fluidised bed reactors, Part A: Eulerian computation of momentum transport in bubbling fluidised beds, Chemical Engineering Science, 63 (16), 4218-4227 (2008).

Assay of corrosion resistance of two selected metals exposed to bio-oil

A synopsis from Rolf Strenziok (pictured above) and Helen Rickhoff from the University of Rostock, Germany

Two materials were tested in different concentrations of fuel and bio-oil by using exposure tests at raised temperature, in a liquid- and vapour-phase region (Figure 1).

1. Experimental setup with the two materials and the ageing oven

As reference fuel(s) E85 (85 vol% Ethanol + 15 vol% ASTM -C) was chosen. In addition three different mixtures of E85 and pyrolysis oil with weight ratios of 2:1, 1:1 and 1:2 were used. The tested material samples consist of an aluminium alloy (AlMgSi1), which is often used in fuel pumps and lines, as well as a lamellar grey cast iron (GG25) which is used widely in cars, pumps, compressors etc.

2. Results

In Figure 3 the macroscopic visible changes of the grey cast iron sample in different fuel mixtures after 13 weeks of exposure are shown. While there were no signs of corrosion detectable in the reference fuel, all other samples showed an extensive decomposition, which seemed to increase in higher concentrations of bio-oil. This could not be verified by determining mass loss (Figure 4), because of the hardly removable, black coating on the surface especially in the vapour phase area, which was also increasing in higher concentrations of oil. This coating might have a preventing effect on the corrosion attack and has to be analysed in further tests.

The microscopic observation and the determination of mass loss showed that the corrosive damage on the aluminium sample seemed to be less distinctive. Under the light microscope numerous areas with damage to the passive layer were found. A metallographic cross section (Figure 2) of one of the samples with the highest concentration of bio-oil showed pitting attacks with a depth of at least as 230 µm after 13 weeks. The pitting corrosion is a far more

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GG25

AlMgSi1

Oven

Figure 1: Experimental setup exposure tests

Assay of corrosion resistance of two selected metals exposed to bio-oil ...continued

significant problem than surface corrosion because despite being very deep and small pits are often macroscopically invisible.

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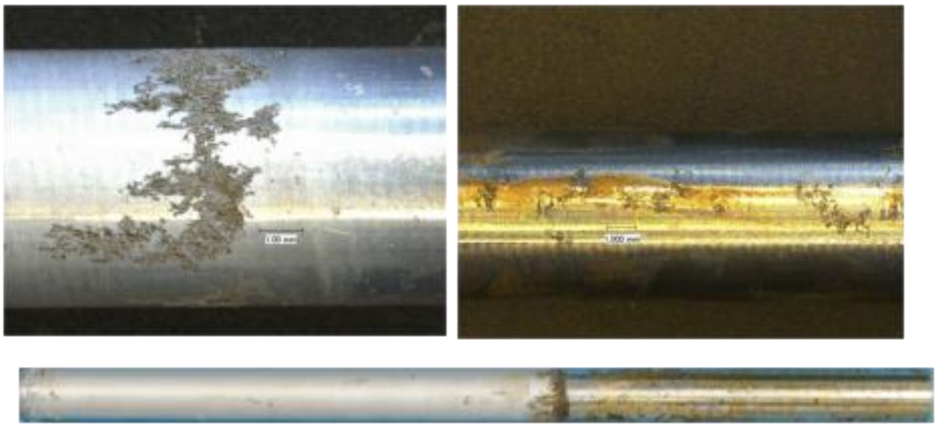

Figure 2: Microscopic documentation of the aluminium sample (E85/Oil 1:2) after 13 weeks of exposure

Figure 3: Macroscopic documentation of the grey cast iron after 13 weeks of exposure

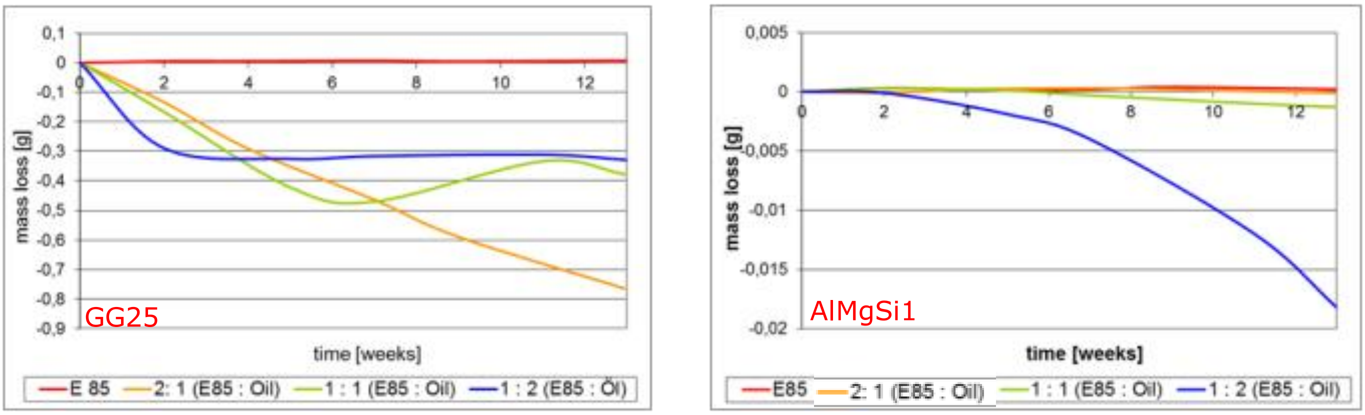

Figure 4: Mass loss of the exposure samples GG25 and AlMgSi1 in different mixtures of fuel with bio-oil at 60°C

TCS 2010—review

Review from Doug Elliott who attended TCS 2010 held in Iowa, USA

The Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products was organized by Prof. Robert Brown of Iowa State University (ISU) and his supporting team and scientific panel. It was held in Ames, Iowa, USA from September 21-23, 2010, with preceding and subsequent technical tours of the ISU biomass facilities. The conference agenda included five plenary speakers:

- Estaban Chornet—biomass gasification
- Jim Dumesic—aqueous reforming (deoxygenation)
- Valerie Reed—DOE program review
- Tom Foust—NABC and other biomass conversion issues
- Desmond Radlein—biomass pyrolysis and upgrading

Seventy-one technical presentations were organized into parallel sessions including:

- Science of Pyrolysis (3 sessions)
- Catalysis and Upgrading (4 sessions)
- Torrefaction and Hydrothermal Pretreatments
- Bio-oil Stabilization (2 sessions)
- Non-fuel products
- Process modelling, design and economics
- Gasification and gas cleanup (2 sessions)

The conference also included 55 poster presentations in the same topic areas. A book of abstracts was prepared and slides of many of the presentations are available on the conference website. http://www.biorenew.iastate.edu/events/tcs2010/media.html

There were 271 attendees at the conference representing 14 countries and the US. Continuing a trend in the recent thermochemical conversion conferences, the bulk of the presentations and posters related to pyrolysis.

Based on email addresses the attendees could be roughly categorized as 50% from universities, 33% from industrial entities, and 20% from government, including government laboratories.

tcbiomass 2011

The 2011 international conference on Thermochemical Conversion Science is to be held in Chicago, Illinois, USA on September 27-30.

See page 42 for more information

Round-up: international collaboration results on lignin processing

Daniel Nowakowski of Aston University, UK summarises the findings of the recent lignin Round Robin

Lignin is the second most abundant biomass component and the only renewable aromatic resource in nature. Lignin pyrolysis has been studied for almost 100 years with the focus on two different aspects: unravelling the structure of the aromatic biopolymer, and production of monomeric phenols.

In the past 25 years little attention has been paid to the use of lignin as a chemical resource. Lignin was rather used for studying degradation mechanisms by advanced pyrolysis methods combined with hyphenated separation and detection systems (GC-MS/FID). Only recently, with the upcoming focus on biorefineries, lignin has gained new interest as a chemical resource, as again the supply of fossil feedstocks is becoming more and more insecure and expensive. On the other hand, in the past 20 years fast pyrolysis techniques have been developed for the conversion of whole plant biomass into a liquid (bio-oil) using mainly fluidized-bed reactors from laboratory to demonstration scale.

Therefore, the objectives of this international study were to attempt to carry out fast pyrolysis of several lignin samples and analyse the products in order to firstly establish the potential for this method of lignin processing, and secondly to compare procedures and results. The research was carried out in the IEA Bioenergy Agreement Pyrolysis Task 34 – PyNe. Fourteen laboratories agreed to participate in the project and each was supplied with

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Figure 1: Lignins studied during the Round Robin
Left: The ALM lignin (manufactured by Asian Lignin Manufacturing India Pvt. Ltd., India) was a sulfur-free lignin obtained from annually harvested non-woody plants (wheat straw and sarkanda grass S. Munja). This highly purified lignin was obtained from the soda pulping process using aqueous NaOH.
Right: The ETEK lignin from Sekab E-Technology, Sweden was a residue from ethanol production by a two-stage weak acid hydrolysis of softwood. This lignin was not a high-purity product but contained carbohydrate polymer degradation products (up to 50% cellulosic) as well as lignin.

Round-up: international collaboration results on lignin processing...continued

samples of two lignins. The participants include:

- Aston University, UK
- Pacific Northwest National Laboratory, USA
- vTI-Institute of Wood Technology and Wood Biology, Germany
- CIRAD-Forêt, France
- ECN, the Netherlands
- Forschungszentrum Karlsruhe GmbH, Germany
- IFP-Lyon, France
- National Renewable Energy Laboratory, USA
- STFI-Packforsk AB, Sweden
- University of Napoli, Italy
- University of Nottingham, UK
- University of Twente, the Netherlands
- USDA Eastern Regional Research Center, USA
- VTT Technical Research Centre of Finland, Finland

Of the nine laboratories with small fast pyrolysis reactor systems who attempted fast pyrolysis of the lignin feedstocks, seven laboratories provided fast pyrolysis processing results. Most of the laboratories provided complementary results of thermogravimetric analysis (TGA and DTA) and other analytical pyrolysis methods.

The results from the international collaboration provide invaluable research results, both for the thermochemical characterisation of lignins and their fast pyrolysis processing.

Table 1: Analytical specification for international lignin characterisation and pyrolysis tests

	Method	**Reporting unit**
FEEDSTOCK		
Moisture content of lignin	Dry at 60°C in vacuum oven	wt.% moisture based on as-received lignin
PRODUCT BIO-OIL		
Water content	Karl Fischer Titration	wt.% water based on wet bio-oil
Viscosity	Capillary or rotary viscosimeter, 2 temp. @ 20 and 40°C	cSt @ 20°C and 40°C
Solids in bio-oil	Insolubles in ethanol, filter pore size 3µm or lower	wt.% based on wet oil
pH	Use pH-meter	pH unit
Elemental analysis	Elemental analyzer (complete oxidation)	wt.%C, wt.%H, wt.%N, wt.%O, based on wet bio-oil
Pyrolytic lignin	Add 60ml oil to 1L of ice-cooled water under stirring, filter and dry precipitate below 60°C	wt.% based on wet bio-oil
Gas Chromatography	Column type DB 1701 dimensions: 60m x 0.25 mm film thickness: 0.25 µm injector: 250°C, split 1:30FID detector: 280°C oven programme: 45°C, 4 min const., 3°C/min. to 280°C, hold 20 min. sample conc.: 6 wt.%, solvent acetone	

The research paper which summarises the international results from the lignin fast pyrolysis can be found at http://dx.doi.org/doi:10.1016/j.jaap.2010.02.009

Reference

Lignin fast pyrolysis: Results from an international collaboration
Nowakowski DJ, Bridgwater AV, Elliott DC, Meier D, de Wild P.
Journal of Analytical and Applied Pyrolysis 88 (2010) 53–72

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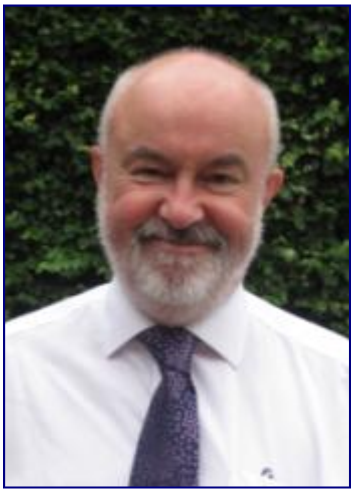
Bioten—review



Tony Bridgwater of Aston University reviews the Bioten conference held in the UK

SUPERGEN Bioenergy hosted the Bioten conference on September 21–23 in Birmingham, UK. The comprehensive programme included 32 oral presentations and 60 poster presentations and was attended by 145 delegates representing nine countries.

Representatives from industry and academia presented their activities and research on biomass, bio-conversion, combustion pyrolysis, gasification, systems studies, modelling, environmental studies and bioenergy policy.

Over 100 abstracts for papers, presentations and posters were received from the UK as well as Brazil, Canada, Denmark, Germany, Greece, Nigeria, South Africa and the Netherlands. The number of papers received according to topic category was as follows:

- Biological—7%
- Biomass—19%
- Combustion—12%
- Gasification—10%
- Pyrolysis—31%
- Systems. Modelling. Environment and Policy (SMEP) —21%

A summary of the pyrolysis papers offered is shown below.

Abstract Title	Author(s)	Institute
Performance study on the use of biomass carbon in a direct carbon fuel cell	O.D. Adeniyi, B.C.R. Ewan	University of Sheffield, UK
Green process for the continuous production of hydroxymethylfurfural (hmf) from biomass	M.N. Baig, S. Bowra, R.C.D. Santos	University of Birmingham, UK
Assess the impact of alkali metals in biomass on the physical and chemical properties of fast pyrolysis bio-oil	S.W. Banks, D.J. Nowakowski, A.V. Bridgwater, J.M. Jones	Aston University, UK
Decomposition of lipids from microalgae and oil seeds using hydrothermal processing	P.B. Biller, R. Riley, A.B. Ross	University of Leeds, UK
The pyros reactor, a cyclonic flash pyrolysis reactor with internal particle filter	E.A. Bramer, G. Brem	University of Twente, the Netherlands
Gas-solid fluidised bed modelling with interphase exchange phenomena	J.B. Bruchmuller, B.G.M. van Wachem,S. Gu, K.H. Luo	University of Southampton, UK
Microwave pyrolysis of structural components of biomass	V. Budarin, J. Fan, M. Gronnow, P.S. Shuttleworth, J.H. Clark	University of York, UK
Vacuum pyrolysis of sugar cane bagasse and its applications	M. Carrier, A. Hardie, J. Gorgens,H. Knoetze	Stellenbosch University, South Africa
Evaluation of various biomass types for suitability for fast pyrolysis processing	A. Fivga, A.V. Bridgwater	Aston University, UK
Thermochemical characterisation of willow src and bio-oil derived from fast pyrolysis	C. Greenhalf, D.J. Nowakowski, J. Titiloye, A.V. Bridgwater	Aston University, UK

Continued on page 17

Bioten—continued

Abstract Title	Author(s)	Institute
The effect of biochemical composition and ash content on the thermal conversion options for different genotypes of willow	B. Gudka, J. M. Jones, I. Shield, S O Trybush, N. E. Yates, G. Allison, J. Cliffton-Brown, I. Donnison, C. Morris	University of Leeds, UK
Rotary kiln pyrolysis – a comprehensive approach of operating a 3 mw pilot plant over a period of two years	M. Halwachs, H. Hofbauer, G. Kampichler, S. Kern, T. Pröll	Bioenergy 2020+ GmbH, Germany
Fast pyrolysis processing of agricultural and forestry residue: nitrogen recycling and carbon sequestration	A.B. Harms, D.J. Nowakowski, A.V. Bridgwater	Aston University, UK
Bio-thermal valorisation of biomass –the btvb process	A. Hornung	Aston University, UK
The effect of the particle size of different biochars derived from biomass pyrolysis on the elution of nutrients during soxhlet extraction	A. Hornung, K Kebelmann	Aston University, UK
Hydrothermal deconstruction of lignocellulosic biomass: new understanding from advanced thermal and physical techniques	R.N. Ibbett, S. Gaddipati, S. Hill, T. Foster, S. Davies	University of Nottingham, UK
High quality fuels via in-situ catalytic flash pyrolysis of biomass	A. Imran, G. Brem, E. Bramer, K. Seshan	University of Twente, the Netherlands
Investigation of biochar production from hydrothermal processing of biomass model compounds	R.S. Johnson, J.M. Jones, A.B. Ross	University of Leeds, UK
Fast pyrolysis of jatropha curcas and moringa olifiera oil seeds residues: conversion of press cake to bio-oil	A. Kalgo, J.O. Titiloye, A.V. Bridgwater	Aston University, UK
Bio-char from biorefinery residue and miscanthus pyrolysis	W. Kwapinski, F. Melligan, D. Hayes,C. Byrne, P. Wolfram, E. Novotny,D. Haverty, J.J. Leahy, M.H.B. Hayes	University of Limerick, Ireland
Catalytic upgrading of pyrolytic-oil	W. Kwapinski, R. Wnetrzak, F. Melligan, J.J. Leahy, M.H.B. Hayes	University of Limerick, Ireland
Qualitative and quantitative analysis of pyrolysis oils by means of gc-fid and gcxgc-tofms analysis	C.M. Michailof, T.S. Sfetsas, D.P. Patiaka, S.L. Lappas	CERTH/CPERI, Greece
Analysis of the physical phenomena occurring in a bubbling fluidised bed reactor using cfd	K. Papadikis, S. Gu, A.V. Bridgwater	University of Southampton, UK
Diesel miscible biofuels via the pyrolysis and upgrading of acid-hydrolysis residues of biomass	M.A. Patel, D.J. Nowakowski, A.V. Bridgwater	Aston University, UK
Is fast pyrolysis bio-oil a suitable green fuel for urban chp plants?	J.G. Rogers, J.G. Brammer	Aston University, UK
Hydrothermal microwave pyrolysis of microalgae	A.B. Ross, V. Budarin, P. Biller, J. Clark, J.M. Jones D.J. Gilmour, W. Zimmerman	University of Leeds, UK
The thermal conversion of cellulose and hemicellulose in thermogravimetric apparatus and a fluidized-bed reactor	D. Shen, N. Dong, A.V. Bridgwater	University of Southampton, UK
Synthesis of impregnated activated carbon from local biomass – application to wastewater treatment	M. Sido-Pabyam, J. Blin, P. Girard, I. Nong-Nogo, E. Somé	Int. Inst Water and Env. Eng., UK
Effect of pyrolysis conditions on the yield and structure of bio-oil produced from rice husk	Y. Somrang, M. Millan, R. Kandiyoti, P. Fennell	Imperial College London, UK
Bubble point pressures of the selected model system for catliq® bio-oil process	S.S. Toor, L. Rosendahl, M.N. Baig, P.T. Robbins, R.C.D. Santos, K.P. Nøgaard	Aalborg University, Denmark

Microwave pyrolysis for chemicals and energy from biomass

James Clark provides an update on microwave processes developed at the University of York, UK

All members of PyNe agree on the benefits of pyrolysis in the generation of high value chemicals and energy products from biomass, however the method of generating them is one of debate. At the Green Chemistry Centre of Excellence in York we have been investigating these conversions under microwave heating. A microwave assisted decomposition process at low temperature has been developed which yields higher value products: char and liquid fractions with unprecedented properties. The chars have similar calorific value and physical properties to coal, making it an improved feedstock for co-firing in power stations. The bio-oil is different to conventional biomass pyrolysis oils and can be applied as a liquid fuel or source of chemicals. This technology may increase the application of renewables in power generation and supply a range of transport fuels and chemicals for the growing market for sustainable products. The process itself is conducted at unusually low temperatures, which allows ease of process scale-up using existing microwave equipment. The scalability of our process has been proven through pilot scale trials using commercial equipment.

Pyrolysis and torrefaction of biomass are both well established research topics. In our work we have found that by using microwave irradiation, it is possible to affect the process of pyrolysis while working under temperature conditions normally associated with torrefaction. Our results show that microwave irradiation at low temperatures has a dramatic effect on the decomposition of major components in plant biomass and in particular cellulose and hemicellulose both in terms of the temperature at which carbonisation occurs, and also in terms of the maximum calorific value of the final char. The process yields high quality

Continued on page 19

Table 1: Composition and properties of crude oil, conventional pyrolysis oil and typical MW low temperature pyrolysis oil

Property	Crude Oil	Pyrolysis oil	Low temperature microwave oil
Water (%)	<0.1	10-20	<1
C (wt.%)	85-87	45-55	58.9
H (wt.%)	10-14	6-7	6.9
N (wt.%)	0.1-2	0.3	1.2
O (wt.%)	0.1-1.5	40-50	33.2
S (wt.%)	0	0.5-5	0.02
Specific gravity	0.8-1.0	1.2-1.3	1.2
Acid number	<1	70-150	1.4
Alkali metal	50	100	5.7
Heat of combustion (kJ/g)	42	16-21	19-26

Microwave pyrolysis for chemicals and energy from biomass...continued

solid and liquid products, which can strengthen the case for the use of biomass for energy production both as a solid and liquid fuel, along with a possible source of chemicals.

Microwave ovens have gained acceptance as a mild and controllable tool, allowing simple and rapid processing. Microwave irradiation is rapid and volumetric, with the whole material heated simultaneously. This feature of microwaves is very important for processing thermally poor conducting materials such as wood.[1] Microwave heating can be controlled instantly and the power applied can be accurately regulated. This allows safe and precise control, even when applying very rapid heating rates.[2]

Microwaves for pyrolysis of biomass dates back to the early 1970s.[3] Processes were conducted at high temperatures typically in excess of 350°C (similar to conventional pyrolysis) with primary focus on pyrolysis, gasification and liquefaction to fuels. However, processing at such high temperatures fails to utilise the unique ability of microwave irradiation to accelerate chemical processes.[4,5,6]

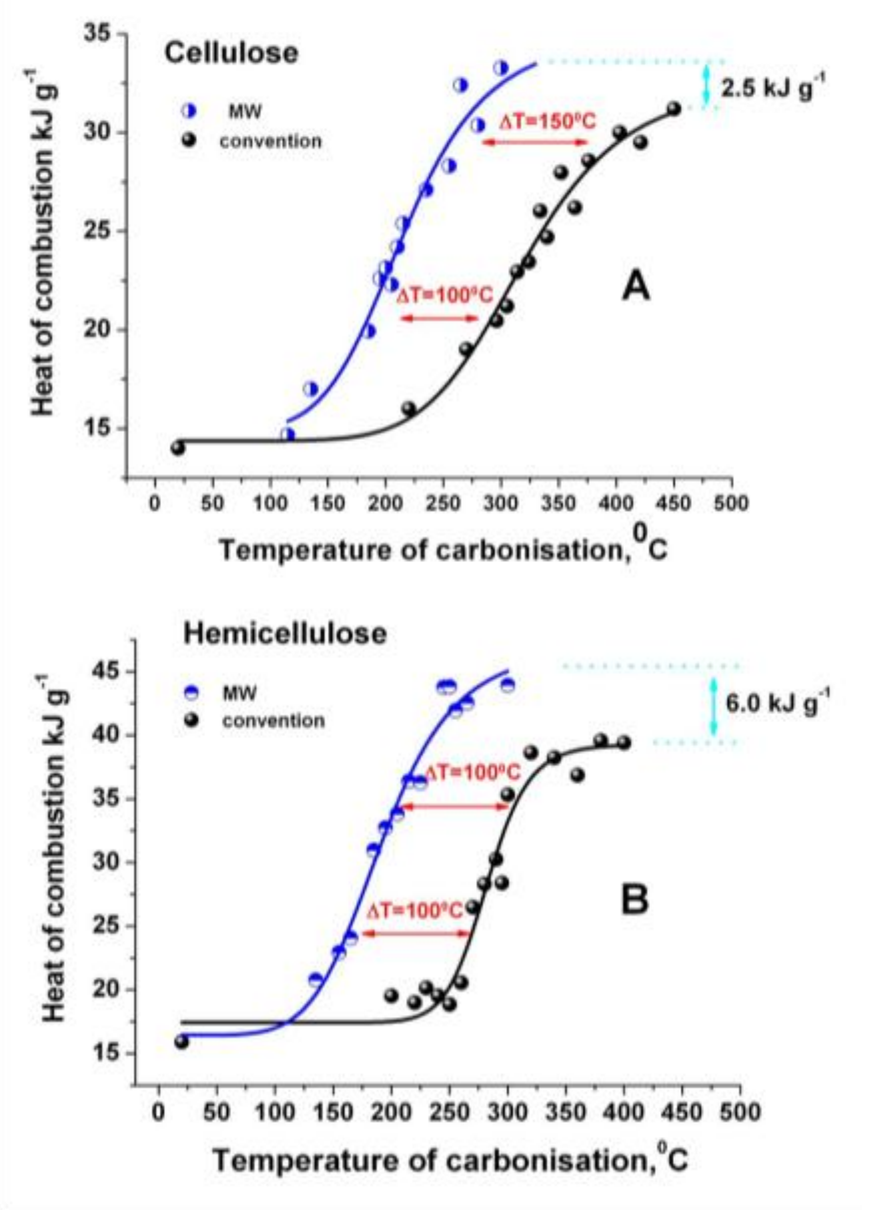


Figure 1: Comparison of influence of char preparation temperature on heat of combustion under conventional and microwave conditions A) cellulose and B) hemicellulose

Under microwave irradiation, cellulose decomposes at lower temperatures and yields chars of higher calorific value in comparison to conventional heating.[7] A detailed study of a range of biomasses revealed that under conventional heating the decomposition processes can be divided into three stages corresponding to each structural component. The thermal decomposition of hemicellulose starts at 220°C and is complete by 350°C. Cellulose decomposes between 350 and 450°C whilst lignin breaks down over a wide temperature range of between 450 and 700°C.[8] Under microwave irradiation the hemicellulose and cellulose decomposed into a char at a significantly lower temperature (ca. 100°C) than with conventional heating (Figure 1).

The lowering in the decomposition temperatures of the cellulosic components (hemicellulose and cellulose) enabled the production of pyrolysis-type products (oil and char) in the range of temperatures conventionally applicable to torrefaction.[9] This effect can be attributed to the presence of extensive hydrogen-bonding networks in these two biopolymers which

Continued on page 20

Microwave pyrolysis for chemicals and energy from biomass...continued

interact with microwaves.

In order to differentiate the specific microwave activation effects from conventional heating a glass tube filled with cellulose was divided into two zones: the upper covered with aluminium foil to shield it from microwaves and the lower left unprotected. The cellulose protected from microwaves irradiation (upper zone) is unaffected by the process temperatures. However, the lower zone, exposed to microwaves, was substantially charred. The fact that the changes occur homogeneously throughout the particulate solid is consistent with the instantaneous and uniform heating of the cellulose compared to conventional heating which occurs from the reaction wall inwards.[10]

> *"The microwave technique produces good yields of oils with low water and acid content."*

As part of our process, good yields of pyrolysis liquid are also obtained in two discrete fractions, one containing mainly water and acidic components and the second being primarily organic. The latter organic fraction, the pyrolysis oil, had a low content of water (<1%) and alkali metals, and a very low acid number compared to conventional pyrolysis oils (Table 1). Conventional pyrolysis oils, are also established as potential bio-fuels, but their conversion into applications such as transport fuels, is severely hampered by adverse properties such as high acidity, high water content and unsuitable chemical functionalities. The microwave technique produces good yields of oils with low water, acid content whilst containing a range of useful chemicals such as platform molecules, fatty acids and phenolic compounds.

Following from these initial studies with model compounds our research has continued using a wide variety of biomass waste ranging from cereal waste and straw to bakery waste and macro/micro alga. Microwave technology is often difficult to scale up due to wave penetration issues, however, this makes microwave irradiation possible in a continuous manner. Holding lower volumes of material at elevated temperatures and pressures is preferable as part of an inherently safer design. At the Green Chemistry Centre of Excellence we are currently in the process of building a continuous demonstration scale microwave pyrolysis system as part of a larger biorefinery. This technology has been proven as a green and flexible method of upgrading biomass for energy applications, allowing progress to a society which is no longer reliant on fossil fuels.

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References

[1] Clark DE, Sutton WH. Microwave processing of materials. Annu.Rev.Mater.Sci.,26:299-331 (1996)
[2] De la Hoz A, Diaz-Ortiz A, Moreno A. Microwaves in organic synthesis. Thermal and non-thermal microwave effect. Chem.Soc.Rev., 34:164-178 (2005)
[3] Allan GG, Bkrieger BB, Work DW. Dielectric Loss Microwave Degradation of Polymers: Cellulose. Journal of Applied Polymer Science, 25:1839-1859 (1980)
[4] Dominguez A, Menendez JA, Inguanzo M, Pis JJ. Production of bio-fuels by high temperature pyrolysis of sewage sludge using conventional and microwave heating. Bioresource Technology 97:1185-1193 (2006)
[5] Dominguez A, Fernandez Y, Pis JJ. Evidence of Self-Gasification during the Microwave-Induced Pyrolysis of Coffee Hulls. Energy & Fuels 21:373-378 (2007)
[6] Huang YF, Kuan WH, Lo SL, Lin CF. Total recovery of resources and energy from rice straw using microwave-induced pyrolysis. Bioresource Technology 2008, (doi:10.1016/j.biortech.2008.03.026)
[7] Budarin VL, Clark JH, Lanigan BA et al. Microwave assisted decomposition of cellulose: A new thermochemical route for biomass exploitation. Bioresource Technology, 101 (10):3776-3779 (2010)
[8] Yang H, et al. DT. In-depth investigation of biomass pyrolysis based on three major components: Hemicellulose, cellulose and lignin. Energy and Fuels, 20: 388-393, (2006)
[9] Budarin VL, Clark JH, Lanigan BA et al. The preparation of high-grade bio-oils through the controlled, low temperature microwave activation of wheat straw. Bioresource Technology, 100 (23): 6064-6068 (2009)
[10] Kappe CO. Controlled Microwave Heating in Modern Organic Synthesis, Angew. Chem. Int. Ed 43: 6250 –6284 (2004)

THE UNIVERSITY *of York*

HydroThermal Liquefaction of biomass

Doug Elliott of Pacific Northwest National Laboratory, USA reviews the HydroThermal Liquefaction research project underway in the US since 2008

HydroThermal Liquefaction (HTL), called high-pressure liquefaction in earlier years [1], is an alternative process for conversion of biomass into liquid products. Some experts consider it to be pyrolysis in solvent phase. It is typically performed at about 350°C and 200 atm pressure such that the water carrier for biomass slurry is maintained in a liquid phase, i.e. below super-critical conditions. In some applications catalysts and/or reducing gases have been added to the system with the expectation of producing higher yields of higher quality products. Slurry agents ("carriers") evaluated have included water, various hydrocarbon oils and recycled bio-oil. High-pressure pumping of biomass slurry has been a major limitation in the process development.

Process research in this field faded away in the 1990s except for the HydroThermal Upgrading (HTU) effort in the Netherlands [2], but has new resurgence with other renewable fuels in light of the increased oil prices and climate change concerns. Research restarted at Pacific Northwest National Laboratory (PNNL) in 2007 with a project, "HydroThermal Liquefaction of Agricultural and Biorefinery Residues" with partners Archer-Daniels-Midland Company and ConocoPhillips. Through bench-scale experimentation in a continuous-flow system this project investigated the bio-oil yield and quality that could be achieved from a range of biomass feedstocks and derivatives. The project was completed earlier this year with the issuance of the final report [3]. HydroThermal Liquefaction research

Continued on page 22

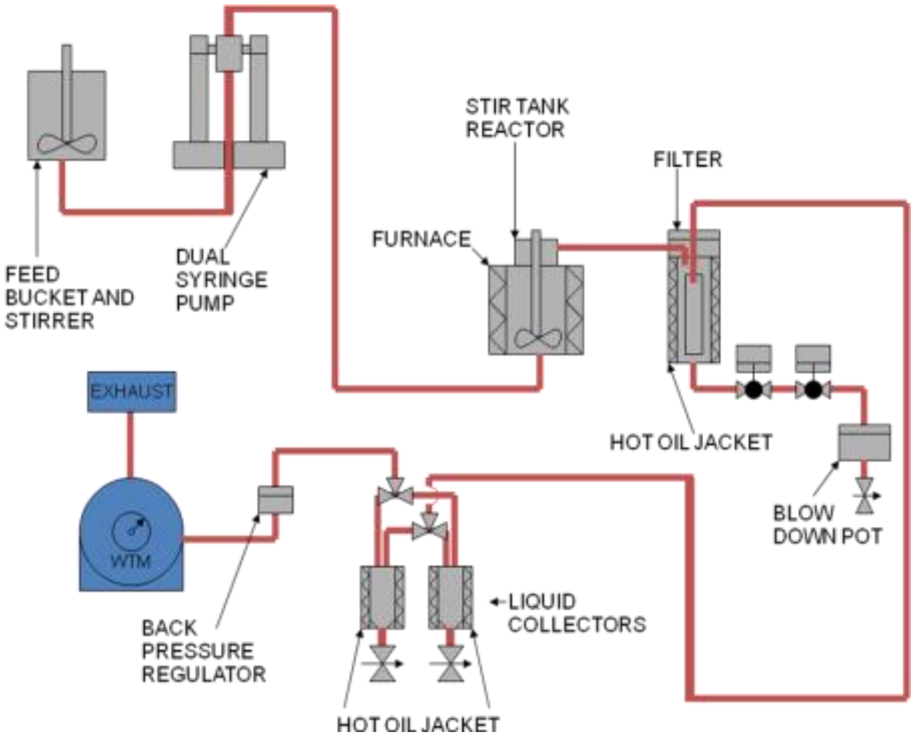

Figure 1: Bench-scale reactor system for HydroThermal Liquefaction at PNNL

HydroThermal Liquefaction of biomass ...continued

continues within the National Advanced Biofuels Consortium with the effort focused at PNNL. The bench-scale reactor is being used for conversion of lignocellulosic biomass including pine forest residue and corn stover. A complementary project is an international collaboration with Canada to investigate kelp (seaweed) as a biomass feedstock. The collaborative project includes process testing of the kelp in HydroThermal Liquefaction in the bench-scale unit at PNNL.

HydroThermal Liquefaction at PNNL is performed in the hydrothermal processing bench-scale reactor system. Slurries of biomass are prepared in the laboratory from whole ground biomass materials. Both wet processing and dry processing mills can be used, but the wet milling to final slurry is accomplished in a stirred ball mill filled with angle-cut stainless steel shot. The PNNL HTL system, as shown in the figure, is a continuous-flow system including a 1-litre stirred tank preheater/reactor, which can be connected to a 1-litre tubular reactor (not shown). The product is filtered at high-pressure to remove mineral precipitate before it is collected in the two high-pressure collectors, which allow the liquid products to be collected batchwise and recovered alternately from the process flow. The filter can be intermittently back-flushed as needed during the run to maintain operation. By-product gas is vented out the wet test meter for volume measurement and samples are collected for gas chromatography compositional analysis.

The bio-oil product is analyzed for elemental content in order to calculate mass and elemental balances around the experiments. Detailed chemical analysis is performed by gas chromatography-mass spectrometry and 13-C nuclear magnetic resonance is used to evaluate functional group types in the bio-oil. Sufficient product is produced to allow subsequent catalytic hydroprocessing to produce liquid hydrocarbon fuels.

The product bio-oil from hydrothermal liquefaction is typically a more viscous product compared to fast pyrolysis bio-oil. There are several reasons for this difference. The HTL bio-oil contains a lower level of oxygen because of more extensive secondary reaction of the pyrolysis products. There are less amounts of the many light oxygenates derived from the carbohydrate structures as they have been further reacted to phenolic Aldol condensation products. The bio-oil is more hydrophobic because of the lower oxygen content and resulting lower polarity and therefore has a lower amount of dissolved water. Without the light oxygenates acting as solvents along with the water, the bio-oil product is much more viscous. Related results are that the bio-oil is less dense and has a higher energy content. These differences in properties led to the earlier held belief that the HTL bio-oils could be upgraded by catalytic hydroprocessing in a manner more similar to simple petroleum hydrotreating.

Some initial results from the HydroThermal Liquefaction of kelp are shown in Table 1. The experiments were performed with kelp slurries of 5-13 wt.% dry solids in water.

Continued on page 23

Table 1: Composition of macroalgal biomass and bio-oil product

Sample	Weight Percent							H/C
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash	Moisture	(Atomic Ratio)
Macroalgae (dried feed)	32.4	4.4	34.4	2.4	0.9	23.0	Dry basis (fed as 5.3% or 13.0% dry solids)	1.61
Bio-oil product (as produced, wet)	72.6	9.0	12.8	3.8	0.6	NA	6.8	1.34 (dry basis)

Compositions are the average of two tests

HydroThermal Liquefaction of Biomass ...continued

Figure 2: High-pressure reactors and separators

Figure 3: High-pressure oil and aqueous product collectors

Oil yields from kelp are low at 24% on ash-free basis but up to 41% calculated on a carbon basis. The bulk of the rest of the carbon ends up dissolved in the water stream.

Figures 2 and 3 show portions of the bench-scale hydrothermal processing system at PNNL.

References

[1] Elliott DC, Beckman D, Bridgwater AV, Diebold JP, Gevert SB, Solantausta Y. Developments in Direct Thermochemical Liquefaction of Biomass: 1983-1990, Energy & Fuels, 1991, 5:399-410.

[2] Goudriaan F, Nabeer JE, Zeevalkink JA, HTU process design and development: innovation involves many disciplines. In: Science in Thermal and Chemical Biomass Conversion, Eds. Bridgwater AV and Boocock DGB, CPL Press, Newbury Berks, UK 2006:1069-1081.

[3] The report is CRADA-protected and is not available to the general audience until 2015.

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Transportable bioenergy systems

Peter Fransham provides an insight into the pyrolysis systems developed at ABRI-Tech in Quebec, Canada

Transportable versus Centralized Systems

The ABRI-Tech business model is to have transportable and efficient 50 to 100 dry tonne per day systems strategically located in areas of biomass production. This is vastly different to large, capital intensive systems that rely on a stable supply of biomass within an economically transportable distance. The general rule is biomass can not be transported more than 100 km before the cost of transportation exceeds the value of the energy in the biomass. In the past few years we have seen a steady decline in the number of operating sawmills as well as pulp and paper mills. Large, fixed installations located close to these sources of biomass is a risky venture at the best of times. Bioenergy is a low margin, high volume enterprise where cents are the difference between economic success and failure. Minimizing transportation costs by moving the pyrolysis plants to the biomass keeps biomass costs to a minimum.

Input Energy Efficiency

Pyrolysis systems require a certain amount of energy to convert biomass to bio-oil, biochar and non condensing gas. Maximizing conversion efficiency means minimizing the heat and electrical demand. Access to grid power is not generally possible for transportable systems and therefore on site power generation is required. Input electrical energy has a significant impact on the overall economics. For example, assuming a cost per kW-hr of $0.10, a pyrolysis plant plant operating 8000 hours per year will have an electricity cost of $800 per kW. Through systematic system analysis, ABRI-Tech has reduced the consumption of electricity in its auger pyrolysis system by approximately 800 kw over equivalent sized fluid and transport bed systems. This equates to a savings of about $640,000 per year for a 50 tpd system.

Figure 1: 1 tpd biomass dryer

Products

ABRI-Tech is more than a pyrolysis company. Like our parent company, Forespect, we are moving towards vertical integration. Biomass dryers, gasifiers for process heat and pyrolysis systems are the main product lines. A short description of our product lines can be found in the following paragraphs.

Biomass Dryers

ABRI-Tech has modified a chain flail type dryer to simultaneously dry and pulverize biomass. ABRI-Tech has built several 1 tonne per day and 50 tonne per day biomass dryers. One of the

Continued on page 25

Transportable bioenergy systems ...continued

Figure 2: Biomass before and after dryer

original prototypes was mounted on a drop deck trailer and was capable of evaporating 11 tonnes of water per hour. ABRI-Tech is presently concentrating its efforts on dryers in the two to four tonnes of finished product per hour. Final moisture content is a function of the application and throughput will depend on the size and type of the raw material and the size reduction and moisture content required.

A picture of a 1 tonne per day system is shown in Figure 1. The feed hopper is located in the back of the skid and fed into the chain flails located behind the drum. Biomass is drawn through the system by a fan. Size reduction is governed by a combination of flail speed and fan speed. Final moisture content is controlled via the dryer outlet temperature. Figure 2 shows the size reduction for a standard 5 cm wood chip. The starting moisture content was 34% and the final moisture content was 4.8%. Propane is used for heating at this scale although small biomass gasifiers are available if required. Low inlet temperature into the flail minimizes the evaporation of light organics and the generation of blue haze.
A mass flow and energy balance has shown the dryer to use less energy than comparable size drum dryers. Drum dryers are reported to require approximately 4.2 MJ to evaporate one kilogram of water whereas the flail dryer requires only 3.3 MJ per kilogram. Since the dryer also reduces the particle size, the downstream hammer mill is either eliminated or greatly reduced in size.
Figure 3 shows a transportable 50 tpd dryer. The skids on which the equipment is mounted match those of tilt deck trucks used for moving waste containers. To move, plenums and augers are disconnected and the skid is winched onto the truck. Experience has shown that a 50 tpd dryer can be disassembled and assembled in about 8 hours.

Feed enters through a live deck on the left side of the picture. Heat is a biomass gasifier – the horizontal cylinder in the lower right hand corner. The cyclone in the lower centre of the picture removes ash from the gasifier and clean hot combustion gas enters the dryer immediately adjacent to the live deck. The finished product is drawn through the system by two fans and separated from the hot vapour in twin cyclones.

Continued on page 26

Figure 3: 50 tpd dryer

Transportable bioenergy systems ...continued

The finished product is then conveyed to intermediate storage (dark blue structure at the right). The dryer was tested on a variety of biomass from corn stover to sawdust. The same heat for drying was confirmed at the 50 tpd as it is at the 1 tpd scale.

Gasifier Furnace
ABRI-Tech has developed an efficient biomass two stage combustion system. The system is shown in Figure 3. Dry feed enters a horizontal screw conveyor at the left end of the horizontal cylinder. The feed is conveyed into the refractory lined cylinder where it is heated to approximately 600C. Combustible vapours released from the biomass travel down the auger and are ignited as they exit the auger. The hot gas then travels back between the outside of the auger and the inside of the refractory. Combustion air is added tangentially and the gas and char particles spiral towards the hot gas outlet. Temperature is controlled by adjusting the feed rate and the amount of combustion air. A flame temperature of over 1200C was measured at the combustion end of the auger. As the hot vapours travel down the auger, they are forced to rotate. The flame can be seen rolling as it exits the auger. The long residence time in the gasifier and the amount of excess air required to keep the temperature below 600C ensure excellent combustion.

Figure 4: 20kg/day research system (note cooling baths not installed)

Pyrolysis Systems
ABRI-Tech's first pyrolysis system was a 200 kg/hr mobile fluid bed system. It became readily apparent from the outset that the system would be problematic. When the biomass was added to a hot fluidized sand the vapours exploded from the biomass and formed a pocket of gas that would breakthrough the surface with sufficient energy to carry the sand out of the reactor. Providing more free board was not an option as it would increase the residence time and decrease bio-oil yield. Fluid bed systems were abandoned in 1994 in favour of an auger reactor concept. A bench scale apparatus was constructed and extensively tested.

Auger pyrolysis systems have generally been limited in size

Continued on page 27

Figure 5: 1 tpd system

Transportable bioenergy systems ...continued

Figure 6: 50 tpd system

on account of the limited heat transfer through the auger shell wall. ABRI-Tech solved that problem by mixing the biomass with a dense heat carrier in the reactor auger. The biomass and the heat carrier are in intimate contact and therefore the transfer of energy from the heat carrier is quick and efficient. By using high thermal conductivity heat carriers, the energy required for fast pyrolysis is rapidly transferred to the biomass without the need for a fluidizing gas. The distance between the reactor gas outlet and the first quench is short and hence residence times are similar to those reported for fluid and transport bed systems. A blower downstream of the condensers improves the removal of the hot vapours and maintains a reactor pressure close to atmospheric. Since a fluidizing gas is not required, then the condensers are required to cool and condense only the pyrolysis vapours and not the recirculating gas. Condensers are therefore smaller and more efficient. The char is separated from the steel heat carrier using a simple gas recycle loop independent of the main pyrolysis reactions. Given the density difference between the char and the shot, only limited gas velocity is needed to strip the char from the shot.
ABRI-Tech is presently manufacturing pyrolysis systems from 20 kg/day – a laboratory scale apparatus for research and development to 50 dry tonnes per day. Figures 4, 5, and 6 show the three sizes currently available. All units are skid mounted for easy rapid assembly and dis-assembly for moving.

The systems are designed with maximum flexibility and can be modified to meet local requirements. A case in point is the unit built under license by AES Bioenergy in New Zealand. AES changed the length of the dryer and added additional thermocouples for monitoring. Local regulations required blow out prevention devices that are not generally required in other jurisdictions. Each system is designed with the ultimate efficiency in mind. The 50 tpd system shown in Figure 6 requires approximately 150 KW of electrical power to run the complete unit (including the dryer/pylverizer). The system is largely hydraulic power as the auger speeds are relatively slow and hence the high torque afforded by hydraulics works well in this application. Process control is relatively straight forward as most of the auger speeds are preset and do not require adjustment during operation.

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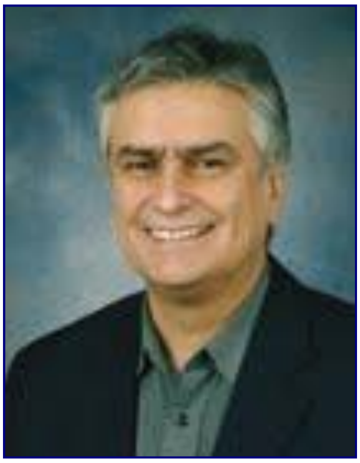
High-value chemicals in bio-oil derived by the fast pyrolysis of agricultural residues



A synopsis from Carlos Monreal (pictured above), Zakir Kazi and Morris Schnitzer of Agriculture and Agri-Food Canada

Food, Energy and Chemicals - A Holistic Approach for Agriculture

Agriculture faces significant challenges as it adopts new and intensive production systems to meet society's demand for low cost food, fibre, biomass for bioenergy and biofuels. Advances in science and technology can help implement, adopt and integrate holistic on-farm food production with complementary biorefineries in rural areas to create value-added products. Such an approach, will support the competitiveness of agriculture and secure the use of residues for the production of bioproducts and co-products for industrial and agricultural uses (see Figure 1). Agriculture has an opportunity to contribute to both, food safety and energy security.

Increased agricultural production inevitably leads to increased production and safe disposal of crop and animal residues. The thermochemical and biological conversion of the latter residues into useful commercial products adds economic value at the farm-gate, prevents the emissions of greenhouse gases, and contamination of water, air and soil with pathogens and chemical agents, and excess nutrients.

Fast pyrolysis is a thermochemical process that converts biomass into bio-oil, biochar and synthesis gas. Bio-oils have a higher energy density than the original residue and contain a great diversity of chemical components including, hydrocarbons, organic acids, alcohols, sterols, phenols and N-heterocyclics, among others.

This note presents a synthesis of research conducted on the chemical composition of bio-oil derived by fast pyrolysis of chicken manure. This work has been conducted in our labs at Agriculture and Agri-Food Canada during the last four years, and provides essential chemical information for establishing extraction and separation processes of targeted chemicals in pyrolytic bio-oil.

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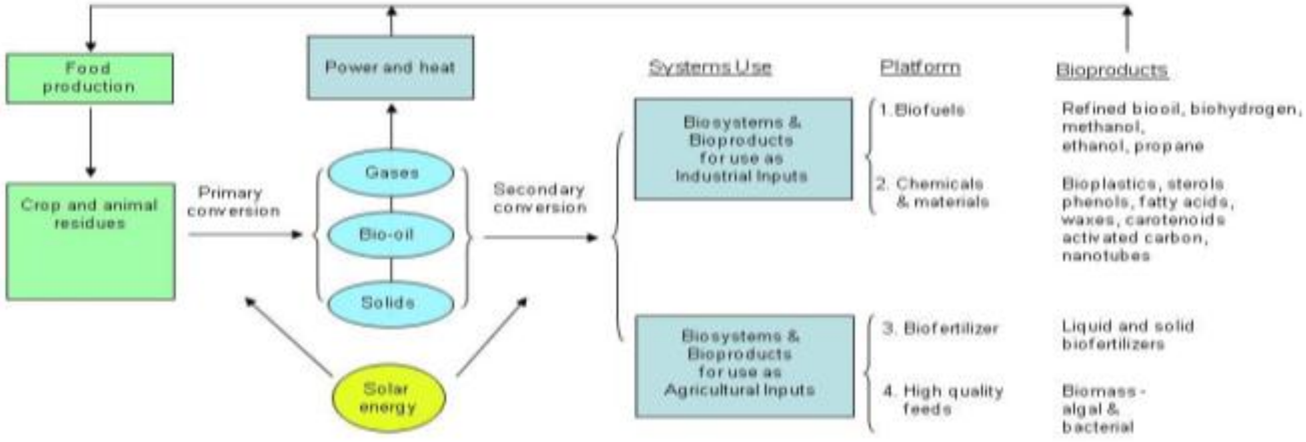

Figure 1. Integration of food production with new technologies and biomass conversion processes for the production of bioenergy, biofuels and green chemicals.

High-value chemicals in bio-oil derived by the fast pyrolysis of agricultural residues ...continued

1 t/d Pyrolysis Plant | Viscous bio-oil | Aqueous bio-oil | Biochar

Figure 2: Fast pyrolysis of chicken manure to produce bio-oil and co-products

Chemical characterization of bio-oil

We have chosen chicken manure as the feedstock because it is widely available, represents other residues having a high content of nitrogen (N), and its conventional disposal has caused contamination of soil and water sources with arsenic and other elements. Our bio-oil samples are produced by Advanced Biorefineries Inc., a company located in Ontario. We used different analytical techniques to characterize the chemical composition of bio-oil and biochar. For example, ^{1}H and ^{13}C Nuclear Magnetic Resonance, Fourier Transform Infrared, and 4 techniques of mass spectrometry (MS), have helped determine the composition of functional groups and species of organic molecules. We have chemically characterized bio-oil samples of viscous and aqueous phases obtained by decantation after their production (Figure 2)

Extraction and separation of major chemical classes

Our work has focused on the extraction and separation of: a) a hydrocarbon enriched fraction for use as a transportation fuel, and b) other fractions with chemical classes of compounds for use as feedstocks by other industries such as the chemical and pharmaceutical industry. In general, the extraction and separation of chemical compounds in bio-oil involved chemical and physico-chemical methods using solvent extraction with low level radiation, followed by chromatographic separation using a combination of solvents and alumina and silica columns (Figure 3).

Chemical properties of bio-oil

We found that relative to other bio-oil fractions, the raw viscous bio-oil derived from chicken manure has a high content of N (6%), O (23%), and viscosity (9 Pa s), and low

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Extraction reactor | Column separation | N-enriched fractions

Figure 3: Extraction and separation of chemical components in bio-oil

High-value chemicals in bio-oil derived by the fast pyrolysis of agricultural residues ...continued

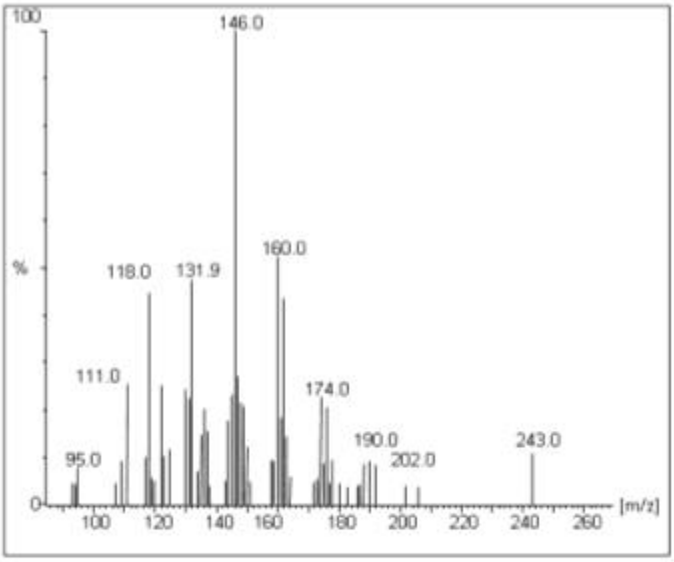

Figure 4: ESI-MS (positive mode) spectra of N-enriched fraction separated on silica by hexane-benzene (50:50)

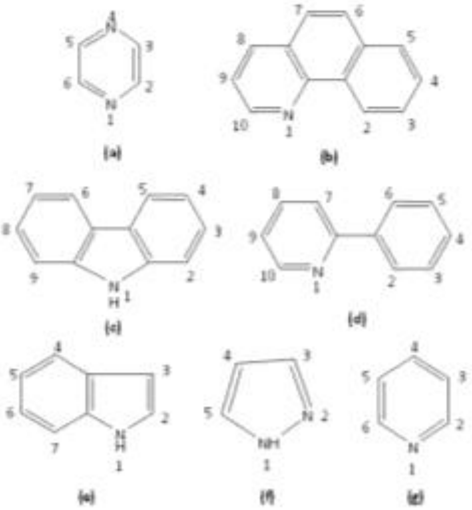

Figure 5: Base structure of heterocyclic-N in bio-oil: (a) pyrazine, (b) benzoquuiloline, (c) carbazole, (d) phenylpyridine, (e) indole, (f) pyrazole, (g) pyridine

heating values (23 MJ/kg) (Table 1). We conducted initial experiments to improve the physical and chemical properties of bio-oil. For example, we found that exposure of the viscous bio-oil to low level radiation in hexane for 5 min "upgraded" its properties: almost doubled its heating value from 23 to 37 MJ/kg, decreased the content of O from 23 to 8.8%, the viscosity from 9 to 0.05 Pa s, and the density by 20% (Table 1). The upgraded bio-oil showed properties similar to those of diesel No. 3.

We further processed the upgraded bio-oil to isolate a hydrocarbon rich fraction for use in transportation. In this process we separated a non-polar fraction, rich in hydrocarbons, from other organic components with increasing polarity. We called the enriched hydrocarbon fraction "refined bio-oil" as it presented properties similar to that of gasoline: high heating value (43 MJ/kg), low viscosity 0.006 (Pa s), decreased N (0.2%) and O content (1.8%). In the near future we are planning to scale-up the process and test the refined bio-oil in an internal combustion engine to determine its combustion properties.

Subsequently we used four different techniques of MS to elucidate the molecular composition of organic compounds in bio-oil. Briefly, we found that the upgraded and refined bio-oil fractions

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Table 1: Yield and fuel characteristics for raw bio-oil and other bio-oil fractions

Sample	**Yield (kg)**	**Content (wt/wt%) (moisture and ash free)**					**Viscosity[1] (Pa s)**	**Density[2] (kg/m^3)**	**Heating value (MJ/kg)**
		C	**H**	**N**	**S**	**O**			
Chicken manure	1000	51.7	5.8	5.9	0.8	35.9	-	-	-
Raw bio-oil	350-600	70.0	7.8	6.3	0.5	23.3	9.050	1179	23
Upgraded bio-oil	147-252	75.0	9.2	6.1	1.2	8.8	0.050	1008	37
Hydrocarbons (Refined bio-oil)	26-45 (30 - 51 L)	82.7	15.3	0.24	0.0	1.8	0.006	891	43
Fossil fuel[3]		85	12	0.01	0.05	1		750	42

1) Viscosity at 40°C; 2) Density at 15°C; 3) Bioresource. Technol. 2002 83:47-54

High-value chemicals in bio-oil derived by the fast pyrolysis of agricultural residues ...continued

Table 2. Heterocyclic-N compounds identified by two techniques of mass spectrometry

m/z	**ESI-MS**	**Py-FIMS**
94	Methylpyrazine	Methylpyrazine
110	Trimethylethylpyrazole	Trimethylethylpyrazole
117	Indole	Indole
131	Methylindole	Methylindole
145	Dimethylindole	Dimethylindole
159	Trimethylindole	Trimethylindole
173	Tetramethylindole	Tetramethylindole
187	Pentamethylindole	Pentamethylindole
201	Hexamethylindole	Hexamethylindole
243	Hexamethyl-propylindole	Hexamethyl-propylindole

obtained from the pyrolysis of chicken manure contained 12 chemical classes of compounds and more than 400 individual organic molecules. Details on the chemical composition of raw bio-oil and separated fractions has been reported in a series of articles published in scientific literature (see reference list).

As part of these efforts, we also chemically extracted and separated organic compounds with increased polarity from the upgraded bio-oil. For example, data obtained by Electrospray Ionization MS (ESI-MS) and Pyrolysis Field Ionization Mass Spectrometry (Py-FIMS) showed the presence of seven major classes of N-heterocyclics (Figures 4 and 5) in a N-rich fraction. Noteworthy, the combustion of these heterocyclic-N compounds in bio-oil may result in air contamination by emission of NH3 and NOxs. On the other hand, many of these compounds are of interest as raw materials to the chemical and pharmaceutical industries.

While conducting the latter work, we discovered that available hydrogens bonded to the ring carbons and nitrogens of the compounds in the seven classes of N-heterocyclics were increasingly substituted mainly by methyl (CH3) groups, to yield mono-, di-, tri- etc., methyl N-heterocyclics (Table 2). In some instances, longer-chain alkyl groups such as ethyl, propyl up to heptyl groups were the substituents. Collision Induced Decay (CID) experiments of ESI-MS confirmed the molecular composition of heterocyclic-N compounds.

In conclusion, our research shows that pyrolytic bio-oil derived from chicken manure contain 12 classes of compounds and more than 400 individual organic compounds. So far, we produced upgraded and refined bio-oil with similar properties to those of diesel number 3 and gasoline, respectively. In complementary research we have demonstrated that other bio-oil fractions of increased chemical polarity have a high N content and contain 7 classes of heterocyclic-N compounds. The extraction and separation of chemical compounds contained in the pyrolytic bio-oil provides support to the view of a holistic and sustainable agriculture by adding value to residues, protecting the environment, producing biofuel and green chemicals for use by other industry.

Acknowledgements
We acknowledge funding provided by the EcoEnergy Technology Initiative of Natural Resources Canada and Agriculture and Agri-Food Canada.

References

Schnitzer M, Monreal C, Facey G, Fransham P. 2007. J. Env. Sci Health Part B, 42:71.

Schnitzer M, Monreal C, Jandl, G., Leinweber P., Fransham P. 2007. J. Env. Sci. Health Part B, 42:79
Schnitzer MI Monreal C, Jandl G, J. Environ Sci Health Part B, 2008, 43:81.

Das D, Schnitzer MI Monreal C, Mayer P, Biores. Technol., 2009,100:6524.
Kazi ZH, Schnitzer M, Monreal C, Mayer, P. 2010. J. Environ Sci Health Part B, 45:1.

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Slow pyrolysis research in Finland

Leena Fagernäs from VTT in Finland provides an insight into a slow pyrolysis project focusing on hardwood

A new joint project of VTT, MTT Agrifood Research and University of Helsinki focusing on the development of slow pyrolysis business operations for hardwood, is underway (2008-2011) within the BioRefine Programme of Tekes, the Finnish Funding Agency for Technology and Innovation [1].

Birch distillate is a new innovation in plant protection. It is obtained as a by-product in slow pyrolysis retort process in charcoal production. In the process charcoal, liquids (distillate and tar) and non-condensable gases are produced. The yield of liquids is 35-40 wt% of hardwood. Previously, MTT and University of Helsinki found the liquid to be an interesting and efficient source for many kinds of biological pesticides [2]. It proved to be an effective repellent to control slugs and snails, and it can also be used for controlling broadleaf weeds and used as insecticides and fungicides. The idea was to replace synthetic pesticides with biological less harmful products. However, in the commercialization of the products there are still problems. For example, EU registration is costly, composition and active ingredients are not known, and constant quality and optimisation of product lines are needed.

The primary aim of the project coordinated by VTT is to support and develop slow pyrolysis business operations of SMEs in Finland. Collaboration between enterprises and research institutes is needed. All the main research groups in the area and the main enterprises producing slow pyrolysis liquids in Finland are involved. The enterprises participating in the project are Biopuisto Oy, Charcoal Finland Oy, Oy Clean Flame Ltd, Mayt Oy, MikTech Oy, Puhku Oy, Raussin Energia Oy, Sinituote Oy and TisleSuomi Oy. In addition, Golder Associates and vTI Johann Heinrich von Thünen-Institut participate as subcontractors in the project.

The project aims at generating knowledge that is needed in the commercialization. New types of distillates will be produced from hardwood in decentralized small-scale biorefineries, and can further be upgraded in an upgrading unit (so-called "distillate dairy concept"). All the products of the process will be utilized. The tasks include optimization of product lines, development of business concepts, characterisation of products, and ensuring constant quality of products. In addition, potential applications for the liquid products as pesticides and biocides, EU registration requirements including REACH,

Continued on page 33

Figure 1: Liquid samples from a test run with a retort

Slow pyrolysis research in Finland ...continued

Figure 2: Liquid including distillate and tar coming out of the retort.

Figure 3: Land snail was used as test organism in the comparison of slow pyrolysis liquids.

biocide and pesticide directives, and environmental impacts of the liquids will be determined.

Slow pyrolysis test runs with different retort furnaces of the enterprises joining the project have been carried out using hardwood (mainly birch) as feedstock. The products recovered include different distillate fractions and tars, charcoal and non-condensable gases (Figures 1 and 2). An analytical scheme was developed for the samples. The methods used for fast pyrolysis oils at VTT were partially applied for the analysis of the liquids. The procedure proved to be workable, the composition of the distillates could be determined in detail. Due to their chemical composition, the distillates are promising to be utilized. The effect of storing on distillates is being studied. In addition, non-condensable gas components and charcoal characteristics have been determined.

Potential applications of the distillates and tars from the test runs have been studied. The focus is on repellents and wood preservatives. Active ingredients of the products are being identified based on the observed impacts on some selected test organisms, particularly land snails and field voles. The land snail has proved to be a very useful organism for testing differences of pyrolysis liquids (Figure 3). The repellent effect has been studied by following the land snails when leaving the rings treated with distillates. The efficacy tests have been successful. The tests indicate that different distillates and tars seem to have different impact as repellent. Efficacy tests on the application of liquids as biocides for wood protection are under way.

Environmental (terrestrial and aquatic) impacts will be determined using conventional tests applied in ecotoxicology. The stability and leachability of distillates are studied in flower pots under greenhouse condition. The EU registration requirements will be determined for the products. The REACH pre-registration process was carried out for the producing enterprises joining the project, and the work related to the SIEFs (Substance Information Exchange Forums) and other tasks required has continued. Economic calculations based on the test runs and efficacy tests are under way. Based on experimental results and economic assessments, optimal product lines and business concepts will be determined. The results of the project will be published in 2011.

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References

[1] Fagernäs L, Tiilikkala K, Setälä H. 2009. Development of slow pyrolysis business operations in Finland. Proc. NWBC 2009, Vol. 1, Helsinki, Finland. Pp. 146-148.

[2] Lindqvist I, Lindqvist B, Tiilikkala K et al. Birch tar oil is an effective mollusc repellent: field and laboratory experiments using Arianta arbustorum (Gastropoda: Helicidae) and Arion lusitanicus (Gastropoda:Arionidae). gricultural and Food Science 19, 1: 1-12.

IEA Tasks 34–42 co-operation on a lignin pyrolysis biorefinery

Update from Paul de Wild of ECN in the Netherlands

The major objective of Task 42 - Biorefineries is to assess the worldwide position and potential of the biorefinery concept. Presently, much attention is focused on a workable biorefinery classification system and on an inventory of the most promising bio-based chemicals. Figure 1 illustrates the myriad of biorefinery possibilities.

An important activity of Task 34 – Pyrolysis of biomass is to focus on resolution of technical issues to aid commercial implementation of fast pyrolysis, e.g. within the framework of a biorefinery. As a co-operation between Task 34 and 42, a case study is conducted on lignin valorization by pyrolysis to facilitate lignocellulose biorefineries.

The main side-stream of a lignocellulose biorefinery is a lignin-rich residue. To date, this stream is mostly burned for heat. Recent developments indicate that lignin can be transformed into valuable products such as phenols by (fast) pyrolysis. A successful lignin pyrolysis concept offers the possibility to increase the economic viability of the biorefinery by converting its main side-stream into value-added materials, thereby enhancing its product portfolio and process flexibility. Figure 1 presents an example scheme of a multi product biorefinery including lignin upgrading.

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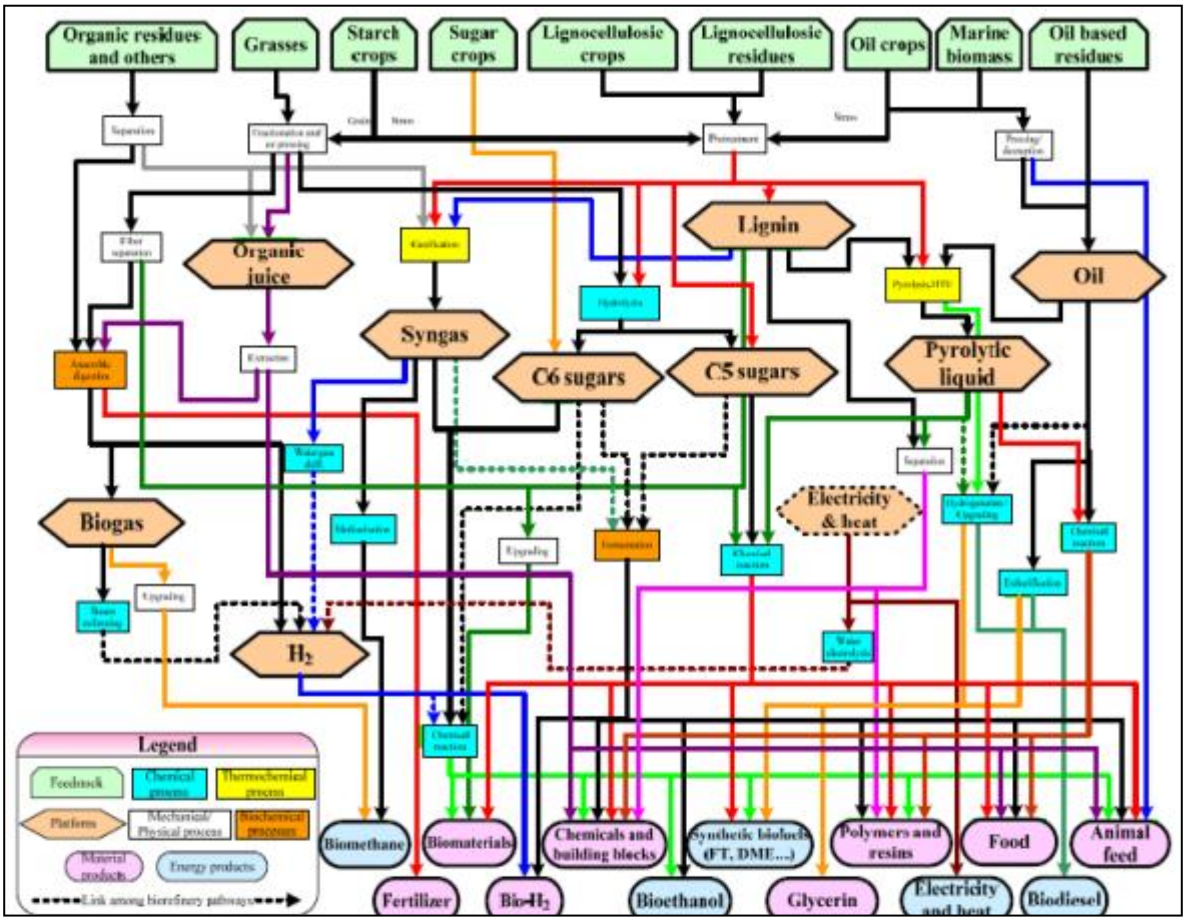

Figure 1: Platforms, feedstocks, processes and products in biorefineries

IEA Tasks 34–42 co-operation on a lignin pyrolysis biorefinery…continued

Second generation biorefineries for the production of bioethanol use pretreatment technologies such as organosolv fractionation to make the (hemi)cellulose accessible for (enzymatic) hydrolysis. One of the main benefits of organosolv fractionation compared to other pretreatment technologies is that the lignin can be recovered from the organosolv liquor with a high purity and essentially free of sulfur and ash. These lignin characteristics will facilitate valorization of lignin into products like resins and phenol (ics). LIBRA is a new Lignin BioRefinery Approach, based on bubbling fluidised bed pyrolysis technology to thermochemically convert lignin in a phenolic bio-oil and biochar. Biochar can be applied as fuel to generate heat for the pyrolysis process. The phenolic bio-oil can substitute phenol in wood resins and is a possible substitute or modifier for petrochemical bitumen. In addition, the phenolic oil is a source of high-value phenols for pharmaceutical, food, and other fine chemical applications. Presently, LIBRA is under evaluation for various lignin types.

The main goal of the lignin-valorisation case study will be a techno-economic evaluation (including life cycle analysis) of the lignin pyrolysis concept both as a stand-alone facility (lignin pyrolysis biorefinery) and as an integral part of a lignocellulosic biorefinery. The approach will be aimed at a combination of literature and available (process) data from Tasks 34 and 42. The lignin study is based on lab-scale experimental data and on the results of a market survey for lignin-derived pyrolysis products. Preliminary results indicate that the annual revenue of a typical 100 – 1000 t/d multiproduct lignocellulose biorefinery producing bio-ethanol and co-products can be increased significantly by implementing LIBRA.

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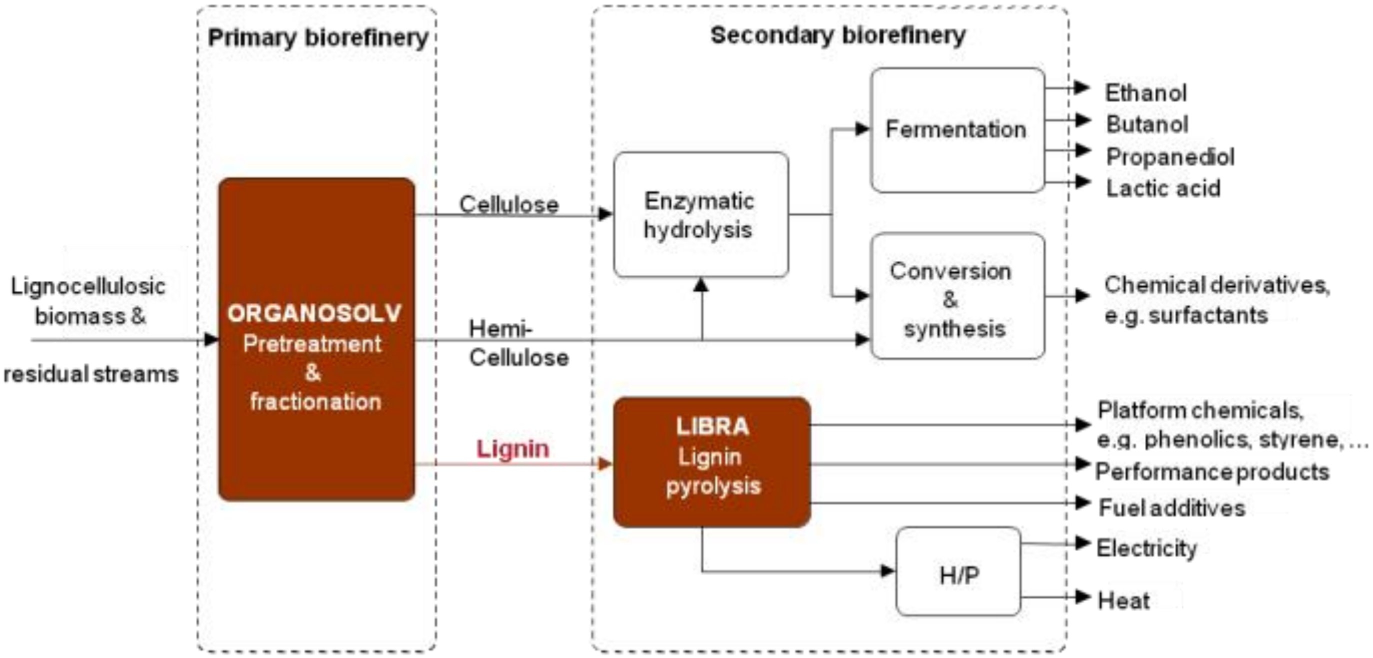

Figure 2: Lignin valorisation in a multi-product lignocellulose biorefinery (http://www.biobased.nl/lignovalue)

Country Update — USA

Pacific Northwest National Laboratory (PNNL)
Catalytic pyrolysis is being investigated including hydrotreating of the bio-oil product to produce hydrocarbons. Daniel (Miki) Santosa presented recent results at the national meeting of the AIChE in Salt Lake City. Upgrading by hydroprocessing remains a key component of the research including operating parameter and catalyst composition effects on fouling of the catalyst bed by polymerization.

NREL (National Renewable Energy Laboratory)
Interaction continues with GEMI and Valero on the evaluation of the introduction of bio-oil into a petroleum refinery. PNNL provided samples of hydrotreated bio-oil on which these assessments could be based.

Canadian Collaboration
Both PNNL and NREL are involved in an International Collaboration project with Canada in which biomass feedstocks (various forest residues) are pyrolyzed in different reactor systems and the products compared. PNNL is using its bubbling fluidized bed reactor, NREL is using a pyroprobe system, and CanMet is using their auger-based pyrolysis system. More detailed results should be available in the next issue of this newsletter.

NABC (National Advanced Biofuels Consortium)
The recently organized consortium is funded by the Department of Energy with industrial cofunding. Advanced technologies being investigated include catalytic pyrolysis, hydropyrolysis, and hydrothermal liquefaction. The goal of the consortium is to have at least one technology ready for building a demonstration plant in three years.

Bio-oil Upgrading Solicitation
The four winning proposals were announced in September and the projects are expected to get underway early in 2011. These include a PNNL-led effort in development of new catalysts and operating parameters to allow extended operation (>1000 hr) of hydrotreating fast pyrolysis bio-oil. Grace will lead an effort to develop a new catalytic reactor system for hydrotreating bio-oil. Battelle will lead a team to develop catalytic pyrolysis as a means to produce a more stable and more readily hydrotreatable bio-oil. GTI will be funded to build and operate their hydropyrolysis technology to demonstrate >1000 hr on stream.

Other news

Pacific Northwest
NATIONAL LABORATORY
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Doug Elliott
2010 Laboratory Fellow

Congratulations to Doug Elliott, Task 34 Leader, who has recently been named a Laboratory Fellow—the highest science and engineering rank that can be achieved at Pacific Northwest National Laboratory (PNNL) in the United States.

Recognised as an international leader in the development of fuels and chemicals from biomass and waste, he has been instrumental in growing the US Department of Energy (DOE) biomass program. Doug, a 2004 Battelle Distinguished Inventor was commended for more than 30 years of research and distinguished service at PNNL.

Country Update — Finland

VTT (Technical Research Centre of Finland)
In the new triennium, Anja Oasmaa of VTT is serving as the national team lead for Finland. At VTT, the biomass pyrolysis research is focused on three areas:

1. The industrial project supports the consortium of Metso Power, UPM Kymmene and Fortum in their effort to demonstrate pyrolysis oil production and long-term use.

2. The national Tekes project aims to create the basic tools for commercialization of pyrolysis oil production and use, for example the creation of standards and norms for pyrolysis oil production and use. This involves the work on MSDS, initialization of standardization in Europe under CEN, developing and validifying test methods for pyrolysis oil specifications, and on-line methods for process quality control. In addition, chemical characterisation for whole pyrolysis oil is further developed. The work also involves work on modelling of biomass pyrolysis.

3. In the EU BIOCOUP project, the focus is on the quality improvement of pyrolysis oil in order to upgrade pyrolysis oil into products which could be fed into the oil refinery.

Experiments are conducted in Metso's pilot plant, VTT's entrained bed pyrolyzer (20 kg/h), VTT's 1 kg/h fluid bed unit, and VTT’s continuous-flow hydrotreatment unit (20–30 g/h).

Other Finnish news

See pages 3-4 and 32-33 for further news from Finland

ÅA (Åbo Akademi University)
At ÅA, pyrolysis and gasification of black liquor (biomass bio-product from pulping industry) is being studied in laboratory-scale units. The purpose is to better understand the fate of the pulp cooking chemicals, sulphur and sodium, in novel thermal conversion processes being planned. Black liquors contain typically 20% (fuel dry solids) of sodium and 3-6% sulphur. These elements need to be recovered and reused in the pulping process, but their behaviour in pyrolysis and gasification is partly unclear and requires laboratory studies at controlled conditions using thermal gravimetry, grid heaters and other small scale reactors.

Also pyrolysis oil production from solid woody biomasses is studied using a special type of dual reactor laboratory system. In the first reactor the biomass is pyrolysed in a fluidized bed, and the vapors are fed to the next reactor. The second reactor is also a fluidized bed reactor but the bed material consists of zeolite based catalyst particles. The system has made it possible to study in-situ catalytic upgrading of the pyrolysis vapors under very well defined conditions[1].

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[1] Aho A, Kumar N, Lashkul AV, Eränen K, Ziolek M, Decyk P, Salmi T, Holmbom B, Hupa M, Murzin D Yu. Catalytic upgrading of woody biomass derived pyrolysis vapours over iron modified zeolites in a dual-fluidized bed reactor. Fuel (2010), 89 (8)

Country Update — UK

A list of known current activities in biomass pyrolysis in the UK is shown below. Additions and/or corrections are welcome—contact Tony Bridgwater at a.v.bridgwater@aston.ac.uk

UNIVERSITIES		
Aston University, Birmingham	Tony Bridgwater (BERG)	Fast pyrolysis in fluid bed and ablative reactors. Analytical pyrolysis. Catalytic and chemical upgrading. Nitrogenolysis. System studies and TEA
	Andreas Hornung (EBRI)	Intermediate pyrolysis of biomass and wastes. Upgrading products. Heat and power applications. Microalgae production and pyrolysis. Biochar
Queens University, Belfast	Robbie Burch	Steam reforming of model compounds and fast pyrolysis bio-oil on supported noble metal catalysts
University of Aberystwyth, IBERS	Ed Hodgson	Slow pyrolysis for biochar production
University of Warwick	Jan Baeyens	CFB fast pyrolysis and modelling
University of Cardiff	Karen Wilson	Heterogeneous catalysis for biofuel synthesis and upgrading
University of Edinburgh	Stuart Haszeldine	Biochar production and evaluation
University of Exeter	Chris Turney	Microwave pyrolysis for biochar
University of Leeds	Paul Williams and Jenny Jones	Fast pyrolysis in fluid beds. Zeolite upgrading of pyrolysis vapours. Analytical pyrolysis
University of Manchester	Patricia Thornley	Bioenergy and biofuel system analysis. Effect of policy. Socioeconomics
	Jhuma Sadhukhan	Modelling and system studies of integrated biofuel and biopower systems
University of Nottingham	Colin Snape	Upgrading pyrolysis liquid products. Microwave processing BMW. Hydropyrolysis for biochar
	John Andresen	Fast pyrolysis in CFB. Catalytic pyrolysis
University of Sheffield	Jim Swithenbank	Slow pyrolysis of MSW and derived SRF/WDF for charcoal
University of Swansea	Alayne Street-Perrott	Small scale biochar production
University of York	Ray Marriott	Use of microwaves for pyrolysis
COMPANIES		
Future Blends: Catal International, CARE and Aquafuels Research	David Penfold	Enhancement of pyrolysis of municipal and wood waste to produce blendable additive to fossil fuel
Bedminster		Pyrolysis of waste
Biomass Engineering	Graeme Shaw	Construction of a 250 kg/h fast pyrolysis demonstration plant is currently suspended
CARE Ltd	Cordner Peacocke	Market assessment of pyrolysis companies. Design, support, commissioning, operation of slow and fast pyrolysis plants for char, power, bio-oil.
2GBiopower	Mike Tooke	Biofuel process development and evaluation via pyrolysis
GEM		Pyrolysis for gas generation
North East Biofuels	c/o NEPIC	Production of FT hydrocarbons via fast pyrolysis liquids. Currently dormant
EPI (Environmental Power International)	Mark Collins-Thomas	Pyrolysis in novel reaction system
Hudol	Robert Pugmore	Slow pyrolysis in rotating kiln

Country Update — Germany

KIT – Karlsruhe Institute of Technology, Karlsruhe is developing the bioliq® process which comprises fast pyrolysis of straw in a twin screw reactor, slurry preparation by mixing bio-oil with char, slurry gasification to syngas in a pressurized entrained flow gasifier, and synthesis of methanol. The pyrolysis section has been operated at full load (500 kg/h) in summer 2010. Another test campaign is scheduled for December 2010. Phase II of the project has started this year involving the operation of the gasifier and the gas cleaning and synthesis systems.

CHOREN Industries GmbH, Freiberg is using their Carbo-V technology for the demonstration of syngas production for making FT-biofuels from wood. They have launched the first BTL project in France with a signature of EPC (engineering, procurement and construction) agreement for a 45-MW synthesis gas plant. The plant is designed to produce at least 23,000 metric tonnes of high-quality bio-synthetic fuel annually. The biomass feedstock, mainly from wood residue, will come from the rural area between Paris and Strasbourg.

Fraunhofer UMSICHT, Oberhausen develops applied and custom-made process engineering technologies. Within their biorefinery activities "Fraunhofer UMSICHT" is currently establishing a technical centre for biomass including also a pilot plant for ablative fast pyrolysis.

PYTEC GmbH, Hamburg have improved their pilot plant for fast ablative pyrolysis by changing from electrical heating to natural gas heating. Tests of the injections system of the diesel engine using innovative new materials are underway. A new laboratory ablative pyrolysis system has been designed and constructed for a client.

vTI-HTB – Inst. of Wood Technology and Wood Biology, Hamburg has been involved in two German biorefinery projects (1) Lignocellulose Biorefinery, (2) Biorefinery 2021. In both projects vTI is dealing with pyrolysis of lignin for the production of monomeric phenols.

Other German news

See the 'Events' section on page 41 for further information about various events around the world

19th European Biomass Conference and Exhibition will take place at ICC Berlin, Germany from 6-10 June 2011.

This event is supported by European and international organisations such as the European Commission, UNESCO—United Nations Educational Scientific and Cultural Organization, Natural Sciences Sector, WCRE—The World Council for Renewable Energy, EUBIA—the European Biomass Industry Association.

See page 42 for further information, or alternatively, visit www.conference-biomass.com or www.exhibition-biomass.com

Country Update — Canada

CanmetENERGY
In the new triennium, Fernando Preto of CanmetENERGY Ottawa is serving as the national team lead for Canada. CanmetENERGY is the science and technology arm of of the Innovation and Energy Technology Sector (IETS) of Natural Resources Canada and operates three labs across Canada with over 450 scientists, engineers and technicians.

At CanmetENERGY, biomass pyrolysis research is focused on industrial partnerships to accelerate implementation of bioenergy technologies:

1. CanmetENERGY in partnership with Ensyn Technologies Inc. and Brais Malouin and Associates Inc. is working on a project to design and develop a bio-oil train and gun burner optimized for the delivery of pyrolysis oil into a packaged boiler. The objective of the boiler demonstration unit is to demonstrate autonomous operation of a commercial/small industrial scale (1 MWth) boiler burning bio-oil as the sole fuel. It is expected that this demonstration could lead to full-scale implementation at CanmetENERGY's Bells Corners Complex heating plant in Ottawa and also at a nearby industrial site.

2. CanmetENERGY is working with ABRITech Inc. to commission a 25 kg/h auger-based (using steel shot as the heating medium) pyrolysis unit to establish the capability to produce and evaluate bio-oils from a wide range of feedstocks.

In separate projects, CanmetENERGY has established linkages to US Pacific Northwest National Laboratory and FP Innovations in order to evaluate the properties of bio-oil produced using different technologies from six major feedstocks from across Canada, including Mountain Pine Beetle-killed wood, currently a major crisis/opportunity in Western Canada.

Other news

TPD, Ottawa, National Resources Canada
ABRI-Tech and Natural Resources Canada (NRCan) have been jointly testing a 1 tpd system at NRCan's research facility in Ottawa, Canada. The testing program over the past year has led to design changes that have improved the recovery of char and the overall system performance. NRCan has been a major supporter of pyrolysis technologies over the past decade and with access to a 1 tpd system at their laboratories are able to produce bio-oil from a range of biomass feedstock. NRCan has analytical laboratory facilities to characterize the produced products. Online emissions monitoring has also provided ABRI-Tech with third party data for environmental permitting of other facilities.

See more news from Canada on pages 24—31

Events

JANUARY 2011

10th —12th
Pacific West Biomass Conference & Expo
Seattle, Washington, USA

25th—26th
Energy from Biomass and Waste UK Exhibition & Conference
London, UK

26th—27th
Global Biofuels Summit 2011
Barcelona, Spain

26th—29th
Central European Biomass Conference 2011
Graz, Austria

FEBRUARY 2011

10th—12th
CEP® Clean Energy & Passivehouse 2011
Stuttgart, Germany

11th
5th International Conference on Application of Biomass Gasification
Stuttgart, Germany

23rd—25th
Biomass Trade & Power Americas
Atlanta, USA

MARCH 2011

1st—2nd
Power Summit 2011
London

2nd—3rd
European Pellet Conference 2011 & International Pellet Business Forum
Wels, Austria

14th—16th
BioPro Expo
Atlanta, USA

22nd—24th
World Biofuels Markets
Rotterdam, Netherlands

22nd—24th
Nordic Wood Biorefinery Conference 2011
Stockholm, Sweden

APRIL 2011

25th—29th
World Congress of Bioenergy
Dalian, China

MAY 2011

2nd—5th
International Biomass Conference & Expo
St Louis, Missouri, USA

2nd—5th
33rd Symposium on Biotechnology for Fuels and Chemicals
Seattle, USA

17th—19th
Waste to Energy + recycling
Bremen, Germany

18th—19th
All-Energy 2011
Aberdeen, Scotland, UK

22nd—27th
Bioenergy III: Present and New Perspectives on Biorefineries
Lanzarote, Canary Islands, Spain

JUNE 2011

6th—10th
19th European Biomass Conference and Exhibition
Berlin, Germany

8th—10th
7th International Conference on Renewable Resources & Biorefineries
Bruges, Belgium

29th—30th
AEBIOM European Bioenergy Conference & RENEXPO® Bioenergy Europe
Brussels, Belgium

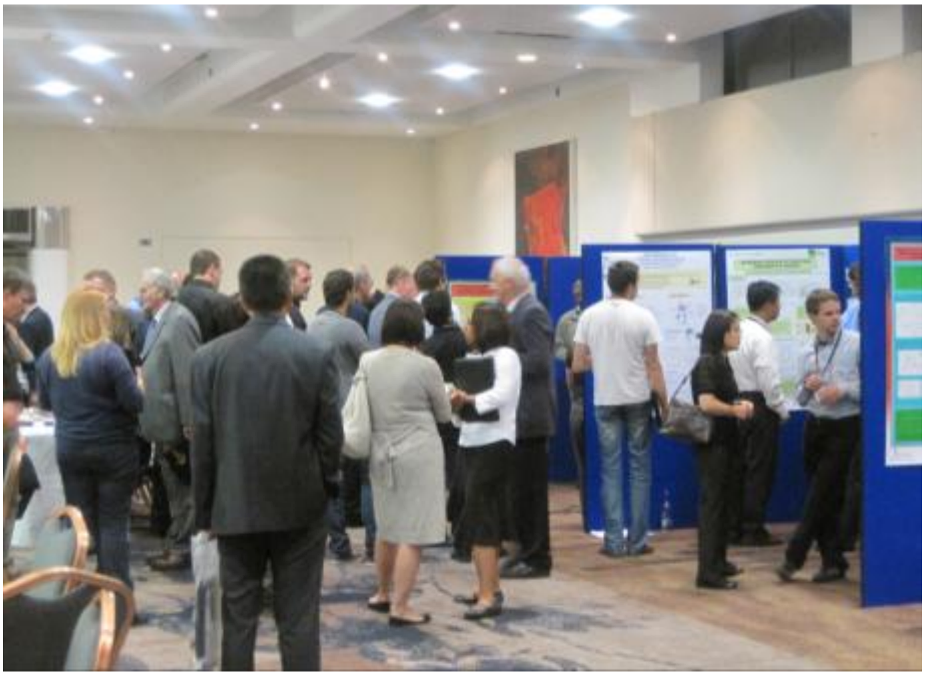
SEPTEMBER 2011

22nd—25th
RENEXPO® 2011
Augsburg, Germany

27th—30th
tcbiomass 2011
Chicago, USA

OCTOBER 2011

Exact date to be confirmed
Bioenergy International Canada Expo and Conference
Calgary, Alberta, Canada



Events...continued

28–30 september 2011

Westin Chicago River North

tcbiomass2011

THE INTERNATIONAL CONFERENCE
ON THERMOCHEMICAL CONVERSION SCIENCE

Join us at the cutting edge of thermochemical biomass conversion science!

Save the Date

Gas Technology Institute is pleased to announce tcbiomass2011, the International Conference on Thermochemical Biomass Conversion Science. Mark your calendars for September 27-30, 2011 and plan to connect with many of the world's leading researchers, scientists and engineers.

The 3-day scientific forum will cover the gamut—from fundamental and applied research to technology lessons learned. Be at the centre of dramatic change to discuss, learn and assess the progress and promise of this exciting area of bioenergy.

Location

Westin Chicago River North, 320 N. Dearborn
Chicago, Illinois, USA

Call for Abstracts

25 abstracts will be selected to present during the conference and up to 50 posters will be displayed. Abstracts are being accepted on the following topics:

- Gasification
- Pretreatment
- Pyrolysis
- Upgrading

Submit abstracts of 250–300 words by March 15, 2011 to Terry Marker at terry.marker@gastechnology.org.

Visit www.gastechnology.org for further information

19th European Biomass Conference and Exhibition

From Research to Industry and Markets

ICC Berlin - International Congress Center Berlin - Germany

Conference 6-10 June 2011 • Exhibition 6-9 June 2011

For over 30 years, the European Biomass Conference and Exhibition (European BC&E) has combined a very renowned international Scientific Conference with an Industry Exhibition. The European BC&E is held at different venues throughout Europe and ranks on top of the world's leading events in the Biomass sector.

This event is supported by European and international organisations such as the European Commission, UNESCO - United Nations Educational, Scientific and Cultural Organization, Natural Sciences Sector, WCRE - the World Council for Renewable Energy, EUBIA - the European Biomass Industry Association.

The 19th European Biomass Conference and Exhibition is realized in Germany by WIP-Renewable Energies with the international support of ETA-Florence Renewable Energies and the scientific support of the European Commission, DG Joint Research Centre. We look forward to welcoming the global scientific and industrial Biomass community in June 2011 in Berlin, Germany.

For further information contact Catherina Bernaschina at catherina.bernaschina@etaflorence.it or call +39 055 5002280

www.conference-biomass.com

Publications

Books

Thermochemical Conversion of Biomass to Liquid Fuels and Chemicals – Royal Society of Chemistry Energy and Environment Series. Edited by Mark Crocker
http://www.rsc.org/shop/books/2010/9781849730358.asp

Energy Crops – Royal Society of Chemistry Energy and Environment Series. Edited by Nigel G Halford and Angela Karp
http://www.rsc.org/shop/books/2010/9781849730327.asp

ThermalNet - the European Network for biomass pyrolysis, gasification and combustion – CPL Press. Edited by AV Bridgwater, H Hofbauer and S van Loo
http://www.cplbookshop.com/contents/C3568.htm

Online Demos

BIOSYNERGY Demo
http://www.youtube.com/biosynergyProject

BIOSYNERGY is a European Commission sponsored integrated project with the overall objective to develop technologies and designs for innovative biorefinery processes.

Other Publications

Renewable Energy Projections as published in the National Renewable Energy Action Plans of the European Member States.
http://www.ecn.nl/publications/default.aspx?nr=ECN-E--10-069

Authors: LWM Beurskens and M Hekkenberg

Published by ECN Policy Studies

Newsletters

Past editions of the PyNe newsletter can be found on the PyNe website at www.pyne.co.uk

Intelligent Energy Europe

iea Energy Technology Network

Further Information

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IEA Bioenergy

Task 34 Pyrolysis

PyNe 28

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