Welcome to Task 34

By Doug Elliott, Task 34 Leader

The IEA Bioenergy Task 34 for Pyrolysis has started up its work in the new triennium, from 2013 to 2015. Current participants in the Task are Finland, Germany, Netherlands, Sweden and UK, with leadership provided by the USA. This newsletter is produced by the Task to stimulate the interaction of researchers with commercial entities in the field of biomass fast pyrolysis.

Aims and 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.

The following are the Priority Topics identified for the triennium by the Task:

- Review of bio-oil applications;
- Bio-oil standardization;
- Round Robin for analytical method development;
- Technoeconomic assessment of thermochemical liquefaction technologies.

In this issue

There are several articles from the participants describing the latest developments in fast pyrolysis including from the Netherlands, the developments in hydrodeoxygenation of bio-oil and initial results from turbine testing.

(Continued on page 2)
Welcome ..continued

with bio-oil; from Germany, the development of on-line measurements in fast pyrolysis and the Bioboost system; and from the USA we have contributions from Utah State, Washington and Maine Universities and from GTI describing their hydropyrolysis developments.

In this issue we have additional contributions from Austria on the Biocrack process; from Canada, a note describing fast pyrolysis of milkweed residues; and from the UK, an article about work at Aston University. There is also an updated calendar of events of interest to the biomass pyrolysis community.

In the past you may have seen the short introductory articles from the national team leaders from each of the participating countries summarizing the particular biomass pyrolysis efforts in their countries. These have been moved to direct links on our webpage - please use the tab for ‘Developments’ for Country Report Updates.

In addition, you may be interested to read the journal publication prepared by the task participants, “State-of-the-Art of Fast Pyrolysis in IEA Bioenergy Member Countries” by Dietrich Meier, Bert van de Beld, Tony Bridgwater, Doug Elliott, Anja Oasmaa, and Fernando Preto in Renewable and Sustainable Energy Reviews, 20, 619-641.

Similarly, in the past we have included an overview of the latest Task meeting with information on the developments within each of the Priority Topics. These summaries will now be found on the website by using the ‘Task 34 Meetings’ tab and linking to the relevant meeting’s Summary Minutes. We hope you find the website (www.pyne.co.uk) useful.

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Sweden - to be announced shortly
Pyrolysis activities at the University of Maine’s Forest BioProduct Research Institute

At the University of Maine’s Forest BioProduct Research Institute (FBRI), we are focused on developing new approaches to removing oxygen from biomass during the conversion process. Our particular focus is on developing processes that are robust and relatively simple, and on removing significant quantities of oxygen without using precious metal catalysts and elevated pressures.

In our research team, we have recently discovered a breakthrough in concentrating biomass into liquid form while removing significant quantities of oxygen using a fast pyrolysis method. In our method, formate-assisted pyrolysis (FAsP), we add an alkaline-earth salt of formic acid to the feedstock. The formate thermally decomposes along with the biomass during processing, creating reactive hydrogen and carbon monoxide which remove oxygen from the biomass. In addition, and perhaps even more important, is the increase in yields we observe relative to competing processes.

We believe this is due to the in-situ deoxygenation that stabilizes intermediate molecules which could either polymerize during pyrolysis or condense resulting in char formation. We have shown this for wood and for lignin, which is a notoriously recalcitrant byproduct of the pulping industry that is currently used as a fuel for process heat source.

The new FAsP method has the potential to produce liquid hydrocarbons meeting target levels of less than 8% oxygen, higher heating values greater than 40 MJ/kg, and overall energy yield greater than 40% of theoretical in the oil product, while avoiding expensive/short-lifetime catalysts, hydrogen, and processing at excessive pressures. Because of its inherent robustness, FAsP is flexible regarding process scale and biomass specificity, both critical because biomass is less densely concentrated in nature than fossil fuels.

In the FAsP method, calcium formate is mixed with biomass (lignin and pine sawdust) and pyrolyzed in a bench-scale, fluidized bed, fast pyrolysis reactor with a solid feed rate of approximately 0.5 kg/hr. Typical pyrolysis conditions include temperatures of ~500ºC and residence times on the order of 1-5 seconds. Solid char product that contained calcium carbonate was separated using a hot gas filter. Liquid was collected in a condenser and electrostatic precipitator in series. The liquid oil from FAsP separated from a less-dense aqueous phase.

Mass ratios of calcium formate to lignin ranged from 0.7-1.4 for lignin. In the liquid oil product, the O/C ratio was reduced from 0.19 (fast pyrolysis without calcium formate) to 0.067 (with calcium formate), while the liquid product yield increased from 23 to 32.5 wt%. Products identified by Gas Chromatography Mass Spectrometry (GC-MS) include a significant quantity of alkylated phenols. Carbon 13 Nuclear Magnetic Resonance ($^{13}$C NMR) (Continued on page 4)
Pyrolysis activities at University of Maine

...continued

Formate salts (not formic acid) will be produced by using carbonylation of lime rather than by neutralizing formic acid which is commercially produced by hydrolysis of methyl formate.

Conceptual integration of the calcium recovery cycle with gasification of FAsP byproducts is shown in Figure 1, and material balances indicate that sufficient carbon exists to provide the required calcium formate, therefore, eliminating the need to purchase formic acid. Interestingly, the process could take advantage of processes such as lime kilns and slakers which are common to pulp mills and biorefineries.

Future directions of the work will include understanding fundamental reactions occurring during FAsP, as well as increasing the overall energy yield of the process.

This work was supported by a Department of Energy/EPSCoR Grant DE-FG02-07ER46373.
The BDI bioCRACK pilot plant at OMV refinery Schwechat

BDI – BioEnergy International AG is a market and technology leader in the construction of customized biodiesel plants using multi-feedstock technology. In 2007, BDI started its research activities in the biomass-to-liquid area. The developed ‘bioCRACK’ technology produces mineral diesel with renewable shares that can be easily upgraded to EN590 quality with existing refinery units. This concept fulfills two fundamental tasks: Producing diesel to meet the growing demand, while simultaneously increasing the biogenic share. Pyrolysis oil and bio-char are additional valuable by-products of this unique conversion process.

OMV and BDI - BioEnergy International AG have been jointly involved in the innovative bioCRACK pilot plant project since 2009 (see Table 1). The bioCRACK pilot plant at the OMV refinery Schwechat is the first of its kind worldwide and converts solid biomass, such as wood chips and straw, directly into diesel fuel (see Figure 1). It is fully integrated into the existing plant and uses a refining by-product as heat carrier oil for underlying in the refinery liquid phase pyrolysis process.

Figure 2 shows the concept for refinery integration. The key-product - a raw fuel fraction - consists of cracked hydrocarbons and converted biomass. It contains a biogenic share in the range of 5 to 20% and can be upgraded with existing refinery utilities into diesel fuel according to the EN590 standard. An advantage of this process is that in the past heavy mineral oil was used mainly for the production of petrol, but now it can be used for the production of diesel, which is in strong demand, especially in Europe.

The uncracked heavy oil fraction will go its conventional way to a fluidized catalytic cracking unit to be converted to gasoline and lower hydrocarbons. This stream contains renewable carbon from the biomass and will hence contribute to a more sustainable carbon balance of the refinery. Currently, the side products pyrolysis oil and biochar have no established way in the refinery integration concept. In cooperation with external research partners, BDI is currently investigating a further upgrade of this sustainable energy carrier to increase the percentage of renewable carbon to be transferred to value added products.

Interested parties are welcome to test our pyrolysis oil - which is free of solids and poor in tars - in their upgrading facilities.

Acknowledgement
This project is funded by the Austrian Climate and Energy Fund as part of the ‘New Energies 2020’ research and technology programme. The author would like to thank project partner OMV Refining and Marketing GmbH for their support.

(Continued on page 6)
The BDI bioCRACK pilot plant

...continued

![Diagram of bioCRACK refinery integration concept]

Figure 2: Process flow sheet of the bioCRACK refinery integration concept.

| Table 1: Key facts and figures relating to the BDI bioCRACK pilot plant. |
|--------------------------|-----------------------------|
| Project Owner | BDI - BioEnergy International AG |
| Project Name | bioCRACK |
| Location (City, Country) | Schwechat/Vienna |
| Technology | Thermochemical |
| Raw Material | Lignocellulosics |
| Input Capacity | 2.4 t/d |
| Product(s) | Raw diesel, bio-oil, bio-char |
| Output Capacity in [t/a] | 500 t/a raw diesel |
| Facility Type | Pilot |
| Investment | 7 million EUR |
| Project Funding | 2 million EUR |
| Status | Operational |
| Start-up Year | 2012 |

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Products from fast pyrolysis of beetle-killed trees

Fernando Resende of the University of Washington, USA details the pyrolysis products identified at different stages of degradation of lodgepole pine

The mountain pine beetle (MPB, or Dendroctonus ponderosa) is one of the most damaging bark beetles attacking lodgepole pine (Pinus contorta var. latifolia). MPB inhabits areas in the north American continent that go from northern Mexico to north-western British Columbia in Canada, and from the Pacific Coast east to the Black Hills of South Dakota

In recent years, drought, warmer winters and aging forest have led to a beetle epidemic with high levels of tree mortality, generating a fire hazard in forests within the USA and Canada. This epidemic has affected more than 4 million acres.

The most important characteristic of the trees attacked by the beetle are the loss of moisture over time. This is a concern to the solid-wood industry sector, because it causes cracking of wood (checking), adversely affecting product quality, especially below 30% moisture. Checking becomes an issue for beetle-affected wood within 2 years of death.

The conversion of beetle-killed trees into bio-oil via fast pyrolysis presents an opportunity to reduce the volume of accumulated dead trees, avoiding a wildfire hazard while simultaneously producing a high-value product in the bio-oil. The dry, affected wood is an excellent feedstock for fast pyrolysis, since drying costs are minimized or even eliminated. Fast pyrolysis also produces biochar, which can be economically used on-site as a solid amendment.

In addition, fast pyrolysis can essentially convert any form of biomass into bio-oil. The process is essentially feedstock agnostic and our working hypothesis is that the quality of the bio-oil product is not affected by the beetle attack to the wood.

We are evaluating the fast pyrolysis products of lodgepole pine at four stages of degradation, as identified in Figure 1:

- Green uninfected or minimally infected tree (LP);
- Partially green terminally infected tree (BKLP1);
- Standing dead with red needles and bark intact (BKLP2);
- Standing dead with loss of small branches, no needles and some bark loss, two to four years after death (BKLP3).

Figure 2 shows the chromatograms and top 20 pyrolysis products identified for the four stages of degradation. The main products are mequinol, 2-methoxy-4-phenol, and 2-methoxy-3(1-propenyl)-phenol. Clearly, the attack of the beetle does not affect the pyrolysis products, even for trees that have been dead for years.

An ablative bench-scale pyrolysis unit is currently being designed.

(Continued on page 8)
Products from fast pyrolysis of beetle-killed trees...continued

and will be constructed in our laboratory during the second half of 2013. Ablative units do not require grinding of wood particles to very small particle sizes, and are an excellent option for small scale reactors such as mobile units. The use of mobile pyrolysis units that can convert wood into bio-oil on-site is essential to make fast pyrolysis an economically viable option to dispose beetle-killed trees. Our approach will allow evaluation of the feasibility of mobile ablative pyrolysis units for the conversion of beetle-killed trees into bio-oil.

Support
This research is supported by the National Institute of Food and Agriculture (NIFA) of the US Department of Agriculture (USDA), under Award Number 2012-34638-2020.

References

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<tr>
<td>2</td>
<td>2,3-dihydro-5-methyl-Furan</td>
<td>C₅H₈O</td>
</tr>
<tr>
<td>3</td>
<td>Furfural</td>
<td>C₅H₄O₂</td>
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<td>4</td>
<td>2-Furanmethanol</td>
<td>C₇H₁₀O₂</td>
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<td>2(5H) - Furanone</td>
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<td>Mequinol</td>
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<td>2-methoxy-p-Cresol</td>
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<td>5-Hydroxymethylfurfural</td>
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<td>20</td>
<td>γ-Hydroxyisoeugen</td>
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Figure 2: Fast pyrolysis products of affected lodgepole pine.
Direct production of gasoline and diesel from biomass using Integrated Hydropyrolysis and Hydroconversion (IH²)

Terry Marker of the Gas Technology Institute (GTI) in USA provides an insight into a new process known as IH²

‘IH² makes high quality hydrocarbon fuels from biomass economically and directly. Testing at the 50 kg/d scale has been very successful, so we expect to take the next step to demonstration scale soon.’

GTI is testing a new process called IH² to directly produce gasoline and diesel blending components from biomass. The IH² process used a first stage catalytic hydropyrolysis step integrated with a second stage hydroconversion step. This combination directly produces high quality hydrocarbon gasoline and diesel blending components. The hydrogen required for the IH² process is produced by reforming the C₁-C₃ products so no supplementary hydrogen is required. The IH² integrated process schematic is shown in Figure 1.

Initial economic analyses suggest that the IH² process has excellent economics and greenhouse gas reduction, and is an improvement compared to pyrolysis plus upgrading for producing transportation fuels from biomass.

The first stage catalytic hydropyrolysis step converts the biomass to hydrocarbons in a fluidized bed of catalyst under hydrogen pressure of 20 to 35 bar and temperatures of 370 to 475°C. Catalytic hydropyrolysis removes 80-90% of the biomass oxygen as water and COₓ, while minimizing undesirable acid-catalyzed polymerization, aromatization, and coking reactions which occur during standard fast pyrolysis. The second stage fixed bed hydroconversion reactor then removes the remaining oxygen and converts the product to high quality hydrocarbon products.

Initial experiments had been conducted in a small scale mini bench unit (MBU) which feeds 1 lb/hr of biomass over a period of 3-6 hours. In 2012, IH² testing was moved to a 50 kg/day continuous IH² pilot plant. A schematic diagram of the IH² pilot plant is shown in Figure 2 and the actual pilot plant is shown in Figure 3.

The IH² 50 kg/d continuous pilot plant produced similar yields and product quality to that found in the small scale testing.

Data from 750 hours of IH² pilot plant testing is shown in Figure 4.

The hydrocarbon liquid yields and (Continued on page 11)
Integrated Hydropyrolysis and Hydroconversion (IH\(^2\))...continued

Figure 2: Schematic of GTI's 50 kg/day IH\(^2\) pilot plant.

Figure 3: GTI's 50 kg/day IH\(^2\) pilot plant.
quality remained high and steady throughout the test. A picture of the products produced from the pilot plant is shown in Figure 5. Throughout the test the oxygen in the hydrocarbon product was less than 1% and the Total Acid Number (TAN) of the hydrocarbons was less than one.

The liquid hydrocarbon products from the pilot plant were in the gasoline and diesel range. As shown in Figure 6.

The IH² hydrocarbon product was fractionated into gasoline and diesel cuts. The gasoline cut is almost at “drop in” quality and has a high octane of 86. The diesel can be used as a blending component or further upgraded to improve its cetane number.

The IH² project was funded through DOE project DE-EE0002873 and DE-EE0004390. Other IH² DOE project partners include CRI Catalyst, Cargill, Johnson Timber, Aquaflow, Blue Marble Energy, NREL and MTU.

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Application of pyrolysis oil in the OP16 gas turbine – feasibility study

OPRA Turbines develops, manufactures, markets and maintains generator sets in the 2 MW power range using the OP16 series of gas turbines. The OP16 gas turbine, shown in Figure 1, is of an all-radial design, which provides robustness, reliability and highest efficiency in its class. A key feature of the OP16 gas turbine is the ability to utilize a wide range of fuels.

As part of OPRA’s continuous effort to extend the fuel capability of the OP16, an R&D project was initiated focusing on utilizing pyrolysis oil. The overall aim of the R&D project was to develop a combustor suitable for efficient combustion of pyrolysis oil. The higher viscosity, lower energy density and limited chemical stability of the pyrolysis oil require different fuel handling compared to conventional liquid fuels. This article will present the initial phase of this R&D project - a feasibility study consisting of several test campaigns performed in OPRA’s atmospheric combustor test rig. As a fuel for the experimental work pyrolysis oil from pine wood, provided by BTG Bioliquids BV, was used.

Test set-up
The properties of the pyrolysis oil used for the experimental investigation are provided in Table 1. The properties of diesel No. 2, which is a common liquid fuel for gas turbines, are included for reference. Due to the higher viscosity of the pyrolysis oil, a pintle airblast nozzle, designed by OPRA, was selected as the fuel injector.

The pintle airblast nozzle can handle liquid fuels with higher kinematic viscosity than a standard pressure nozzle. A major advantage of the pintle airblast nozzle is that it works with the pressure difference caused by the pressure loss across the combustor flame tube. This means that a pintle airblast nozzle does not need any external source of air or steam.

The OP16-3A gas turbine conventional combustor working in diffusion mode was used for the experiments. A benefit of this combustor is that the flame tube is very flexible for changes related to the effective flame tube area and the air split across the combustor.

(Continued on page 13)
Application of pyrolysis oil in the OP16 gas turbine...continued

Table 1: Comparison between pyrolysis oil and diesel No. 2.

<table>
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<th>Property</th>
<th>Pyrolysis oil</th>
<th>Diesel No. 2</th>
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<tbody>
<tr>
<td>Density at 15°C [kg/m³]</td>
<td>1150</td>
<td>840</td>
</tr>
<tr>
<td>Low Heating Value [MJ/kg]</td>
<td>18.7</td>
<td>42.7</td>
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<tr>
<td>Viscosity at 38°C [cSt]</td>
<td>17</td>
<td>1.9-4.1</td>
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<td>Polymerization temperature [°C]</td>
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<td>pH</td>
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Hence, with this flexibility the optimum condition for pyrolysis oil burning can be relatively easily defined with respect to the combustor loading. The combustor loading is an important parameter since it is closely related to the emission figures and combustion efficiency. The OP16-3A conventional combustor was adjusted in several steps to find the optimal configuration for pyrolysis oil burning.

Results from the tests
The first test was performed with the standard flame tube and without fuel pre-heating. The purpose of this test was to establish a baseline data set for further research. With the standard configuration it was found to be possible to keep a stable combustion process with a mixture of 25% pyrolysis oil and 75% ethanol. The residence time is related to the combustor volume. Due to the differences in fuel composition, especially the large amount of dilutants associated with the pyrolysis oil, the residence time for pyrolysis oil is longer than for fossil fuels. From the initial tests it became clear that the required combustor outlet temperature could not be reached.

The unburned fuel resulting from incomplete combustion formed sediment on the flame tube inner wall and in the exhaust duct. Based on the test results from this configuration, the combustor geometry was adjusted and an optimized geometry was found. To simulate the effect of a larger volume the effective area of the flame tube and the amount of air entering the combustor were decreased.

The pressure loss of the combustor is an important parameter governing the mixing process and the function of the airblast atomizer. Therefore, it was important to decrease the effective combustor area and air mass flow to maintain the same pressure loss as the original combustor. By decreasing the effective flame tube area and the inlet air mass flow, a significantly longer residence time was achieved. A significant improvement of the flame stability was achieved and no unburned fuel in the exhaust duct was observed. Due to the decrease of the combustor loading the full load condition was reached.

Furthermore, it was found that with between 70% to 100% load, it is possible to burn 100% pyrolysis oil without the need of mixing it with ethanol. Based on this research, OPRA has been able to design a new combustor for burning pyrolysis oil and other low-calorific fuels. The new combustor is large enough to provide sufficient residence time for complete combustion of the pyrolysis oil.

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BioBoost – biomass based energy intermediates boosting bio-fuel production

Objectives

The overall objective of this project is to pave the way for de-central conversion of biomass to optimised, high energy density carriers, which can be utilised either in large scale applications for the synthesis of transportation fuel and chemicals or directly in small-scale combined heat and power (CHP) plants.

Concept

BioBoost studies the conversion technologies Fast Pyrolysis (FP), Catalytic Pyrolysis (CP) and Hydrothermal Carbonisation (HTC). Together, these technologies enable the flexible use of a wide range of biomass including wet, grassy and ash-rich feedstock, focusing on residues and waste as sources for bioenergy generation. These technologies offer various decentral conversion capabilities for the production of bio-oil, -char and -coal. FP and HTC plants in pilot size of 0.5–1 t/h are available within this project. Prior to the energetic use valuable chemicals like phenols or food flavourings from FP and CP, fertilisers and furfural from the HTC process are extracted as valuable side products.

The energy carrier may be transported to further use either “as produced” (oil, char, coal) or further processed to e.g. oil/char slurries or pellets and other suitable forms. BioBoost develops the best energy carrier regarding the mode of transportation, respective infrastructure, cargo handling, safety and economy. Among different sectors of application, all conversion products have been proven to be well suited for gasification and production of synthetic transportation fuels.

However, a respective central gasification facility has a high feedstock demand requiring a developed energy carrier market. Therefore, a market implementation plan is developed. In the ramping phase it proposes the use of energy carriers in available applications of the heat and power sector (CHP) or refineries. Later, a gasification plant would be phased into a developed bioenergy carrier market according to its economic and technical performance (Figure 1).

Overall strategy and work plan

The project comprising seven work packages addresses the complete value chains from feedstock potential, conversion processes, optimisation of transport and logistics to the exploitation of the energy carrier and its by-products. The techno/economic and environmental assessment integrates the complete supply chain (Figure 2).

During the first year the technical processes were defined and investigated. The feedstock potential has been determined, the procedures of the socio-economic and environmental assessment were defined and the logistics model was built up. First results are expected in the third quarter of 2013.
BioBoost – biomass based energy intermediates boosting bio-fuel production…continued

Consortium
The BioBoost project consortium consists of 13 beneficiaries, plus one third-party contributor from six countries (Austria, Finland, Germany, Greece, the Netherlands and Poland):
1. Karlsruhe Institute of Technology (KIT);
2. Centre for Research and Technology Hellas (CERTH);
3. AVA-CO2-Forschung GmbH (AVA-CO2);
4. CHIMAR Hellas SA (CHIMAR);
5. EnBW Energie Baden-Württemberg AG (ENBW);
6. Nederlandse Organisatie voor Toegespaste Natuurwetenschappelijk Onderzoek (TNO);
7. GRACE GmbH & CO KG (GRACE);
8. Instytut Uprawy Nawożenia I Gleboznawstwa, Państwowy Instytut Badawczy (IUNG);
9. FH OÖ Forschungs & Entwicklungs GmbH (FHOÖ);
10. Neste Oil Corporation (NESTE);
11. SYNCOM Forschungs- und Entwicklungsberatung GmbH (SYNCOM);
12. DSM Chemical Technology R&D BV (DSM);

Project facts
- Start: 01/2012
- Duration: 42 months
- Total budget: 7.3 million EUR
- Funding: 5.1 million EUR
- Website: www.bioboost.eu

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Figure 2: Project structure including Work Packages (WP); parties involved (shown in brackets) and WP leaders (shown in brackets in bold).
Milkweed pyrolysis

In the past, extraction of phytochemicals by pyrolysis was investigated at the authors’ laboratories (see references 1, 2, 3 and 4 for further details). Compounds of interest were plant-derived bio-molecules like cannabinoids, taxanes, nicotine, caffeine, limonene, betulin, fatty acids and resin acids, steroids and sugars.

One of the “medicinal” plants, popular in the folklore/tradition of indigenous groups of North America Indians (Mohawks, Cherokee) is a milkweed. The natives reportedly, used milkweed as a source of food (flower buds, young shoots and seed pods), fibre and medicine (anti-fertility concoction, warts/ulcer remedy). *Asclepia Syriaca*, a common milkweed, is a North American native, abundant and perennial plant.

It is named for its milky juice and is known to contain alkaloids, latex and several cardenolides (toxins). It grows to a height of approximately 1 metre.

Milkweed leaves are the sole food source of Monarch butterfly larvae. This common wild plant is often grown in gardens by butterfly lovers. The migration of millions of Monarchs (see Figure 1) from Canada to Mexico is a celebrated naturalist event in September every year. Full grown stems of milkweed (see Figure 2) decorate borderlands of creeks, farmers’ fields, pastures, woodlots and roadsides.

Every autumn, the stems contribute to soil humus content by lignin degradation and to atmospheric carbon dioxide by holocellulose oxidation. Milkweed white fibrous filaments from seed follicles have good insulation qualities. In the past, these filaments were contemplated commercially as a hypoallergenic filling for pillows as well as a substitute for kapok fibre.

(Continued on page 17)
Milkweed pyrolysis

...continued

Results

Feed
Milkweed stems with partially empty seed pods were collected from the Waterloo countryside in autumn 2012. Plants were dried and ground to pass through a 1.00 mm sieve. The moisture and the ash were determined as below:
- Moisture - 4.4 wt%, as used;
- Mineral ash - 3.7 wt%, on dry basis.
The ash (grey solids) in water exhibited some solubility/alkalinity - pH ~10.

Pyrolysis
The bench scale, fluid bed continuous fast pyrolysis test was carried out (similar to the one developed for hydrous fast pyrolysis - see Pyne 27, pp. 24-26).
The pyrolysis recovery train consisted of two ice-water condensers, one electrostatic precipitator and one drierite dessicant column. This set up allowed for carrying out a complete material balance.

Under the pyrolysis condition used, two condensates were collected:
1. Aqueous fraction containing most of the stopped/condensed water-soluble-organics. This fraction was analyzed quantitatively by HPLC, K-F, and GC-MS.
2. Oil fraction (water dissolved in organic phase). This fraction was removed with the addition of methanol and evaluated by K-F and GC-MS.

Characterization
Aqueous fraction (24.6 g, Brix=12)
Water - 86.7 wt%
Hydroxycetaldehyde - 2.5 wt%
Acetic acid - 3.1 wt%
Acetol - 2.0 wt%
Glyoxal, levoglucosan, formaldehyde, formic acid and furfural were each also identified in concentrations below 1.0 wt%.

Oil fraction
Oligomeric lignin as water insoluble fraction extracted and contributed to 26.29% by weight of maf feed basis.

The following volatile degradation products and natural waxy and phytochemicals were identified in the oil phase:

Degradation products
- 2-methoxy-4-(1-propenyl) phenol
- 2, 6-dimethoxyphenol
- 4-ethyl-2-methoxyphenol
- 2-methoxyphenol
- 4-methylphenol
- 1, 4-methoxyphenylethanone
- 1, 2-Benzenediolic acid
- 2, 6 dimethyl-3-(methoxymethyl)-p-benzoquinone
- Levoglucosan
- Acetol
- Furfural

Waxy products
- Methyl-9,12-Octadecadienoate
- 9-Octadecenoic acid
- Methyl-7,10-Octadeicadienoate
- 3-(2-pentenyl)-1,2,4-cyclopentane trion,
- 9-Octadecanoic acid
- Hexadecanoic acid
- Hexatriacontane
- 3-butylpentylether
- 1-Hexadecene

Phytochemicals
- Phytosteroids
- Alkaloids
- Tri-terpenes
- Pentacyclic tri-terpenes

The following chemicals with physiological importance for plants, and of potential importance for animals including humans (anti-cancer, anti-tumour properties) were identified. The assignment was based on the GC-MS library match only.
- D:A-Friedo-oleana-3,7-diene
- 5-Acetylpyrimidone
- Caffeine
- 1,1-dicyano-2-Me-3-phenylpropene
- Ergosta-4,6,22-trien-3b-ol
- 2,6-dimethyl-3-(methoxymethyl)-para-benzoquinone
- Taraxasterol
- 6a-hydroxy-14-methyl-5a-cholest-8-en-3-one

Table 1: Selected conditions/parameters of pyrolysis.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>480</td>
</tr>
<tr>
<td>Duration, min</td>
<td>45</td>
</tr>
<tr>
<td>Milkweed feed rate, g/hr</td>
<td>54</td>
</tr>
<tr>
<td>Steam feed rate, g/min</td>
<td>0.5</td>
</tr>
<tr>
<td>Nitrogen, l/min (room tp)</td>
<td>8.5</td>
</tr>
<tr>
<td>Apparent vapour residence time, s</td>
<td>~1</td>
</tr>
</tbody>
</table>

Table 2: Material balance, in wt% on dry ash free basis.

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHAR/solids</td>
<td>18.50</td>
</tr>
<tr>
<td>WATER (pyrolysis water only)</td>
<td>23.27</td>
</tr>
<tr>
<td>ORGANICS (condensed/captured)</td>
<td>39.90</td>
</tr>
<tr>
<td>GAS – includes experimental losses (by difference)*</td>
<td>18.22</td>
</tr>
<tr>
<td>Total above</td>
<td>100</td>
</tr>
</tbody>
</table>

*Mostly carbon dioxide and carbon monoxide.
Milkweed pyrolysis
...continued

Figure 2: Milkweed stems.

Conclusion
Dried, ground milkweed stems upon fast pyrolysis yield more fractions of char and water with lower oil yield than a typical wood pyrolysis. The minerals forming very alkaline ash, 3.7wt%, mf could be the reason for augmented dehydration/carbonization.

Milkweed stems seem to be a good starting material to consider in biochar processing towards potential soil enhancers. Biochars production could be contemplated with expected output rich in minerals and humus-like oligomeric lignin.

By pyrolysis, a variety of phytochemicals were produced. The biological importance of these requires additional, in-depth knowledge.

References

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Together the authors of this article have contributed to more than 200 publications, patents and reviews in the area of pyrolysis.
Fractional catalytic pyrolysis of biomass research at Utah State University

Biomass pyrolysis is a complex thermal process that converts biomass into undefined slate of liquid products, gases, and solids. The liquid product (bio-oils) has been of considerable interest because of its potential as a feedstock for production of liquid transportation fuels. The biochar is also attracting attention because of its potential for soil amendment applications.

The gases for most part have been considered for combustion to fuel the pyrolysis process. Because the bio-oils are unstable, acidic and considerably difficult to process into liquid transportation fuels, a number of upgrading methods have been investigated for stabilizing the oils. These include esterification, post pyrolysis catalytic upgrading, liquid-liquid extraction and gasification. An alternative approach to addressing the bio-oil stability problem is the in situ and ex situ catalytic pyrolysis with the sole aim of producing stable pyrolysis oils that can be easily upgraded to liquid transportation fuels.

At Utah State University, we are continuing with catalytic pyrolysis research that was started at the Virginia Polytechnic Institute and State University, Blacksburg Virginia, USA. This approach, which is called fractional catalytic pyrolysis produces a narrow slate of compounds instead of the large number of compounds produced in the conventional pyrolysis. The catalysts are selected for specific target products. Thus, catalysts are developed to target the hemicellulose component of the biomass, the cellulose component, or the lignin component.

The undesired biopolymer is selectively gasified into non-condensable gases and water. The oils have much lower oxygen content and are immiscible with the aqueous phase. If the condensation train is carefully designed, the pyrolysis products can be fractionated in the condensers with most of the aqueous fraction with a small amount of oil collected in the water/ethylene glycol cooled condensers while almost pure oil (<2% water) can be collected in the electrostatic precipitator.

This process enables you to characterize the properties of the bio-oil without much interference from the aqueous phase. On the other hand the aqueous phase can also be characterized without much interference from the heavy organic phase products. We have developed these processes for various products according to our needs, as well as the needs of (Continued on page 20)
Fractional catalytic pyrolysis of biomass

...continued

various sponsors. Thus we have developed processes for high phenolic oils, high sugar oils, and oils for hydrocarbon fuel production. Examples of some of the processes are highlighted below.

Production of stable biomass pyrolysis oils

One of the most important applications of fractional catalytic pyrolysis of biomass is the production of stable biomass pyrolysis oils. Conventional biomass pyrolysis oils contain heavy fractions that agglomerate with time to increase the viscosity of the bio-oils. However, by applying fractional catalytic pyrolysis, most of the heavy fraction can be broken down into low molecular weight products and the viscosity of the oil lowered considerably. The decomposition of these heavy fractions also increases the pH of the oils and reduces its density. The levoglucosan content is considerably reduced and the oils can be distilled without forming solids or chars.

Additionally, these oils also have lower oxygen content and their calorific values are about 25% higher than those of conventional bio-oils. Because of their relatively low oxygen content, they can be easily upgraded or co-processed with petroleum fluid catalytic cracking feed. These oils have been upgraded on a standalone basis to diesel and gasoline fractions.

A major drawback of fractional catalytic pyrolysis is the production of a considerable amount of non-condensable gases that can be as high as 40 wt% yield. Although these gases are composed of mostly carbon monoxide and carbon dioxide, and low concentrations of low molecular weight hydrocarbons, which can be compressed and used to fuel the pyrolysis process, we discovered that recycling of the gases can increase the yield of the organic liquid fraction.

Thus, the recycling process is an effective means of carbon recovery and thus increasing the overall carbon efficiency of the process. These recycle gases are very effective in lowering the activation energy of the pyrolysis process and thus increasing the process efficiency.

Production of phenolic liquids for adhesives and epoxy novolac

The production of phenolic liquids from biomass pyrolysis requires several liquid-liquid extraction steps to separate the acidic products from the phenols and neutrals. This process is time consuming and the final products can be used in limited applications because of interference from the other pyrolysis compounds. We have developed new catalysts that can be used to target the carbohydrate decomposition products of the biomass and these fractions are converted into non-condensable gases and thus leaving a clean product very rich in phenols.

The liquid product can be used “as is” without any liquid extraction to replace phenol in phenol formaldehyde resins. Our tests showed that we can substitute 95% of phenol in phenol/formaldehyde resins with these pyrolysis products and obtain excellent products. These pyrolysis liquids can also be used as is to produce novolac resins and epoxidized to produce epoxy novolacs with excellent properties. Thus this one step fractional catalytic pyrolysis holds promise for the production of high value products.

Production of anhydrosugars

Instead of functionalizing the catalyst to target carbohydrate polymers and preserving the phenolic moieties, one can target the lignin fraction of the biomass. In this case, the catalyst gasifies the lignin component of the biomass leaving mostly carbohydrate decomposition products that is dominated by levoglucosan monomers and oligomers. We have used this approach to produce levoglucosan-rich pyrolysis oils for further processing to value-added products. This technique can also be used to produce bio-oils of varying viscosities and densities to study the phenomenon of viscosity related ageing of bio-oils.

Our goals now are to develop new catalysts that can be used to refine the biomass pyrolysis products in a one pot operation, and thus reducing the cost producing high value products, and to make biobased products competitive with petroleum derived products.

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NMR methods for product quality diagnostics in bio-oil production

A summary by Klaus Raffelt of Karlsruhe Institute of Technology (KIT) in Germany

During flash pyrolysis, the polymeric structures (mainly lignin, cellulose and hemicellulose) are broken down to a complex mixture of monomeric and oligomeric organics and water. The accurate analysis of the condensate is sophisticated and time consuming; at least three laboratory methods are needed, e.g. Karl Fischer titration for water quantification, fractionated extraction for the pyrolytic lignins and GC for the organic monomers.

On the other hand, for the successful operation of the pyrolysis and gasification units the detailed knowledge of the composition is not necessary and could be constrained to key properties like heat content, viscosity and phase stability. Accomplishing this, the water content and the elemental composition of organic carbon, hydrogen and oxygen are useful parameters.

The low-field NMR approach

One possibility for a quick inline quantification of the water content is to use nuclear magnetic resonance (NMR) methods, a powerful and well known technique for structure determination of organic molecules. In the last few decades, instruments were developed with very high magnetic fields of up to 24 Tesla, which enables excellent signal resolutions and sensibility.

On the other hand high-field NMR is far too expensive for process control and the in-time adjustment of an adequate homogeneous magnetic field is problematic in multiphase pyrolysis product streams. An alternative is provided by cost-efficient low-field NMR using permanent magnets with B<1T. The lower sensibility is no concern due to the strong water singlet in the NMR spectrum. The lower resolution can partly be balanced by a thorough calibration using multivariate mathematical analyses.

Alternatively to the spectral distinction by the chemical shift, water can be quantified by measuring the signal relaxation behaviour and referring it to the relaxation in calibration systems. The promising relaxation methods are described in detail in the scientific literature. Here, we present the application of the so-called Medium Resolution NMR (MR-NMR) system. The spectrometer was developed by Bruker GmbH (Rheinstetten, Germany).

A bandwidth of 3.1 kHz was used during data acquisition of the free induction decay (FID) of one pulse sequence, which was more than enough to catch all 1H signals in the sample, making a quantitative analysis possible. The measured spectra were processed with a self-written Matlab script of the working group of Gisela Guthausen (KIT, Karlsruhe, Germany). The calibration model was obtained by partial least-squares regression (PLS-R). The results from the Karl Fischer titration were used as reference values.

Water quantification by HR-NMR is sensible to operational errors (initial weight of sample and reference, phase- and baseline correction of the NMR spectrum, broad overlapping of signals at low intensity if the magnetic field is not optimally homogenized). If the processing is done correctly, the integrals of the NMR signals are directly proportional to the molecule concentration. But in the case of water an additional important systematic error has to be considered - the hydrogen atoms in the sample exchange quickly with hydrogen.

(Continued on page 22)
NMR methods for product quality diagnostics in bio-oil production...continued

Figure 2: **Left:** Medium-resolution spectrum (20 MHz) of a pyrolysis oil of beech wood with a water content of 36.5%. Water quantification by PLS-R. **Right:** High resolution spectrum (400 MHz) of a highly organic fraction of pyrolysed eucalyptus wood with very low water content (2.7%). Water quantification by mixing a weighted sample with a known amount of reference substance (TMSP sodium salt) in an excess of deuterated methanol, and additionally comparison with a calibration curve (see the black line in Figure 3).

Water quantification from the MR-NMR Spectra by direct signal integration is not possible due to signal overlapping. Therefore chemometric methods need to be used, in this case PLS-R was applied. Once the preliminary calibration has been done with appropriate reference samples, an automated water analysis can be carried out by appropriately adapted software. The addition of an accurately weighed reference is not necessary because the PLS-R compares the water-region of the proton spectra with the organic regions and relates it to the Karl-Fischer values.

To ensure reproducibility of signal intensities the receiver gain of the detector was adjusted by pure water. In the 5th order PLS-R the sample weight and the filling level of the measurement tubes were taken into account at 500 iteration steps. Validation was made by cross validation and also by a test-set, both leading to errors of less than 2% compared to the Karl-Fischer titration results. Although the information density of high field NMR is significantly higher than in the medium field NMR, the latter is superior in the case of water quantification, even if high field NMR is combined with chemometry. As the medium field method is considerably cheaper in equipment procurement and

(Continued on page 23)
**NMR methods for product quality diagnostics in bio-oil production...continued**

Table 1: Typical properties of the examined pyrolytic liquids.

<table>
<thead>
<tr>
<th>Condensates obtained at 20°C after separation of the higher boiling species (&gt;100°C), diverse biomass origin.</th>
<th>Condensates obtained at 20°C after separation of the higher boiling species (&gt;100°C), diverse biomass origin.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water / wt.%</td>
</tr>
<tr>
<td></td>
<td>45 - 95</td>
</tr>
<tr>
<td>Light phase after storage of beech wood tar.</td>
<td>Light phase after storage of beech wood tar.</td>
</tr>
<tr>
<td></td>
<td>30 - 45</td>
</tr>
<tr>
<td>Heavy phase after storage of beech wood tar.</td>
<td>Heavy phase after storage of beech wood tar.</td>
</tr>
<tr>
<td></td>
<td>3 - 12</td>
</tr>
</tbody>
</table>

Table 2: Comparison of the quality of water quantification by NMR at different magnetic fields (different proton frequencies). The errors of validation and prediction are lower at medium field (20 MHz) than at high field (250 and 400 MHz).

<table>
<thead>
<tr>
<th>NMR-field (frequency)</th>
<th>Evaluation of the PLS-R model</th>
<th>RMS (root mean squares)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deviation from regression</td>
<td>Error of validation</td>
</tr>
<tr>
<td>400 MHz-spectrometer</td>
<td>Cross validation</td>
<td>4.007</td>
</tr>
<tr>
<td>250 MHz-spectrometer</td>
<td>Test-set validation</td>
<td>2.215</td>
</tr>
<tr>
<td>20 MHz-spectrometer</td>
<td>Test-set validation</td>
<td>0.990</td>
</tr>
</tbody>
</table>

maintenance, and also less time-intensive in sample preparation, a future development for a flow cell and automated water quantification in the condensation part of a pyrolysis plant is an interesting option. This could provide the operators of the pyrolysis facility with quick and considerably accurate data of process conditions and product quality.

As a next step it should be examined which additional information can be extracted from the MR-NMR spectra. Also, for example, the lignin content should be able to be modelled by PLS-R, but so far it is not certain if the sensitivity is enough, as the aromatic part of the spectrum (6-8 ppm in Figure 2) shows low signal intensity and the foothill of the water signal at 5 ppm still influences the aromatic region. As a potential hindrance it should also be examined to what extent solid (char) contamination lowers the quality of the spectrum interpretation bearing in mind that the separation efficiency of the hot cyclones is typically not 100%.

**Reference**


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Biomass to diesel through pyrolysis: an update

Pyrolysis liquid from biomass (PL), which has approximately 70% of the carbon from the biomass going into the bio-oil, can be an interesting feedstock for petroleum refineries. The main problem related to PL however is its high coking tendency. The use of catalysts to improve the physical and chemical properties of such liquids upstram of the refinery is an active area for RD&D.

For more than a decade and together with Groningen University (Netherlands) and Boreskov Institute of Catalysis in Novosibirsk (Russia), BTG has been developing a catalytic hydrotreating process to improve relevant properties of such pyrolysis liquids. The products are referred to as ‘Stabilized Pyrolysis Oil (SPO)’, ‘Cracked Pyrolysis Oil - CPO’ (further low-oxygen products), and oxygen-free ‘Mixed Transportation Fuels (MTF)’. Further details and results are shown in Figure 1.

PL comprises fractions from the lignins and ‘carbohydrates’ derived from the cellulosic fractions. In the approach undertaken the low-temperature induced ‘carbohydrate’ chemistry is physically separated from a high temperature lignin chemistry. Dedicated Picula™ catalysts have been developed and further optimized for this purpose. This family of these Picula™ catalysts comprises high active metal loaded catalysts based on Nickel. A conventional catalyst can subsequently be applied to convert the SPO at either atmospheric FCC operations (co-feed), or at high pressures in a subsequent deoxygenation - cracking step. A general process scheme is shown in Figure 1. SPO (with oxygen content >10 wt.%daf) is produced at reduced temperatures, which can be further converted over conventional catalysts (such as NiMo – CoMo) to CPO. This second deoxygenation step requires higher temperatures (from 325°C yielding a residual oxygen content <10 wt.%daf). If preferred the CPO can be further deoxygenated to yield a mix of hydrocarbons (MTF) at even higher temperatures.

A mechanistic view is shown in a Van Krevelen plot (Figure 1) where the molar ratio of O/C is plotted against the molar ration of H/C for the products on a dry basis. The different products derived from different process conditions are indicated. Two regions can be distinguished. The first is a stabilization regime where (Continued on page 25)
Biomass to diesel through pyrolysis

...continued

liquids to MTF are hydrogenation (low temperatures <200°C), dehydration of the alcohols (intermediate temperature range 200-300°C) and a further (hydro) cracking – deoxygenation of the lignitic materials at the high temperature range (>300°C). Chemically the stabilization as well as deoxygenation reactions mainly affect first the functionality of the oxygen in the pyrolysis liquid and then the oxygen content in the following sequence: (i) reactive groups (mainly aldehydes) are transformed into alcohols, followed by (ii) dehydration of the alcohols towards carbonyls and olefins and finally (iii) deoxygenation of the more stable components (such as phenols, diphenylethers and benzofuranics (see also Figure 1) to obtain the hydrocarbons.

The CPO and MTF are completely distillable below 400°C; the MTF is a product with physical (smell, colour) and chemical (SimDis, FTIR and 2D-GC) properties similar to fossil fuels. A picture for the different samples is shown in the insert in Figure 3. The colour of the product obtained strongly depends on the severity of the process applied, providing a good indication of the residual amount of oxygen remaining in the product.

Functional groups in the pyrolysis liquids and products derived thereof can be distinguished in FTIR analysis, and going from pyrolysis liquids to stabilized oils - and finally to oxygen-free liquids - a clear transition is noted from the typical pyrolysis liquid components to alcohols and then further to aliphatic C-H groups (3000 - 2800 cm⁻¹).

The similarity between the final MTF and conventional diesel is striking (see Figure 2). A typical 2D-GC plot (prepared by the University of Groningen) for the oxygen-free MTF clearly shows a broad band of aromatics, cyclohexanes and alkanes. FTIR and 2D-GC data for the PL and intermediates SPO and CPO also show a smooth transition towards the hydrocarbons.

A further proof of principle for the proper MTF product properties is shown by demonstrating fuel mixtures (up to 75% replacement) in a commercial 5 kW diesel aggregate (diesel electrical generator), and in a 100 km test trial in a JCB Workmax Utility.

(Continued on page 26)
Terrain Vehicle (UTV); see Figure 3. Similar emissions level (CO; NO\textsubscript{2}; O\textsubscript{2}; CO\textsubscript{2} and hydrocarbons) and fuel consumptions (g/km) are reported for diesel: MTF mixtures (50:50 and 75:25).

So far hundreds of continuously operated experiments (24 h/7 d) have been carried out in 100 ml and 2 L volume packed bed systems (oil flow rates from 40 ml/h to 4 L/h), at catalyst testing stream times up to 500 h for both the stabilization and the deoxygenation step. Overall carbon yields (biomass to MTF) are in the order of 40 to 50%. Further work will be focused on an optimization of the (Picula\textsuperscript{TM}) catalysts for stabilization and on improving the overall carbon-to-oil yields.

More information and informative videos are provided on the BTG website www.btgworld.com.

**Acknowledgement**

The work described here is a summary of work carried out over a period of more than ten years in a framework programme supported by the Dutch government, European and local funds. The author would like to acknowledge the EU for partial funding of the work through the 6th Framework Programme (Contract Number: 518312), AgentschapNL (CORAF-project no. EOSLT04018, NEO-project, no. 0268-02-03-0001; GAP-project no. BIORF01016), the Province of Overijssel and Twente University (BE2.O project).

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Fast pyrolysis processing of rape straw from Spain

Large amounts of residual straw are generated every year and this waste can be a potential resource for chemicals production and energy generation. Thermal conversion of the straw can provide useful products and helps to reduce waste accumulation. Agricultural residues can be processed by thermochemical conversion including pyrolysis, gasification and combustion.

Aston University bioenergy researchers with the collaboration of engineers from University of Leon, Spain investigated the impact of pyrolysis temperature on the quality of rape straw fast pyrolysis derived bio-oil. The rape straw was delivered from Villaturiel, Province of Leon (Spain). Biomass was characterised using a wide range of analytical techniques including thermogravimetric analysis (TGA) and analytical pyrolysis (Py-GC-MS). Bio-oil was produced using a 1 kg/h fast pyrolysis reactor.

The experiments were carried out at four different reaction temperatures (450, 480, 510 and 550°C). Bio-oil quality was defined by its stability measured by a viscosity index, a water content index and analysis of phase separation. The normalised fast pyrolysis mass balances are shown in Figure 2. This clearly shows the differences in pyrolysis yields between different pyrolysis temperatures. The organic liquid yield was highest for rape straw processes at 450°C.

The properties of the bio-oil are affected by feedstock variation, production processes, reaction conditions, and collecting. In this study, all experiments were carried out under the similar conditions, and the only exception was the pyrolysis temperature. It was found that the bio-oil produced at 450 and 480°C was a single-phase product. Phase separation occurred when rape straw was pyrolysed at 510 and 550°C. Figure 3 shows the percentage of each phase depending on the pyrolysis temperature.

(Continued on page 28)
Fast pyrolysis processing of rape straw from Spain...continued

For the purpose of measuring bio-oil stability, accelerated storage tests were performed at 80°C for 24 h, which is claimed to simulate degradation at ambient temperatures for one year. The whole bio-oil from the 450 and 480°C runs and the heavy fraction from the 510 and 550°C runs were assessed for stability. Figure 4 shows the results for phase separation after the accelerated storage experiment.

**Conclusions**

- Pyrolysis temperature impacts the bio-oil quality and stability. Fast pyrolysis processing of rape straw up to 480°C gives the highest organic yield with a single-phase bio-oil with a low water content.
- Accelerated storage experiment revealed that rape straw bio-oil undergo phase separation during long storage, thus this type of bio-liquid should be used or upgraded immediately after its production.

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International Events

JULY 2013
3rd-5th
Bioenergy China
Beijing, China

22nd-28th
Catalysis for Renewable Sources: Fuel, Energy, Chemicals
Lund, Sweden

SEPTEMBER 2013
3rd-5th
International Conference on Polygeneration Strategies
Vienna, Austria

3rd-6th
tcbiomass2013
Chicago, USA

4th-6th
Bioenergia - Bioenergy Exhibition and Conference
Jyväskylä, Finland

9th-11th
Asia Pacific Clean Energy Summit and Expo
Honolulu, Hawaii

11th-12th
Biofuels International Conference
Antwerp, Belgium

23rd-26th
EPNOE International Polysaccharide Conference
Nice, France

25th-26th
Lignofuels
London, UK

30th September - 4th October
Sardinia 2013 - 14th International Waste Management & Landfill Symposium
Cagliari, Italy

30th September - 2nd October
EFIB 2013
Brussels, Belgium

OCTOBER 2013
7th-11th
ISWA World Congress 2013
Vienna, Austria

8th-10th
Biotechnica 2013 Marketplace Industrial Biotechnology
Hannover, Germany

16th-18th
International Seminar on Gasification
Göteborg, Sweden

NOVEMBER 2013
6th-7th
Gasification
London, UK

7th-9th
Wood Science and Engineering in the 3rd Millennium
Brasov, Romania

20th-21st
Bioenergy Commodity Training
Brussels, Belgium

MARCH 2014
11th-13th
International Bioenergy Conference
Manchester, UK

MAY 2014
19th-23rd
Pyro 2014
Birmingham, UK

22nd-23rd
REGATEC 2014 - Renewable Energy Gas Technology
Malmö, Sweden

JUNE 2014
3rd-5th
World Bioenergy 2014
Jönköping, Sweden
Biofuels Research Infrastructure for Sharing Knowledge

Are you interested in thermal biomass conversion and biofuels; and using the facilities of leading European laboratories?

BRISK provides access to a wide variety of research facilities at the project partners (see Table below) via Transnational Access. This allows researchers to conduct experiments at facilities in other laboratories.

Any researcher can apply to go to any of the project partners located outside of their home country to utilize the facilities. BRISK will pay for facility access costs along with a grant for travel and subsistence for those researchers based in an eligible country.

BRISK aims to improve the rate of development and success of biofuels implementation by integrating research facilities in the European scientific community. This will foster a culture of cooperation and lead to new activities across the whole of the European region.

Please visit the BRISK website www.briskeu.com for details of how to apply for Transnational Access.

<table>
<thead>
<tr>
<th>Partner (Acronym)</th>
<th>Location</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>KTH</td>
<td>Sweden</td>
<td>Combustion, Gasification</td>
</tr>
<tr>
<td>Åbo Akademi</td>
<td>Finland</td>
<td>Characterisation, Pyrolysis</td>
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<tr>
<td>Arris BEH4</td>
<td>UK</td>
<td>Analysis, Characterisation, Fast pyrolysis, Upgrading bio-oil</td>
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<tr>
<td>BIOENERGY 2020+</td>
<td>Austria</td>
<td>Aromatics, Analysis, Combustion</td>
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<td>Cardiff University</td>
<td>UK</td>
<td>Combustion, Spray cell, Turbine simulation</td>
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<tr>
<td>DERITHE</td>
<td>Greece</td>
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<td>CIUDEN</td>
<td>Spain</td>
<td>Gasification</td>
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<tr>
<td>TU Delft</td>
<td>Netherlands</td>
<td>Analysis, Characterisation, Combustion, Fuel cell, Gasification</td>
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<td>ECN</td>
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<td>ENEA</td>
<td>Italy</td>
<td>Gasification, Hydrogen</td>
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<td>ETC Piteå</td>
<td>Sweden</td>
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<td>TU Graz</td>
<td>Austria</td>
<td>See BIOENERGY 2020+ for further information</td>
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<td>NERCO</td>
<td>Spain</td>
<td>Transnational access through CIUDEN</td>
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<td>IFFR</td>
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<td>NTNU</td>
<td>Norway</td>
<td>Biofuel synthesis</td>
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<tr>
<td>FALL F</td>
<td>Germany</td>
<td>Transnational access through Delft University of Technology</td>
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<td>Paul Scherrer Ins</td>
<td>Switzerland</td>
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<td>SINTEF</td>
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<td>TUBITAK</td>
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<td>UNINA Naples</td>
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<td>Pyrolysis</td>
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<td>TU Vienna</td>
<td>Austria</td>
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<td>TU Wrocław</td>
<td>Poland</td>
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<tr>
<td>U. Zaragoza</td>
<td>Spain</td>
<td>Gasification, Hydrothermal processing</td>
</tr>
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</table>
Pyrolysis 2014

We cordially invite you to participate in the 20th International Symposium on Analytical and Applied Pyrolysis to be held at the Birmingham City Centre Holiday Inn in the United Kingdom. The conference will cover the latest results in all areas of pyrolysis and related thermal processes and will attract a wide range of researchers from academia and industry.

Topics

1. Analytical pyrolysis (including biomass, polymers, etc.)
2. Applied pyrolysis (including biomass, polymers, waste, bio-oils, biochar, etc.)
3. Catalysis in pyrolysis
4. Pyrolysis kinetics and mechanisms
5. Reactive pyrolysis

Scientific Committee

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Franco Berruti</td>
<td>Dietrich Meier</td>
</tr>
<tr>
<td>Marianne Blazso</td>
<td>Hajime Ohtani</td>
</tr>
<tr>
<td>Robert Brown</td>
<td>Wolter Prins</td>
</tr>
<tr>
<td>Doug Elliott</td>
<td>Clemens Schwarzinger</td>
</tr>
<tr>
<td>Daniele Fabbri</td>
<td>Kent Voorhees</td>
</tr>
<tr>
<td>Robert Helleur</td>
<td>Tom Wampler</td>
</tr>
</tbody>
</table>

Organising Committee

Chairman
Tony Bridgwater: a.v.bridgwater@aston.ac.uk
Bioenergy Research Group,
European Bioenergy Research Institute,
Aston University, Birmingham, B4 7ET

Local organization
Emma Wylde: e.wylde@aston.ac.uk
Tel: +44 121 204 3438

Registration

<table>
<thead>
<tr>
<th></th>
<th>Early Bird</th>
<th>After 01 April 2014</th>
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</thead>
<tbody>
<tr>
<td>Regular</td>
<td>£550</td>
<td>£650</td>
</tr>
<tr>
<td>Student</td>
<td>£425</td>
<td>£525</td>
</tr>
<tr>
<td>Accompanying Person</td>
<td>£140</td>
<td>£160</td>
</tr>
</tbody>
</table>

Sponsorship

Sponsors and hardware vendors are welcome and will be offered an attractive conference package. For details please enquire with: e.wylde@aston.ac.uk

Important dates

- Abstract submission: 01 Feb 2014
- Early bird registration: 31 March 2014
- Conference: 19-23 May 2014

www.pyro2014.co.uk
Publications

**Fuel Oil Quality and Combustion of Fast pyrolysis Bio-oils**
Published by VTT.
Publication date: March 2013.
Authors: Jani Lehto, Anja Oasmaa, Yrjö Solantausta, Matti Kytö, David Chiaramonti.

**Sustainable Chemistry Engineering** - Volume 1, Issue 4.
Published by ACS Publications.
Publication date: April 2013.
Within this journal is the following paper:
*Hydroprocessing Bio-Oil and Products Separation for Coke Production*.
Authors: Douglas C. Elliott, Gary G. Neuenschwander, Todd R. Hart.

**Renewable & Sustainable Energy Reviews** - Volume 20.
Published by Elsevier.
Publication date: April 2013.
Within this journal is the following paper:
*State-of-the-art of fast pyrolysis in IEA bioenergy member countries*.
Authors: Dietrich Meier, Bert van de Beld, Anthony V. Bridgwater, Douglas C. Elliott, Anja Oasmaa, Fernando Preto.

**Virtual Special Issue on Biomass, Biodiesel and Bio-Ethanol**
Published by Elsevier.
This includes recent review articles published in Elsevier's key energy journals, including: Biomass and Bioenergy, Bioresource Technology, Fuel, Fuel Processing Technology, Progress in Energy and Combustion Science and Renewable Energy.

**Biomass Combustion Science, Technology and Engineering**
Edited by Lasse Rosendahl.
Published by Woodhead Publishing.
Publication date: April 2013.
Within this journal are the following papers:
- Fast pyrolysis of biomass for the production of liquids.
  Author: Anthony V. Bridgwater, Aston University, UK.
- Intermediate pyrolysis of biomass.
  Author: Andreas Hornung, Aston University, UK.

**Technologies for Converting Biomass to Useful Energy**
Combustion, Gasification, Pyrolysis, Torrefaction and Fermentation.
Edited by Erik Dahlquist.
Published by CRC Press, Taylor and Francis Group.
Publication date: April 2013.
Video links

Click on the links below to activate the relevant video clips.

90 Seconds of Discovery - Fast Pyrolysis (English)
A summary by PNNL, USA

Bioenergy in Ov (English)
This video overviews the multidisciplinary research into biomass conversion at the University of Twente in the Netherlands. It covers the development of mobile torrefaction equipment and a flash pyrolysis plant.

Diesel from Pyrolysis Oil (Dutch)
Produced by BTG (Biomass Technology Group) in the Netherlands.

BTG’s Fast Pyrolysis Process (English)
Within this process solid biomass is reformed in a rotating cone in the absence of air to pyrolysis oil.

LinkedIn

Did you know there are a number of biofuel-related groups on LinkedIn where members can start a discussion and share information/news with the group? Here is a selection:

- Biomass Pyrolysis (969* members)
- Biofuels (6,462* members)
- Biomass to Energy (10,344* members)
- Biomass Combustion and Co-firing GVB (231* members)
- Biomass, Bioenergy and Biofuels (1,570* members)
- World Bioenergy Association (522* members)
- Bioenergy, by Biofuels Digest (7,199* members)

* figures as at 18/06/2013
If you require further information about the PyNe newsletter, or you would like to contribute to future editions, please contact the Editor:

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Past editions of PyNe newsletters are available on the website.