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Task 34 Pyrolysis
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### Inside this issue

# *Welcome to Task 34*

### *By Doug Elliott, Task 34 Leader*

The IEA Bioenergy Task 34 for Pyrolysis is hard at work in the new triennium from 2010 to 2012. Current participants in the Task are Canada, Finland, Germany, the 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 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 and an overview of the latest Task meeting including information about the Round Robin on bio-oil viscosity and aging.

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# Welcome...continued

Also, there are several articles from around the world describing the latest developments in fast pyrolysis including work in Finland at Åbo Akademi University and at VTT. From the USA we have a contribution from Utah State University, an overview of the new catalytic pyrolysis (in hydrogen) technology from the Gas Technology Institute (GTI), plus news about a USA/ South African collaboration.

There's also an article from Envergent Technologies in Canada, and an update from the Energy research Centre of the Netherlands about IEA Bioenergy Task 42. From the UK, there's an overview of a biorefinery chain methodology, plus an article regarding lignin pyrolysis testing at different temperatures. On pages 28-31 you can find a useful summary of reviews on biomass pyrolysis and related aspects.

This electronic newsletter is published twice a year. Comments and suggestions for future input are invited: please contact the editor, Irene Watkinson at i.i.watkinson@aston.ac.uk.

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# Envergent Technologies and Ensyn demonstrate renewable liquid fuel for heat and power at Crane & Co

*An update from Stefan Müller of Ensyn Technologies*

In February 2011, Envergent Technologies, a Honeywell company, announced that its RTP™ technology will be used by Crane & Co. to convert biomass feedstock into a renewable fuel oil to heat and power the Crane Massachusetts facility where it produces paper for USA currency.

Envergent's RTP™ (Rapid Thermal Processing) Technology will convert local forest residue into a clean-burning, nearly carbon-neutral liquid biofuel that can be used as a direct replacement for petroleum-based fuel in today's burners and generators.

Envergent Technologies is a joint venture of Honeywell's UOP and Ensyn Corporation. It combines nearly 100 years of refining and process technology development from UOP, and more than 25 years of biomass conversion technology experience from Ensyn Corp.

Use of the technology will help Crane, which has been the provider of currency paper to the U.S. Treasury for more than 130 years, stabilize energy costs and remain a competitive supplier to the US Government. Once approved, the project has the potential to bring nearly 100 new green jobs to the region.

In addition to Envergent Technologies, Crane & Co. is working with Berkshire Renewable Power and ReEnergy Holdings for implementation of the project. All the partners involved hosted a demonstration of the process at Crane & Co's. headquarters in Dalton, Massachusetts on February 24th.

> *"It will serve as an excellent model for other businesses across the nation and around the world."*
>
> David Cepla
> Managing Director
> Envergent Technologies

**Continued on page 4**

# Envergent Technologies and Ensyn demonstrate renewable liquid fuel for heat and power at Crane & Co...continued

"For more than two centuries, Crane & Co. has worked to innovate at the highest level while keeping our environmental impact at a minimum," said Charles Kittredge, CEO of Crane & Co. "With the addition of this technology from Envergent and the participation of ReEnergy Holdings and Berkshire Renewable Power, we can better fulfil this promise with a reliable, sustainable fuel source that keeps us competitive in the marketplace, delivers a superior-quality product to our customers and stimulates our local economy."

"To have one of the oldest and most important companies in American history take such a leading position by using renewable fuel oil from RTP for its energy needs speaks of the incredible benefits this technology provides," said David Cepla, managing director for Envergent Technologies. "The success of Crane & Co. and its local partners with RTP will serve as an excellent model for other businesses across the nation and around the world."

Because the forest residues to be converted into the renewable liquid fuel will come from the region, Crane's use of renewable power can be thought of as an extension of a larger regional initiative called "Berkshire Grown," which aims to stimulate the area by creating, growing and buying all products locally.

RTP technology works by rapidly heating biomass – in this case, forest residue - at ambient pressure to generate high yields of a liquid biofuel. The fuel can be burned in industrial burners and furnaces for heat, or to power electric generators. RTP is currently in use in seven commercial biomass processing plants in the USA and Canada.

Wholly owned by Honeywell, UOP equipment can be found in the majority of petroleum refineries worldwide. 60% of the world's gasoline is produced in UOP equipment and UOP engineers have generated thousands of patents covering process technology and equipment design.

In 2006, UOP formed its Renewable Energy & Chemicals division to develop ways to efficiently and profitably convert biological feedstocks into more valuable, environmentally friendly biofuels and chemicals.

This powerful partnership combines Ensyn's RTP technology that converts wood biomass to high yields of light liquid with UOP's technology to provide engineering and support for RTP projects worldwide, and to upgrade RTP fuels to transportation fuels.

Ensyn and Envergent have announced four RTP projects to date, including projects in Malaysia, Italy, Canada (Alberta) and this initiative in Massachusetts.

Learn more about Ensyn at www.ensyn.com and about Envergent Technologies at www.envergenttech.com.

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# USA - South African Collaboration on Combustion-Reduction Integrated Pyrolysis System (CRIP)

*Akwasi Boateng (above) of the United States Department of Agriculture (USDA) provides an overview of a joint project with Mike Heydenrych (below) of the University of Pretoria in South Africa*

The Agricultural Research Service (ARS), the principal intramural research arm of the United States Department of Agriculture (USDA), and University of Pretoria, South Africa, have entered into a Non-funded Cooperative Research Agreement (NFCA) for two years (ending July 31st 2012) to develop an energy self-sufficient pyrolysis system for the production of renewable bio-crude.

The collaboration is to explore some existing twin-bed gasifier designs in South Africa for catalytic pyrolysis to produce fuels and chemicals. Dr. A.A. (Kwesi) Boateng of ARS, who has demonstrated experience in the design of similar systems, and Professor Mike Heydenrych of the Department of Chemical Engineering at University of Pretoria (UP), with synergic experiences, are the collaborators on this project.

In a visit to UP in July through to August 2010, Kwesi and Mike completed a design for a 20 kg/hr Combustion-Reduction Integrated Pyrolysis System (CRIPS) which is currently under construction in South Africa, and is expected to be operational in the summer of 2011. In the meantime, a cold flow model of CRIPS is also under construction at the ARS lab near Philadelphia to study the hydrodynamics of the system.

Professor Mike Heydenrych is supported in part by the Pulp & Paper Manufacturing Association of South Africa (PAMSA), which has provided funds and sponsored graduated students (1 PhD and 3 MS) to carry out pyrolysis studies under his guidance. The ARS project is part of research funded by USDA and entitled "Distributed scale pyrolysis of agricultural biomass for production of refinable crude bio-oil and valuable co-products," for which Kwesi is the lead scientist. http://www.ars.usda.gov/main/site_main.htm?modecode=19-35-57-00

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USDA United States Department of Agriculture

# *Task 34 Pyrolysis meeting*

## *Hamburg, Germany*

## *April 6-8, 2011*

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

*Figure 1: Left to right: Steffen Krzack, Daniel Nowakowski, Irene Watkinson, Paul de Wild, Anja Oasmaa, Fernando Preto, Dietrich Meier, Doug Elliott, Tony Bridgwater.*

> *"An important outcome of the meeting was the organization of an extension to the Round Robin analysis of bio-oil samples."*

All National Team Leaders (NTLs) were present for the recent meeting of the Task 34 on Pyrolysis. The agenda items included country reports and formulation of a plan to publish the information; norms and standards developments and discussion of publication efforts for information on sulfur/nitrogen analysis and bio-oil transport and infrastructure issues, as well as an improved Material Safety Data Sheet (MSDS) for bio-oil; and the status of the Round Robin on bio-oil viscosity and thermal stability.

An important outcome of the meeting was the organization of an extension to the Round Robin analysis of bio-oil samples for viscosity and thermal aging to extend a portion at some of the study at some of the labs for a full year. The list of participants in the initial Round Robin includes 15 laboratories in the five participating countries. The bio-oil samples were being distributed by CanMet with the expectation that the results will be received by the time this newsletter is published in June.

The group also toured the biomass pyrolysis laboratories of Dr. Meier at the Johann Heinrich von Thünen-Institut for Wood Technology and Biology at the University of Hamburg. Most of the members also took part in a study tour to the PyTec ablative fast pyrolysis pilot plant.

The next meeting of the Task is scheduled for October 3-4, 2011, in Richland, Washington, USA, including a tour of the Pacific Northwest National Laboratory pyrolysis and bio-oil upgrading laboratories.

**Doug Elliott**
**Task 34 Leader**

# The greenhouse gas emission saving of logging residue-based pyrolysis oil

*A synopsis from Reetta Sorsa of VTT Technical Research Centre of Finland*

> *“The emissions from changes in soil carbon stocks, due to raw material harvesting, is one of the most critical issues to be dealt with in the use of logging residues.”*

The greenhouse gas emission saving of pyrolysis oil was calculated by following the method provided in the European Union’s (EU) Renewable Energy Directive (RED) [1]. The RED establishes a mandatory target to increase the use of renewable energy sources in final energy consumption to a level of 20%, and in transportation to a level of 10%, within the EU by 2020. In addition, the RED introduces the first ever mandated method to calculate the greenhouse gas (GHG) emissions of biofuels and bioliquids, and the GHG emission reduction compared with fossil fuels. The emission reductions should be at least 35% for biofuels and other bioliquids produced before the end of 2016. From the beginning of 2017, the target increases to 50% and from the beginning of 2018 to 60% for biofuel production installations where production begins after 1st January 2017. The above mentioned emission reduction targets have to be achieved in order for biofuels and bioliquids to be accounted for renewable energy targets and to benefit from subsidies.

The pyrolysis oil was assumed to be produced in a fast pyrolysis reactor integrated with a combined heat and power production (CHP) plant. The CHP plant provides heat for the district and the pyrolysis reactor, and power to the electric grid. The boiler is fuelled with logging residue chips and milled peat, which is a typical fuel in co-firing in Finland. The share of logging residue chips was varied between 0% and 100% in order to assess how boiler fuels affect GHG emissions of pyrolysis oil. In addition, a case study where the CHP plant is only fuelled by logging residues was carried out. The fuel capacity of the CHP plant was calculated to be 96 MW, and the electricity and heat outputs correspond to 27 MW and 54 MW respectively [2]. Pyrolysis oil was assumed to replace heavy fuel oil in heat production.

The raw material for pyrolysis oil was assumed to be logging residues from boreal Scots pine and spruce forests. The emissions from changes in soil carbon stocks, due to raw material harvesting, is one of the most critical issues to be dealt with in the use of logging residues. When residues are harvested, the soil carbon stocks reduce compared to the reference situation (the decomposition of logging residues at the site). When logging residues are combusted carbon is released instantly. If logging residues are left on the site, the carbon would still have been released to the atmosphere through decomposition but over a much longer period of time. The difference in carbon contents released to the atmosphere between bioenergy utilisation and reference situation can be considered as indirect emissions [3]. To find out the effect of these emissions, three different scenarios were calculated. Firstly, we excluded soil carbon changes. Secondly, we calculated them using 20 and 100 year time frames.

The system boundaries were set in accordance with the framework given in the RED.

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# The greenhouse gas emission saving of logging residue-based pyrolysis oil...continued

However, the RED leaves room for setting system boundaries and select parameters differently. All the possible interpretations were considered. With the information provided in the RED, we could not determine whether or not logging residues should be classified as 'residues or wastes'. Thus, the system boundary was divided in two parts (Figure 1). If raw materials are classified as 'residues or wastes' they are considered to have zero lifecycle GHG emissions up to the collection of raw materials. The RED also determines that the unit of analysis for the purposes of allocation is the refinery if the fuels are produced in a refinery [1].

However, according to the particular definition it is unclear whether the pyrolysis reactor and the CHP plant should be assumed to be two separate units or one combined refinery. Therefore, we considered both options. Case 1 covers two separate units, and case 2, one combined refinery.

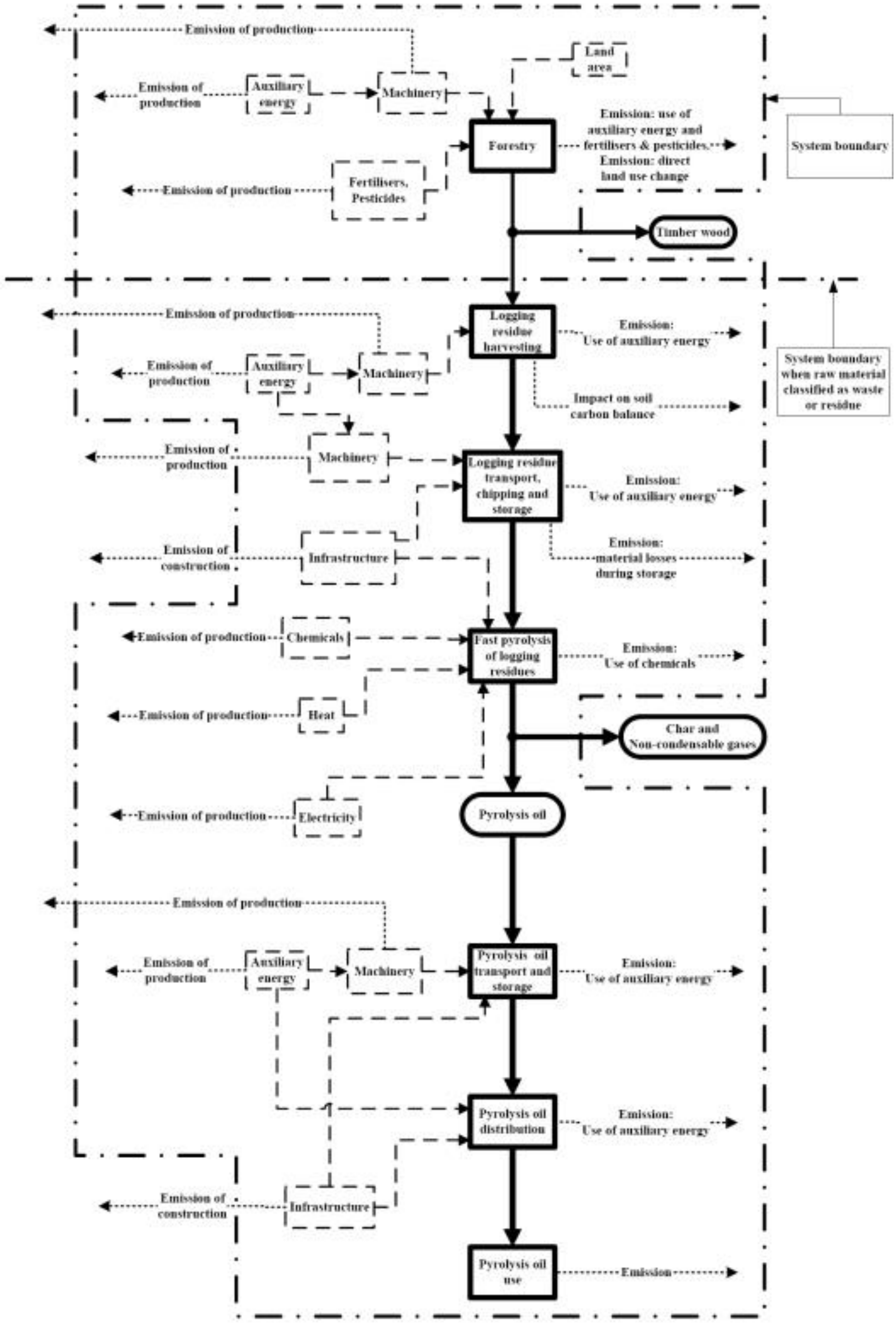

*Figure 1: System boundary according to the Renewable Energy Directive (RED)*
*• denotes allocation*

In-house data of VTT Technical Research Centre of Finland was

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# The greenhouse gas emission saving of logging residue-based pyrolysis oil...continued

used for the process parameters of the pyrolysis reactor. All the other parameters were gathered from literature sources. Firstly, we determined the best estimates for each of these parameters. Secondly, we determined confidential levels and probability distributions for each parameter. The uncertainty analysis was then carried out using a Monte Carlo simulation [4]. When calculating the GHG emission reductions, heavy fuel oil in heat production was used as a fossil comparator. The contribution of each variable to the emission saving result was measured using Spearman's rank correlation.

***Table 1***
*The probabilities of achieving 35%, 50%, and 60% emission savings. "1" refers to case where pyrolysis reactor and CHP plant were assumed to be two separate units and "2" refers to case where pyrolysis reactor and CHP plant were assumed to be one combined unit. Letters "a", "b", and "c" refer to the consideration of changes in soil carbon balances (a=excluded, b=100-year time frame, c= 20-year time frame). Bio-CHP refers to the case where the boiler is fuelled by logging residue chips.*

| RED | | | | | | | Bio-CHP | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1a [%] | 1b [%] | 1c [%] | 2a [%] | 2b [%] | 2c [%] | 1a [%] | 1b [%] | 1c [%] | 2a [%] | 2b [%] | 2c [%] |
| **35%** | 100 | 100 | 99 | 48 | 38 | 4 | 100 | 100 | 100 | 100 | 100 | 78 |
| **50%** | 100 | 100 | 51 | 30 | 19 | 0 | 100 | 100 | 78 | 100 | 100 | 17 |
| **60%** | 100 | 100 | 6 | 18 | 10 | 0 | 100 | 100 | 23 | 100 | 100 | 1 |

Table 1 shows the probabilities of achieving 35%, 50%, and 60% emission saving. Consideration of the pyrolysis reactor and the CHP plant as two separate units or one combined refinery has a significant impact on the results. However, the difference gets lower when the proportion of peat in the CHP decreases. In addition, consideration of changes in soil carbon balances has a remarkable influence on the results. A 60% emission reduction target is achieved if changes in soil carbon balances are excluded except in case 2a in which the probability of achieving the 60% emission saving remains low. This results from the system boundary setting, in which significant amounts of emissions from the CHP plant (based on the energy content of the products), are attributed to pyrolysis oil. Generally, the results depend significantly on the selection of parameter set and interpretation of the definitions provided in the RED to set the system boundary for the pyrolysis reactor and the CHP plant.

### *Acknowledgements*

Reetta Sorsa's masters thesis was carried out as a part of the TEKES project: "Integrated utilisation chains of second generation pyrolysis". Acknowledgements go to TEKES, Fortum, Lassila & Tikanoja, Metso Power, UPM and VTT for funding, as well as Sampo Soimakallio, Yrjö Solantausta and Esa Vakkilainen for guidance with her thesis.

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# Direct production of gasoline and diesel from biomass using integrated hydropyrolysis and hydroconversion (IH$^2$)

*Terry Marker provides an insight into new processes being developed at the Gas Technology Institute in USA*

> *"IH$^2$ makes high quality hydrocarbon fuels from biomass cheaply and directly. The key to commercial success is demonstrating catalyst stability in our new continuous pilot plant."*

The Gas Technology Institute (GTI) in the States is developing  a new process called integrated hydropyrolysis and hydroconversion (IH$^2$) to directly produce gasoline, jet and diesel hydrocarbon blend stock from biomass.

The key to the process is the first stage catalytic hydropyrolysis step where biomass is converted to low TAN 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 more than 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 integrated hydroconversion step then produces a final IH$^2$ product with less than 1% oxygen and less than 1 TAN.

Furthermore, catalytic hydropyrolysis is exothermic because oxygen is removed and hydrogen is added to the hydrocarbon structure, which eliminates the need for recirculation of the solid heat carrier which is required in pyrolysis.

Another inherent advantage of catalytic hydropyrolysis is that a hydrocarbon product is directly produced which can be easily upgraded in an integrated hydrotreating reactor to stabilize and polish the product.

A unique feature of this process is that all the hydrogen required for the IH$^2$ process is produced by reforming the C1-C3 products so no supplementary hydrogen is required, allowing greater flexibility with respect to unit location. The IH$^2$ integrated process schematic is shown in Figure 1.

Initial economic analyses suggest that the IH$^2$ process

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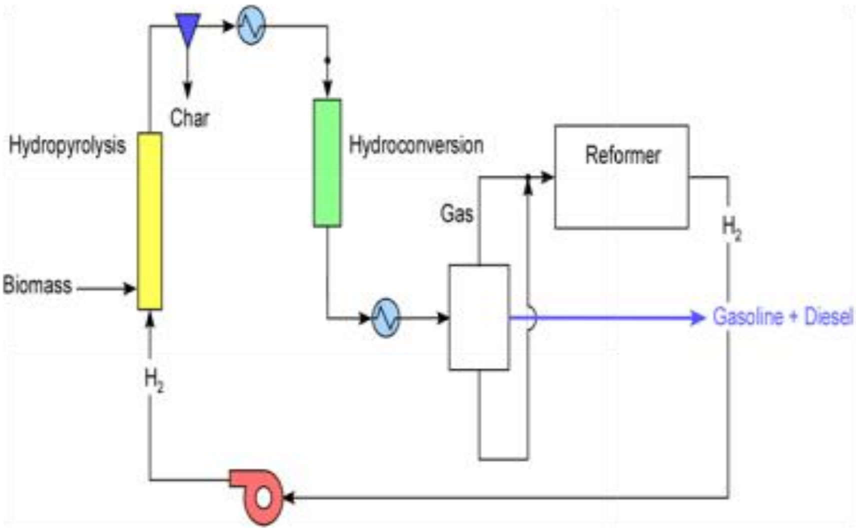

*Figure 1: IH$^2$ system schematic, showing overall process flow*

# Direct production of gasoline and diesel from biomass using integrated hydropyrolysis and hydroconversion ($IH^2$) ...continued

has excellent economics and 90% greenhouse gas reduction, and is an improvement compared to pyrolysis, plus upgrading for producing transportation fuels from biomass.

To achieve good separation of biomass and catalyst in catalytic hydropyrolysis, the catalyst is a larger diameter and denser than the biomass. The mechanism of first stage catalyst-char separation is shown in Figure 2.

Initial experiments have been conducted in a small scale mini bench unit (MBU) which feeds 1 lb/hr of biomass over a period of 3-6 hours. A drawing of the MBU is shown in Figure 3.

Yields and product quality data from MBU tests of hydropyrolysis and integrated hydropyrolysis, and hydroconversion using various wood feeds is shown in Table 1.

*Table 1: Hydropyrolysis and $IH^2$ experimental yields – wt% MAF*

| | Hydropyrolysis | $IH^2$ |
|---|---|---|
| % $C_4$+ Liquid | 27 | 26.5 |
| % O in C4+ | <3 | <1 |
| TAN in C4+ | <2 | <1 |
| C4+ % Gasoline | 53-75 | 53-75 |
| C4+ % Diesel | 25-47 | 25-47 |
| % Char | 13 | 13 |
| % COx | 17 | 17 |
| % $C_1$-$C_3$ | 14 | 14 |
| % Water | 33 | 33.5 |
| % $H_2$ uptake | 3-4 | 3-4 |

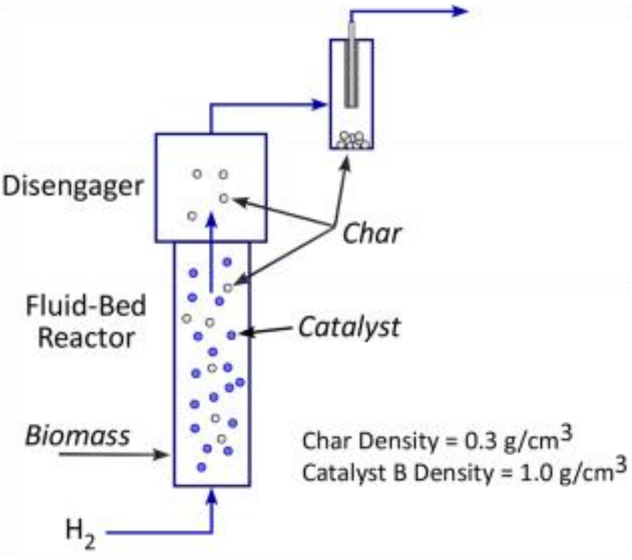

*Figure 2: Mechanism of char-catalyst separation*

The heart of the catalytic hydropyrolysis step is the catalyst. CRI/Criterion supplies the proprietary catalysts used in both the first and second $IH^2$ stages. CRI/Criterion is helping to commercialize the $IH^2$ technology and have exclusive global sublicensing rights when it has been fully demonstrated.

Based on the data obtained to date, the $IH^2$ process appears to be a highly advantaged solution to producing high quality hydrocarbon fuel blendstocks cheaply and directly from lignocellulosic feeds. But to demonstrate that the process is commercially viable, long term catalyst stability and attrition tests must be completed. In order to accomplish this goal, GTI is currently building a 50 kg/day $IH^2$ pilot plant working with Zeton. This pilot plant should be delivered by September 2011 and operational by the end of the year. Discussions with various parties regarding larger, demonstration scale facilities are well advanced.

A picture of the partially constructed skid is shown in Figure 4.

The $IH^2$ project was funded through the U.S. Department Of Energy (DOE) project DE-EE0002873. Other $IH^2$ DOE project partners include CRI/Criterion, Cargill, Johnson Timber, Aquaflow, Blue Marble Energy, NREL and MTU.

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# Direct production of gasoline and diesel from biomass using integrated hydropyrolysis and hydroconversion ($IH^2$) ...continued

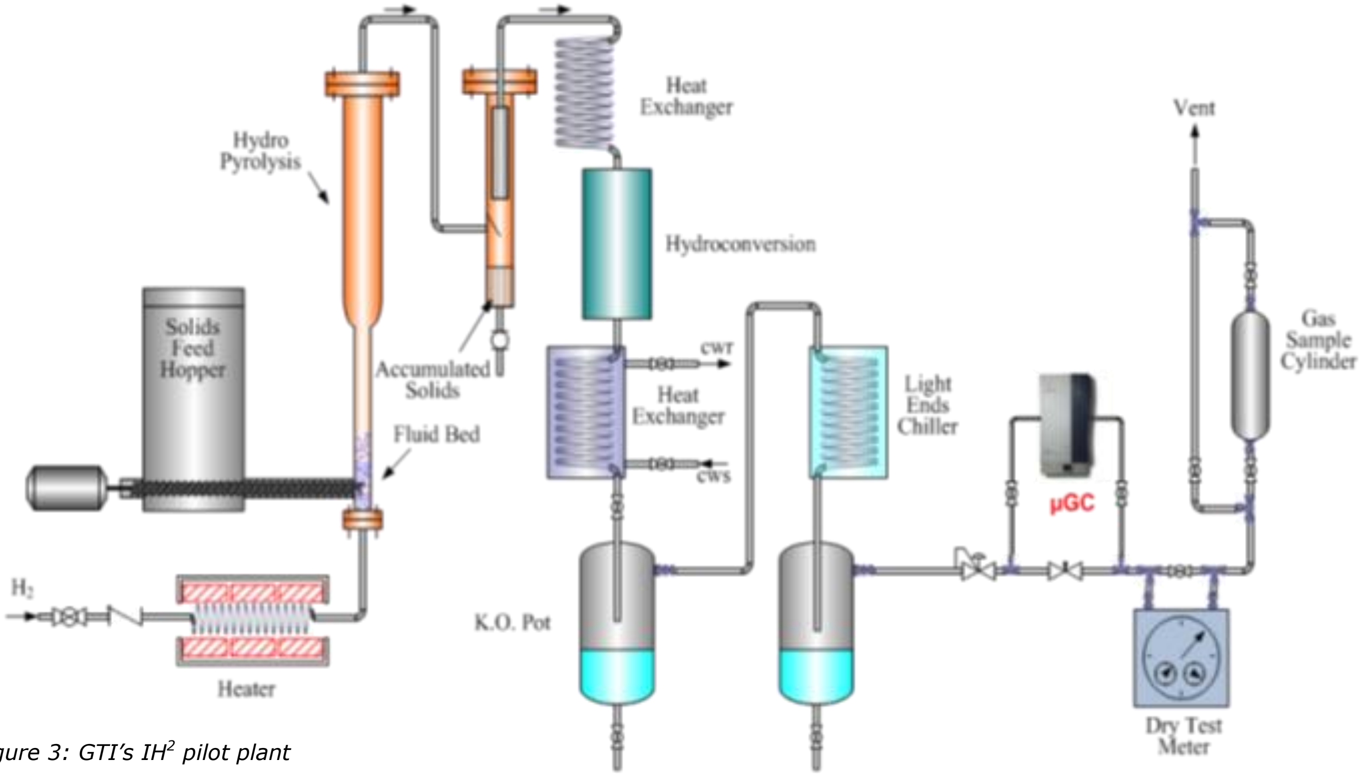

*Figure 3: GTI's $IH^2$ pilot plant*

*Figure 4: GTI's new 50 kg/day $IH^2$ pilot plant under construction*

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# Woody biomass catalytic pyrolysis research at Åbo Akademi University

*Atte Aho outlines latest activities at Finland's Åbo Akademi University*

> *"The first challenge was to design and build a catalytic pyrolysis reactor."*

Catalytic pyrolysis of woody biomass has been studied at Åbo Akademi Process Chemistry Centre since the beginning of 2006. The research is funded by Tekes, the Finnish Funding Agency for Technology and Innovation, and several companies. The catalytic pyrolysis research was a new research topic for Åbo Akademi, although the Centre has an excellent long-term experience in catalysis (Prof. Dmitry Murzin), reaction engineering (Prof. Tapio Salmi) combustion (Prof. Mikko Hupa) and wood chemistry (Prof. Bjarne Holmbom).

The first challenge was to design and build a catalytic pyrolysis reactor. The initial set-up consisted of a biomass screw feeder, a fluidized bed reactor, a cyclone and condensers all made of glass (except the feeder). In this set-up, catalysts (i.e. various zeolites) were used as a catalytic bed material in the pyrolysis reactor. Several experiments were made using this set-up. The influence of the zeolite's acidity [1] and structure [2] was investigated.

After gaining some knowledge about catalytic pyrolysis, a new and improved set-up was built. The current set-up consists of a biomass feeder (the same as in the initial set-up), a dual-fluidized bed reactor, condensers, filters and online analysis for CO and $CO_2$. The dual-fluidized bed reactor is designed in a way that the pyrolysis takes place in the lower reactor, and the catalytic upgrading of the pyrolysis vapors occurs in the upper reactor. By separating the pyrolysis and catalysis into two reactors it is easier to investigate the catalytic phenomena at lab-scale. The pyrolysis of biomass is carried out in section '2', and the catalytic upgrading of the pyrolysis vapors in section '3' in the scheme presented below (Figure 1). Both reactors are heated inside a tube-oven.

The two fluidized beds are separated by a fine wire mesh. The pyrolysis is performed in a

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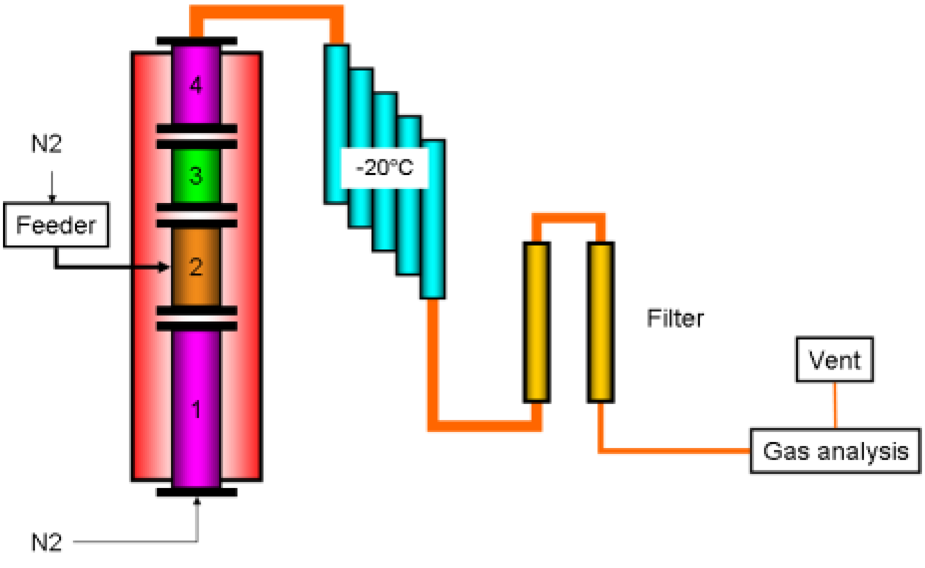

*Figure 1: Pyrolysis reactor 1*

# Woody biomass catalytic pyrolysis research at Åbo Akademi University ...continued

*Table 1: Results of several different catalysts tested in the dual-fluidized bed reactor*

| | | Char | Coke | Organic phase | Water | CO | $CO_2$ | Mass balance |
|---|---|---|---|---|---|---|---|---|
| **Non-catalytic** | Pine 400°C | 23.5 | 0.0 | 51.5 | 8.1 | 3.0 | 6.3 | 92.4 |
| | Pine 450°C | 17.6 | 0.0 | 51.7 | 7.8 | 6.0 | 7.3 | 90.4 |
| | Pine 500°C | 14.7 | 0.0 | 48.7 | 8.4 | 7.7 | 5.8 | 85.3 |
| | Cellulose 450°C | 14.5 | 0.0 | 55.1 | 7.0 | 2.9 | 5.7 | 85.2 |
| **Catalytic pine** | H-Beta-25* | 23.5 | 7.6 | 20.8 | 12.7 | 8.3 | 7.1 | 80.0 |
| | H-ZSM-5-80* | 21.1 | 4.9 | 27.6 | 16.6 | 10.2 | 7.0 | 87.4 |
| | H-FER-20* | 20.8 | 1.5 | 43.8 | 7.8 | 3.5 | 5.3 | 82.7 |

**The numbers after the zeolite structure name corresponds to the $SiO_2/Al_2O_3$ molar ratio*

semi-continuous mode, i.e. by continuous feeding of the biomass but without removal of the formed char. The catalytic upgrading reactor operates in a continuous mode during the experiments, where the pyrolysis vapors formed in the lower reactor flows through the fluidized catalyst bed.

The major challenge in both set-ups has been the separation of the pyrolysis vapors. Currently three types of condensers are used, namely a jacketed condenser and two types of spiral condensers, all operated at -20°C. After the condensers, the remaining vapors/aerosols are led through two ~25 cm long cotton filled tubes. The mass balance closure, 85–95 wt-%, can be considered as a good one when taking into account the extremely small amount of biomass used in the experiments. During a typical run with this set-up only about 10–20g of biomass is fed to the pyrolysis reactor.

*Figure 2: Pyrolysis reactor 2*

Most of our pyrolysis research has been made with pine wood as the raw material. In addition, the most abundant polymers in pine wood, namely cellulose [3], galactoglucomannan (hemicellulose) [3] and lignin [4], have been tested separately. The feeding of pure compounds to the reactor was quite challenging, therefore different modifications to the set-up and the raw material had to be made in order to successfully study them.

Several different catalysts have been tested in the dual-fluidized bed reactor. As in the first set-up, the influence of different acidities [5,6] and structures [5-8] has been investigated. Moreover, different zeolite structures have been modified with metals [7] and furthermore, an attempt to increase the mechanical strength of the catalyst particles was undertaken by using bentonite

**Continued on page 15**

# Woody biomass catalytic pyrolysis research at Åbo Akademi University ...continued

as a binder [8]. Some selected results are given in Table 1.

It is well known that the char yield decreases when the pyrolysis reaction temperature is increased, as noticed in the table. However, in our set-up the bio-oil yield (organic phase + water) is fairly constant in the tested temperature range. Among the tested raw materials, cellulose produces the highest organic yield.

The aim in the catalytic pyrolysis is to deoxygenate the pyrolysis vapors. Usually this occurs through decarbonylation, producing more CO, and dehydration, producing more water. This can be achieved by selecting a zeolite, or another catalyst, with pore sizes large enough to accommodate the pyrolysis vapors. H-FER-20 has smaller pores than Beta and ZSM-5, and as seen in the table the water and CO yields are similar to the non-catalytic pyrolysis. A drawback in the use of zeolites in the upgrading is the loss of organics due to coking of the catalyst.

More results can be found in papers written by Åbo Akademi University.

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Åbo Akademi

# IEA Bioenergy Tasks 34 and 42: co-operation on a lignin pyrolysis biorefinery

*Update from Paul de Wild of the Energy research Centre of the Netherlands (ECN)*

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, as well as an inventory of the most promising bio-based chemicals. Production of chemicals from lignin is seen as a long term opportunity that depends on the (increasing) availability of high -purity lignin, e.g. as a by-product from lignocellulosic biorefineries for transportation fuels such as bioethanol.

An important activity of Task 34 – Pyrolysis of biomass is to focus on the 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 valorisation by pyrolysis to facilitate lignocellulosic biorefineries.

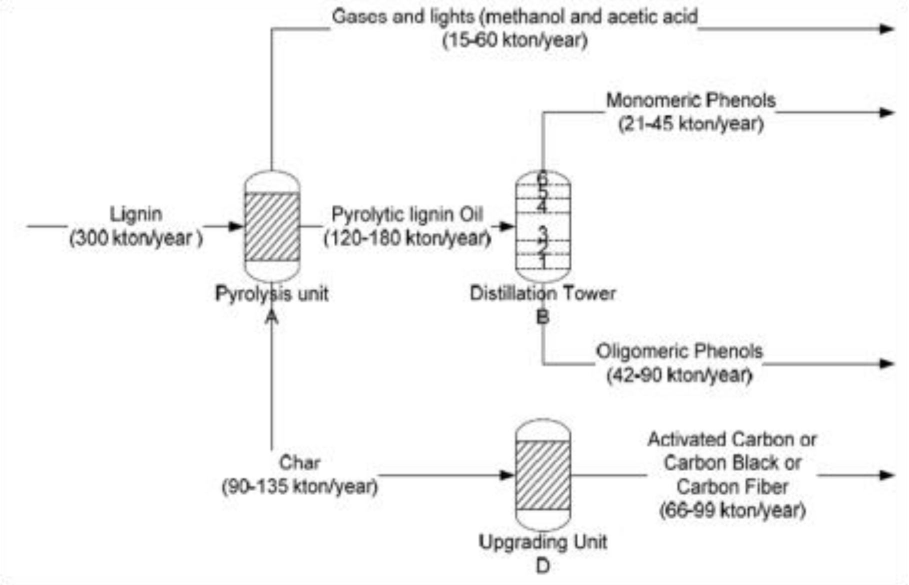

*Figure 1: Simple flow scheme of the pyrolytic valorization of lignin into monomeric phenols, oligomeric phenols and biochar*

The main goal of the study is a limited techno-economic evaluation of lignin valorisation to gas, phenols and biochar via fluidised-bed pyrolysis technology.

Currently, 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 lignocellulosic biorefinery producing bioethanol and co-products can be increased significantly by implementing the pyrolysis of lignin.

**Approach/assumptions**
Economic margin analysis and preliminary capital and operational expenses have been estimated for a lignin pyrolysis plant that processes 300,000 ton/year of lignin (> 95% pure) to gas, lignin pyrolysis oil and char. It is assumed that the lignin production/separation/purification costs in the biorefinery are €500 per dry ton of lignin.

The pyrolysis reactor is modelled as a typical petrochemical Fluid Catalytic Cracking (FCC) unit including primary downstream treatment, such as collection of the oil and char. Further downstream processing is also modelled according to petrochemical analogs such as vacuum distillation to split the

***Continued on page 17***

# IEA Bioenergy Tasks 34 and 42 ...continued

monomerics and oligomerics, visbreaking and coking units for the upgrading of the heavy oil fraction and the char and distillation/solvent extraction to separate individual phenols.

The lignin pyrolysis oil is comprised of a monomeric and oligomeric phenolics fraction. The lignin pyrolysis gas mainly consists of CO, $CO_2$, methane and minor amounts of other hydrocarbons, such as ethylene. Typical yields (based on the dry lignin intake) are 15% gas, 35% char and 50% oil. Approximately 20% of the oil is made up by a great variety of monomeric phenols, with guaiacols and syringols being the most abundant ones. Another 40% of the oil consists of a tarry fraction, presumably oligomeric substances of phenolic origin. The remaining 40% is mainly water with minor amounts of low-boiling components, such as methanol and acetic acid.

Four product driven cases were distinguished: 1) all products to fuel, 2) use pyrolytic lignin oil as such, 3) separate pyrolytic lignin oil in monomers and oligomers, 4) separate pyrolytic lignin oil in oligomers and monomers and extract individual phenols from the monomeric fraction.

**Results/discussion**

The fuel case proved to be not economical at any lignin price. In the other three models, it is estimated that the lignin pyrolysis oil and the char fraction need to be upgraded to products that represent a significant value, approximately €800-1000/ton.

For the char fraction, carbon black, carbon fibers and activated carbons were identified as potential high value high volume marketable outlets that meet this price requirement. For the lignin pyrolysis oil as such, bitumen and phenolic resin additive and carbon fibres are potential marketable outlets. The monomeric phenol fraction could be marketed as a substitute in phenolic resins at or above this price range. The oligomeric phenol fraction was evaluated as bitumen additive and appears to be able to command this market price. Finally, the monomeric phenolics could be separated to some or all of the individual very high value compounds and individually marketed.

The most complex case isolates some or all of the monomeric phenols from the pyrolytic oil, and evaluates several char upgrading cases. This is the most profitable case, but it is expected that the market for the individual phenols is likely to be difficult to penetrate and probably can adsorb a limited number of biorefineries only. Return on investments (ROI) range from 20 to 300% for the viable cases, with a total capital investment of around €200 million.

Figure 1 represents a less complex option in which the lignin pyrolysis oil is separated into monomeric and oligomeric phenols, and in which the char is upgraded to the three carbon forms. Here, it is estimated that profitable scenarios are clearly possible depending on the final application and valorisation of the products. The attributed value for the oligomeric phenols and the biochar (e.g. as bitumen additive) determines the outcome of the analysis. The best results are based on the expected benefits of using the char and the oligomeric phenols as additives that improve the final product quality of bitumen and resins. This is not proven yet. The cases in which the biochar is regarded as a fuel or as a low-value soil improver are not economic.

**Conclusion**

In general, the economic potential for the three non-fuel product cases is strongly dependent on the lignin price, on the valorisation possibilities for the biochar product and on the yield of the lignin pyrolysis oil. Realistic and profitable uses of the lignin pyrolysis oil, as such is currently the preferable option, because of the uncertainty of more complex approaches to further purify the product slate. This is an interesting and challenging option that merits prolonged RTD and intensive co-operation between academia, industry and research institutes because the pyrolytic-valorisation of biorefinery side-streams, such as lignin is a key issue for an economic biorefinery.

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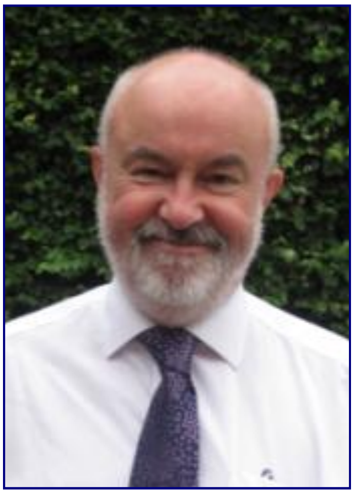
# A methodology for the generation and evaluation of biorefinery chains



*Tony Bridgwater outlines a biorefinery chain methodology developed at Aston University*

A methodology was required for the generation and evaluation of new process chains for converting biomass into one or more valuable products that properly considers performance, cost, environment, socio-economics and other factors that influence the commercial viability of a process.

The significance of the approach is that the methodology is defined and is thus rigorous and consistent and may be readily re-examined if circumstances change. The result will be the identification of the most promising biorefinery chains. There was the requirement for consistency in structure and use, particularly for multiple analyses. It was important that analyses could be quickly and easily carried out to consider, for example, different scales, configurations and product portfolios and so that previous outcomes could be readily reconsidered. A comprehensive, thorough and methodological approach to consideration of the full range of process and product opportunities will allow both their short term and long term evaluation, and will allow the identification of the most promising biorefinery concepts. This will provide some clear directions for research and policies in the short, medium and long term, as well as identifying the most interesting opportunities for industry to enable the development of a robust bio-based industrial sector. The work flow is shown in Figure 1.

The methodology includes process chain generation, process modelling and subsequent evaluation of results in order to compare alternative process routes. A modular structure was chosen to give greater flexibility allowing the user to generate a large number of different biorefinery configurations. Each module represents a processing step and fully describes that process step in

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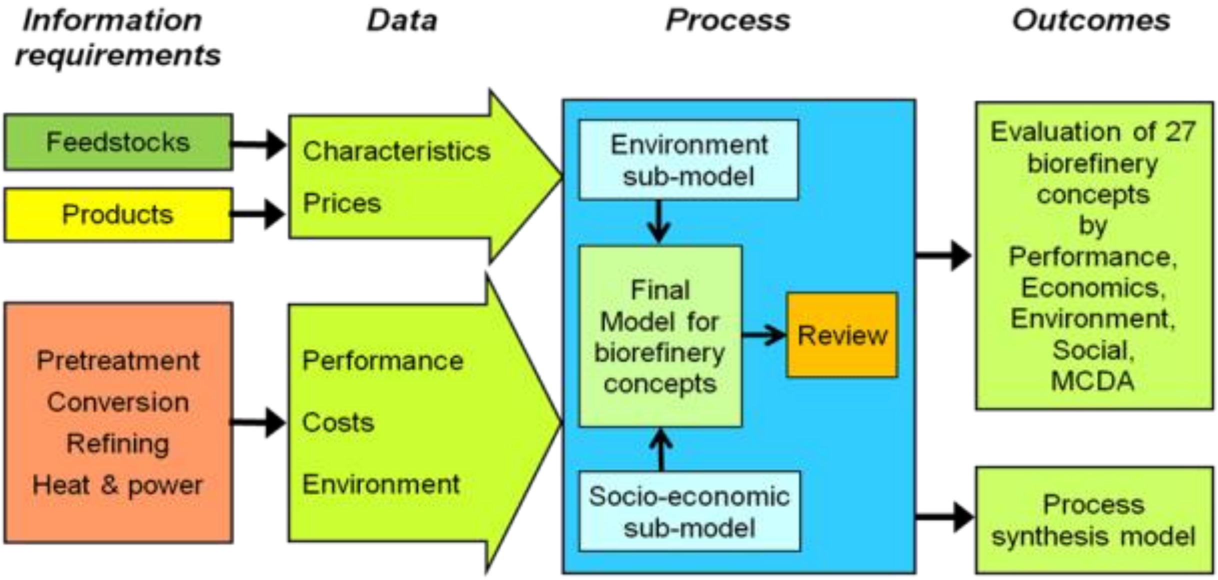

*Figure 1: Schematic diagram of work flow*

# A methodology for the generation and evaluation of biorefinery chains ...continued

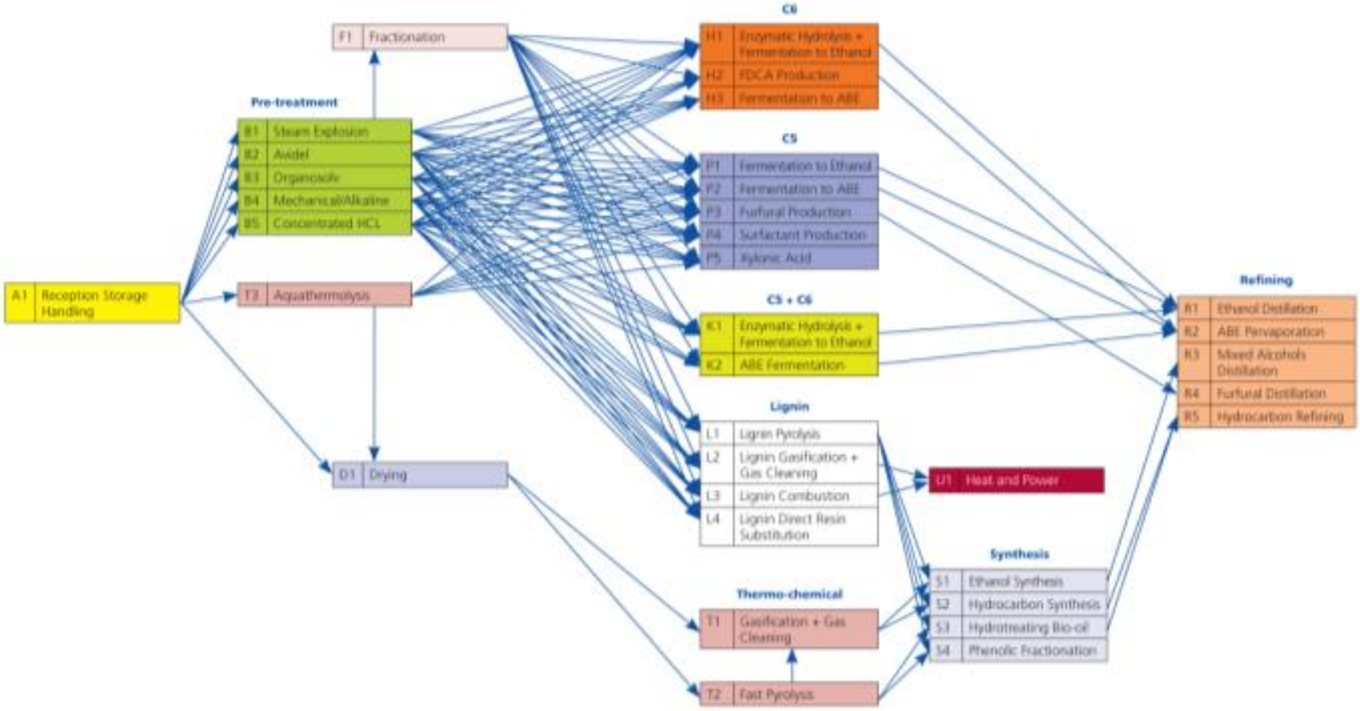

*Figure 2: Mix and match process modules*

terms of mass and energy balances and cost estimations. A user interface was created so that the model can be used externally to the project. The user interface allows the user to specify feedstock, key variables and preferred technology combinations. It is possible for the user to mix and match process modules (see Figure 2) based on inbuilt logic rules. The output will provide biorefinery process chains ranked by performance, cost, environmental performance or socio-economic performance.

One of the advantages of this approach to process definition and evaluation is that it is based on a set of defined rules or relationships. These are transparent and can be readily changed by the project team to reflect changing scenarios, such as feedstock or product prices, crude oil prices, new technology developments, new processes etc. This will enable the final model to be updated and can thus be maintained as a valuable procedure for evaluation of new opportunities.

This work formed part of the BIOSYNERGY project, a four-year Framework 6 project partially funded by the European Commission, which finished at the end of 2010. There were 17 partners involved in BIOSYNERGY from across the European Union (EU) and different market sectors. The full description and definition of the Integrated Project (IP) BIOSYNERGY project was “The IP BIOSYNERGY aims to use *BIO*mass for *SYN*thesis processes (transportation fuels, platform chemicals) and en*ERGY* production (power, CHP) by application of innovative fully integrated, synergetic biorefinery concepts, using advanced fractionation and conversion processes, and combining biochemical and thermochemical pathways.”

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# Biomass conversion research at Utah State University

*Foster Agblevor gives an insight into biofuel research activities in the State of Utah, USA*

The State of Utah is much more known for coal research and coal utilization because most of Utah is semi-arid; it has rich coal deposits, but is not very rich in lignocellulosic biomass resources. However, recently there has been a major push to develop biofuel research and production in the state as a response to the national need for domestic fuels production and the creation of jobs in rural America.

The State of Utah has focused its biofuel research on two major biomass feedstocks: algal biomass which derives from its rich salt lake and other marshes; and forestry biomass (pinyon-juniper) from its national forests which are prone to wild fires. The lignocellulosic biomass research is driven by the need to control wildfires in the summer especially from pinyon-juniper woodlands.

The Utah State University (USU) is positioning itself to become the lead institution in the State of Utah for biofuel research and deployment. The USU is located in northern Utah where it has access to forestry biomass and is also well situated for algal biomass research. The City of Logan, UT alone has 460 acres of algal lagoon which are harvested on regular basis. The question is what to do with these large quantities of algal biomass and over 15 million tons of pinyon-juniper which are removed on a regular basis to reduce wildfires. Thus, research at USU is focused on converting these two feedstocks into high value products and biofuels.

The research areas are:

1) pyrolytic conversion of lignocellulosic and algal biomass into liquid fuels and bioproducts;
2) pyrolytic conversion of biomass/coal mixtures to liquid fuels;
3) insitu transesterification of algal biomass into biodiesel.

**Pyrolysis research**
The pyrolysis research is centered on fractional catalytic pyrolysis (FCP) of lignocellulosic, algal and coal/ biomass mixtures. The USU has both basic and applied research facilities, such as bench scale fluidized bed

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> *"The ultimate goal of the research team is to develop a technology for producing drop-in hydrocarbon fuels from various biomass resources."*

# Biomass conversion research at Utah State University...continued

pyrolysis reactors, 2 kg/h fluidized pyrolysis reactor, pyroprobes, catalyst synthesis and pyrolysis product characterization. These research activities are conducted through three centers: Synthetic Biomanufacturing Center (SBC), Algal Biofuels Center (ABC) and Sustainable Waste to Bioproducts Center (SWEBEC).

These three centres are involved in feedstock production, conversion and value-added products research. The pyrolysis research effort is led by Dr. Agblevor, a Utah Science Technology and Research (USTAR) Chair Professor, who recently moved from Virginia Tech to USU.

Since moving to USU in January 2011, USU through the SBC has commissioned the design, construction, and installation of the 2 kg/h fractional catalytic pyrolysis reactor to produce stable biomass pyrolysis oils. The pyrolysis reactor was recently delivered at the USU Innovation Campus, Logan UT (Figure 1).

Current projects in progress at USU include:

1) production of stable biomass pyrolysis oil from hybrid poplar wood;
2) conversion of poultry litter into pyrolysis oils and biochar;
3) pyrolytic conversion of algae to hydrocarbon fuels; pyrolytic conversion of pinyon-juniper woods into value added products;
4) catalytic pyrolytic conversion of biomass/coal mixtures into hydrocarbon fuels.

*Figure 1: Fractional catalytic biomass pyrolysis unit at Utah State University*

These research activities are being conducted by a team of eight researchers which include: three visiting researchers from China, Tunisia, and Ghana; two postdoctoral fellows; and three graduate students.

The ultimate goal of the research team is to develop a technology for producing drop-in hydrocarbon fuels from various biomass resources. The technology should be flexible enough to use any kind of feedstock for drop-in fuel production.

Our motivation is based on the fact that sustainable production of drop-in hydrocarbon fuels cannot be based on only one feedstock. The development of technology based on mono-cultural feedstocks could eventually lead to unintended consequences, such as environmental degradation. Thus, our technology should be such that it can handle multiple feedstocks. We believe the best way to achieve this goal is through catalytic pyrolysis which will convert the biomass into a stable pyrolysis oil that can be refined into hydrocarbon fuels.

Other factors driving our research direction is the challenge of biomass feedstock logistics and the high capital investment required for biorefinery development. We believe that a true biorefinery to produce hydrocarbon will

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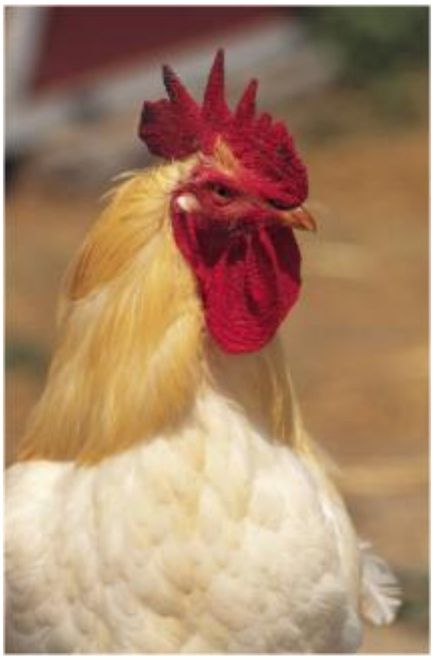
# Biomass conversion research at Utah State University...continued



> *"We are working with the poultry industry to convert poultry litter into pyrolysis oils and biochar."*

not only require several hundred millions of dollars in capital investment for the refinery, but will also require several hundred million dollars for infrastructure development to distribute the fuels. Additionally, there will be a major marketing effort for consumer acceptance of the biofuel. The sum of these efforts will range in the billions of dollars which increases the risk for private sector capital investment. Thus, the strategy at USU is to develop stable pyrolysis oils that can be blended with standard petroleum crude oil for co-processing. This approach will eliminate the need to build independent biorefineries, distribution and marketing.

To address feedstock logistics and harvesting challenges, we are collaborating with researchers at the Idaho National Laboratory, Idaho Falls, ID to ensure that technologies that we develop at USU can be easily implemented in the real world. Thus, we are using the systems approach to guide us in our research and development efforts.

Pyrolysis technology can also be deployed to solve environmental pollution problems and simultaneously address biofuel production targets. Thus, we are working with the poultry industry to convert poultry litter into pyrolysis oils and biochar. The biochar will be used as slow release-fertilizer or soil ammandment while the pyrolysis oils will be used as fuel for heating the poultry houses during the winter. Our goal is to make the poultry industry energy self-sufficient and reduce pollution from both phosphorous and ammonia emission. The biochar captures all the phosphorous and some nitrogen, whereas the bio-oils contain all the organic liquids. The non-condensable gases produced in the process are burnt to fuel the pyrolysis process. Current research is still on the bench scale, although a transportable poultry litter pyrolysis unit is being built.

Coal is a major fuel resource not only in the State of Utah, but throughout the entire USA. However, coal has several negative attributes including carbon dioxide emission, SOx and NOx emissions. Thus, one of the goals of our research team is to make coal a cleaner fuel by combing coal and biomass feedstocks to produce a much more environmental friendly fuel. Pyrolysis is an excellent tool that could be used to achieve this goal. Thus, we will soon start our biomass/ coal biomass research at USU.

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# Modelling an integrated fast pyrolysis process with Aspen Plus

*Kristin Onarheim outlines a simulation model developed at VTT Technical Research Centre of Finland*

VTT has developed a simulation model of a process concept where bio-oil production from fast pyrolysis of biomass has been integrated into an industrial fluidized bed boiler producing heat and electricity. The model can be used as a tool to investigate the effects of varied process conditions on bio-oil, heat and power production. It can also be used to predict variations in output and process performance under a range of process modifications and alternative process conditions. In addition, the model can be used for equipment and process design, and process optimization. The model has been run with two different pyrolysis raw materials; pine and forest residue.

An integrated fast pyrolysis process can be more feasible in terms of energy efficiency, investment costs and operational costs compared to a stand-alone fast pyrolysis process. The concept of an integrated fast pyrolysis process allows both the pyrolysis process and the heat and power boiler to take advantage of each other. The pyrolysis reaction temperature is supported by heat from the fluidizing material of the boiler. The pyrolysis raw material dryer utilizes heat from the boiler flue gases and in return, fast pyrolysis by-products such as carbon-rich char and non-condensable gases are applied as additional fuel sources for the boiler. By combusting these by-products in the boiler there will be no need for char disposal or specific gas treatment before emission, as this will be taken care of in the flue gas treatment in the boiler

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> *"The model can be used for equipment and process design, and process optimization."*

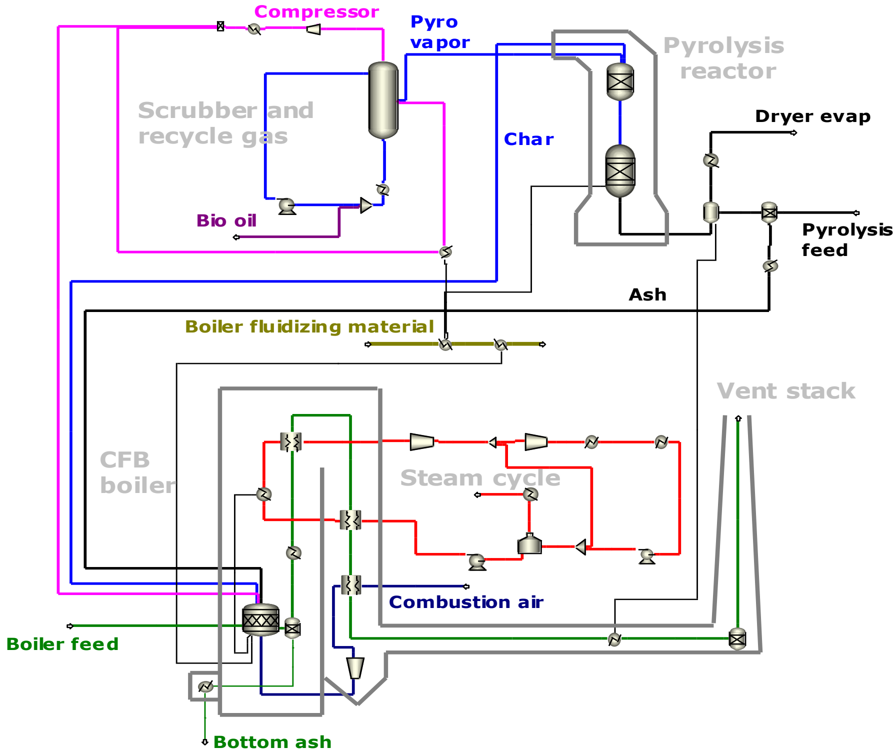

*Figure 1: Integrated fast pyrolysis process flowsheet*

# *Modelling an integrated fast pyrolysis process with Aspen Plus...continued*

process.

Modelling processes require appropriate selection of model compounds, thermodynamic property methods and binary interaction parameters in order to achieve correct results. Pyrolysis vapour products originate from the cellulose, hemicellulose and lignin structures in the wood. These structures are thermally broken at the pyrolysis reaction temperature through numerous mechanisms and they decompose into several hundred more or less complex compounds. As a consequence, a wide range of thermodynamic properties in both vapour, liquid and solid phases are represented and the behaviour of the components can differ significantly under the same process conditions. As a result, it can be challenging to apply the correct property method for the fast pyrolysis process as no method in Aspen Plus has yet been developed to handle all possible conditions in this type of process. To approach a realistic model, simulation measured results and analyses from the VTT integrated fast pyrolysis Process Development Unit (PDU) of 20 kg/h were used as a basis for the simulation development.

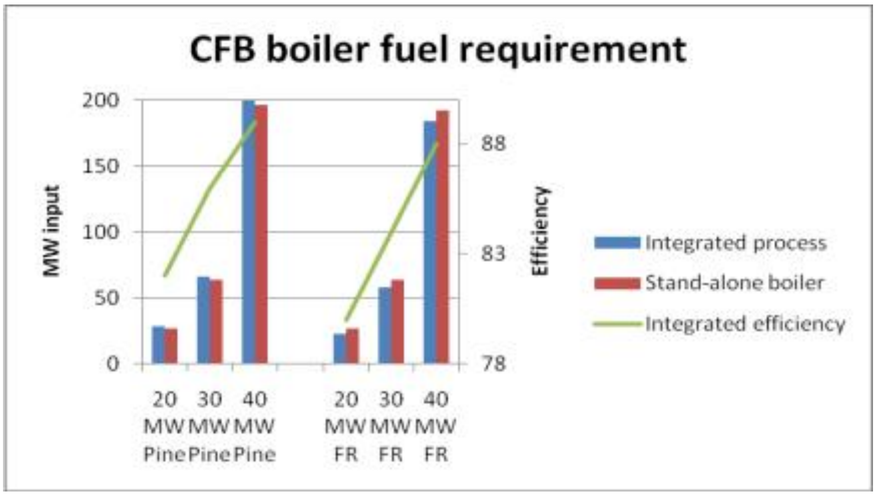

*Figure 2: The variations in fuel input to CFB process. The integrated process includes also char and purge gas from the integrated pyrolysis process. The stand-alone boiler is a conventional boiler process with no integrated pyrolysis.*

Only the major compounds and chemical groups present in bio-oil were chosen for the simulation model. For components not present in the Aspen Plus databanks, a set of model components were chosen, for instance to represent the pyrolysis vapour sugar fraction, forest residue top-phase fraction and high and low molecular lignin. The components in vapour phase are not very well identified. In addition, part of the primary pyrolysis products in the vapour phase may be only intermediate components that interact with other components before and during condensation. Polymerization and secondary reactions are challenging to determine, and as a consequence, most model compounds for pyrolysis processes are based on component analyses of the condensed vapours. The vapour composition of the pine based pyrolysis process was defined as 64% organic vapours, 12% non-condensable gases, 12% pyrolysis water and 12% char, while for the forest residue the composition was 52%, 14%, 12.5% and 21.5%, respectively.

The results from the model show that the boiler performance is clearly dependent on the type of raw material for the pyrolysis process. A stand-alone heat and power boiler process would require up to 18% higher fuel input compared to that of an integrated fast pyrolysis process based on forest residue. For a pine based pyrolysis process the result is different, and a stand-alone boiler would need less feed input, around 6–7% for boilers around 6 MWe, and decreasing with increasing boiler size (see Figure 1). The main reason for this is the higher amount of carbon-rich char by-product in forest residue based pyrolysis.

The efficiency of the bio-oil production is fairly stable both when producing from pine wood and forest residue. The efficiency is calculated as the chemical energy in bio-oil divided by the sum of energy in the pyrolysis feed plus the dryer energy requirement. The efficiency for pine is significantly higher. The reason is that we need less raw material input for the pine pyrolysis process and thus lower dryer duty compared to the forest residue based process in order to achieve the

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# Modelling an integrated fast pyrolysis process with Aspen Plus...continued

*Table 1: Overall process input and results for two different feedstock types and three different process sizes*

| | Pine | | | Forest residue | | |
|---|---|---|---|---|---|---|
| **Pyrolysis process**<br>**CFB process ($\mathrm{MW_e/MW_h}$)** | **20 MW**<br>**6/17** | **30 MW**<br>**17/40** | **40 MW**<br>**60/120** | **20 MW FR**<br>**6/17** | **30 MW FR**<br>**17/40** | **40 MW FR**<br>**56/120** |
| Pyro feed, kg/s | 3.0 | 4.5 | 6.1 | 3.8 | 5.6 | 7.5 |
| Bio-oil, kg/s | 1.3 | 1.9 | 2.6 | 1.4 | 2.1 | 2.8 |
| Purge, kg/s | 0.2 | 0.3 | 0.4 | 0.3 | 0.4 | 0.6 |
| Char, kg/s | 0.2 | 0.3 | 0.4 | 0.4 | 0.6 | 0.8 |
| CFB feed, kg/s | 3.4 | 8.1 | 24.6 | 2.8 | 7.1 | 22.6 |
| Heat for pyrolysis, MJ/kg | 2.9 | 2.9 | 2.9 | 2.8 | 2.8 | 2.8 |
| Dryer duty, MW | 4.6 | 6.9 | 9.4 | 5.9 | 8.7 | 11.6 |

same amount of energy from the bio-oil. The efficiencies of power production and district heat production increase by increased process size as expected. Also these efficiencies have been calculated as power or heat output divided by total energy input including char and purge from the fast pyrolysis process. Comparing the efficiencies for integrated and non-integrated power and heat production, it is clear that in non-integrated cases where we have a stand-alone CFB boiler, the heat and power production efficiencies are larger than for the integrated processes, but the difference decreases with increasing boiler size.

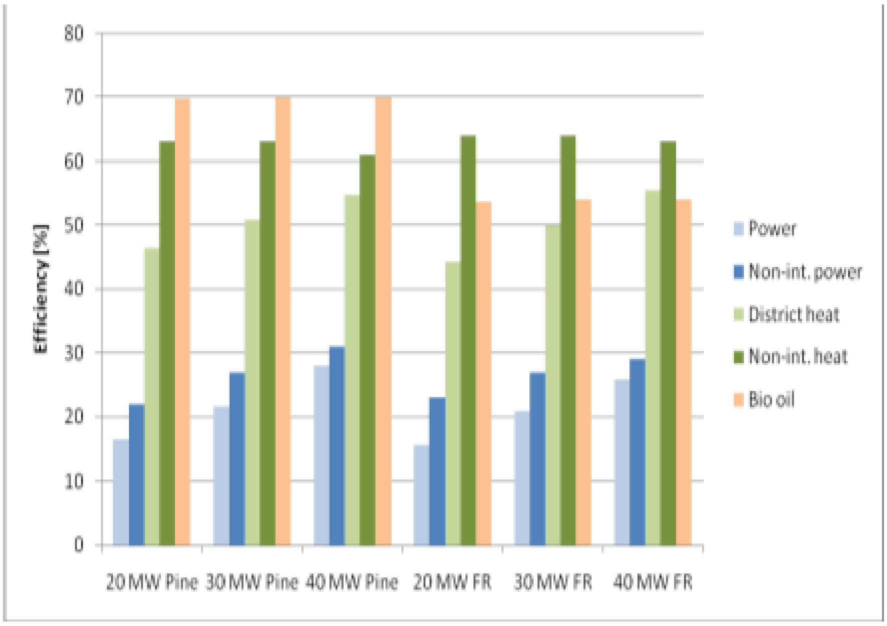

*Figure 3: Production efficiencies integrated vs. non-integrated process*

**Future work**

The model is under constant development and can possibly be improved, for instance by changing model components, calculation routes, algorithms and nesting specifications. In addition, changing or modifying physical property methods could give improved results.

Straw has been planned as a third raw material option for the pyrolysis process. Straw contains a number of alkali components and the high content of ash makes it challenging to use straw as a direct boiler fuel.

***Acknowledgement***

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# Lignin pyrolysis testing at different temperatures

*Daniel Nowakowski of Aston University, UK summarises the findings of the analytical pyrolysis studies of lignin*

It is well known that temperature plays an important role in affecting product distribution of lignin pyrolysis due to its complex structure, which is formed by the dehydrogenative polymerisation of three main monolignols via various types of linkages. This is the reason that lignin can be decomposed at a wide range of temperatures. At low temperatures, only side chain scission occurs to form gases such as CO, $CO_2$ and condensation reactions to form water. The predominant β-O-4 bonds may be broken down at about 300°C. However, the monolignols are also connected via C-C bonds that need a higher temperature to be cleaved.

The objective of this investigation is to find a temperature that can break both β-O-4 and aryl-aryl carbon-carbon bonds to release simple phenolic compounds maximally, while avoiding extensive secondary reactions of the formed simple phenolic compounds. Researchers at the Aston University Bioenergy Group have been working on the quantification of the temperature dependence of production of different phenolic compounds from lignin pyrolysis.

Two types of lignins were used for pyrolysis experiments, as follows:

- Alcell lignin was provided by the Energy research Centre of the Netherlands (ECN), which was produced via the organosolv pulping process from a mixture of hardwoods.
- Asian lignin Protoband 1000 was provided by Asian Lignin Manufacturing of

**Continued on page 27**

> *"The objective of this investigation is to find the temperature where we can obtain the maximum bio-oil yield from lignin."*

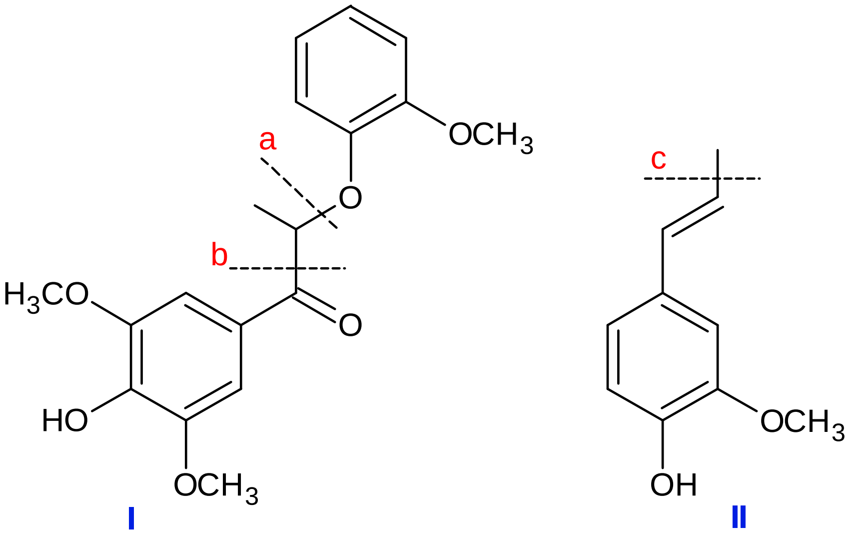

*Figure 1: Structures in lignin responsible for the formation of the main pyrolysis products (I – structure predominant in Alcell lignin; II – structure predominant in Asian Lignin)*

*The β-O-4 linkage in structure I is broken first at position "a" forming a free radical, which induces bond cleavage at position "b". After the demethoxylation reaction forming the main pyrolysis product is formed - 5-hydroxyvanillin. Cleavage of the bond at position "c" in structure II leads to the main pyrolysis product: 2-methoxy-4-vinylphenol.*

# *Lignin pyrolysis testing at different temperatures...continued*

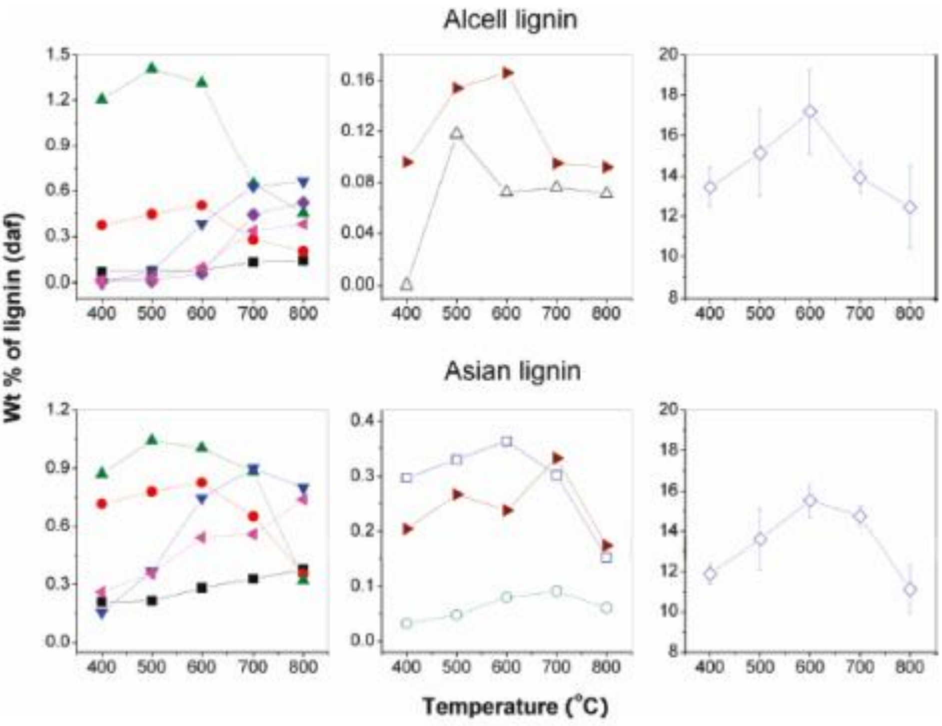

*Figure 2: Dependence of the yields of some important compounds and phenolic compounds from lignin pyrolysis on the temperature: (■) phenol, (●) guaiacol, (▲) syringol, (▼) catechol, (◆) pyrogallol, (◀) alkylphenol, (▶) ferulic acid, (□) isoferulic acid, (○) syringic acid, (△) homosyringic acid, (◇) total phenolics detected by GC.*

India, which was a co-product of pulp and paper via the soda pulping process from a mixture of wheat straw and Sarkanda grass.

Lignin samples were characterised for the ash content (using ASTM E1534-93 method), proximate analysis (with PerkinElmer Pyris 1 Thermogravimetric Analyser), as well as for carbon, hydrogen nitrogen and oxygen analysis. Analytical pyrolysis of lignin samples was performed using Py-GC-MS system - a new model of CDS Pyroprobe 5200 series coupled with a Varian 450-GC gas chromatograph with 200-MS mass spectrometer. Pyrolysis tests were performed on each sample - the temperature ranged between 400 and 800°C, at 100 degree increments.

The following conclusions may be drawn from the research:

- The product distribution from lignin pyrolysis depends upon the pyrolysis temperature. The maximum yield of phenolic compounds was obtained at 600°C for both lignins, which is a higher temperature than for cellulose and/or whole biomass.
- At higher temperatures, demethylation, demethoxylation, decarboxylation, and alkylation occur, leading to the change of product distribution toward alkylphenol and polyhydroxybenzene.
- For Alcell lignin, 5-hydroxyvanillin was the highest yield at 4.29%.
- For Asian lignin, 2-methoxy-4-vinylphenol was the highest yield at 4.15%.

This work guided researchers towards choosing the pyrolysis temperature for larger (bench) scale fast pyrolysis units to maximize the yield of specific or general phenolic compounds by lignin pyrolysis. Results from the bench scale fast pyrolysis of lignin will be presented in the next issue of the PyNe newsletter (December 2011).

The research paper which summarises the effect of temperature on the composition of lignin pyrolysis products can be found at [http://dx.doi.org/doi:10.1021/ef100363c](http://dx.doi.org/doi:10.1021/ef100363c)

### *Reference*

Nowakowski D, Jiang G, Bridgwater AV, Effect of the temperature on the composition of lignin pyrolysis products; Energy & Fuels, 2010, 24 (8), pp 4470–4475

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# Reviews on biomass pyrolysis and related aspects

**Colomba Di Blasi[1] and Tony Bridgwater[2]**

A list of significant review publications on biomass fast pyrolysis and related aspects has been compiled from 1982 up to the beginning of 2011. For each reference a set of key words is also provided.

[1]Dipartimento di Ingegneria Chimica,
Università degli Studi di Napoli "Federico II", Italy
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Aston University, Birmingham B4 7ET, UK
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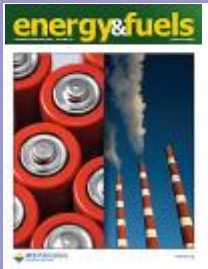
| | Author, Paper, Publication | *Key words* |
|---|---|---|
| 1 | Antal MJ. *Biomass Pyrolysis: a Review of the Literature. Part I - Carbohydrate pyrolysis.* In: Boer KW, Duffie JA, editors. Advances in Solar Energy, Vol. 1, Boulder (CO): American Solar Energy, 1982; pp. 61-111. | *pyrolysis, products, carbohydrates, chemical kinetics* |
| 2 | Shafizadeh F. *Thermal conversion of cellulose materials to fuel and chemicals.* In: Soltes J, editor. Wood and Agricultural Residues - Research on use for feed, fuels, and chemicals. New York: Academic Press, 1983, pp. 415-438. | *pyrolysis, products, cellulose, chemical kinetics* |
| 3 | Shafizadeh, F. *The Chemistry of Pyrolysis and Combustion*, in "The Chemistry of Solid wood", ed. R. Rowell, Advances in Chemistry Series 207, American Chemical Society, Washington, D.C.; 1984. | *pyrolysis, combustion, cellulose, anhydrosugars, chemical kinetics* |
| 4 | Shafizadeh F. *Pyrolytic reactions and products of biomass*. In: Overend RP, Milne TA, Mudge LK, editors. Fundamentals of Biomass Thermochemical Conversion. London: Elsevier, 1985, pp. 183-217. | *cellulose, hemicellulose, lignin, devolatilization rate, products* |
| 5 | Antal MJ. *A review of the vapor phase pyrolysis of biomass derived volatile matter.* In: Overend RP, Milne TA, Mudge LK, editors. Fundamentals of Biomass Thermochemical Conversion. London: Elsevier, pp. 511-537, 1985. | *biomass, cellulose, tars, tar cracking, chemical kinetics* |
| 6 | Glasser WG. *Lignin.* In: Overend RP, Milne TA, Mudge LK, editors. Fundamentals of Biomass Thermochemical Conversion. London: Elsevier, pp. 61-76, 1985. | *lignin chemistry* |
| 7 | Diebold JP. *The cracking kinetics of depolymerized biomass in a continuous tubular reactor.* PhD Thesis T-3007 - Colorado School of Mines, Golden Co, 1985. | *biomass, cellulose, tars, tar cracking, chemical kinetics* |
| 8 | Antal MJ. *Biomass Pyrolysis: a Review of the Literature. Part II - Lignocellulose pyrolysis.* In: Boer KW, Duffie JA, editors. Advances in Solar Energy, Vol. 2, Boulder (CO): American Solar Energy, pp. 175-255, 1985. | *biomass, cellulose, tars, tar cracking, chemical kinetics* |
| 9 | Evans RJ, Milne TA. *Molecular Characterization of the pyrolysis of biomass. 1. Fundamentals.* Energy & Fuels 1: 123-137, 1987. | *biomass, pyrolysis, bio-oil, bio-oil composition*<br> |
| 10 | Evans RJ, Milne TA. *Molecular Characterization of the pyrolysis of biomass. 2. Applications.* Energy & Fuels 1: 311-319, 1987. | *biomass, pyrolysis, bio-oil, bio-oil composition* |
| 11 | Antal MJ, Mok WSL, Varhegyi G, Szekely T. *Review of methods for improving the yields of charcoal from biomass.* Energy & Fuels 4: 221-225, 1990. | *biomass, pyrolysis, charcoal* |
| 12 | Bridge SA. *Flash pyrolysis of biomass for liquid fuels*, M.Sc. Thesis, The University of Aston in Birmingham, 1990. | *biomass, pyrolysis, fast pyrolysis technology, products* |
| 13 | Bridgwater AV, Cottam ML. *Opportunities for biomass pyrolysis liquids production and upgrading.* Energy & Fuels 6, 113-120, 1992. | *biomass, pyrolysis, bio-oil, bio-oil upgrading* |
| 14 | Bridgwater AV. *Catalysis in thermal biomass conversion,* Applied Catalysis A: General 116, 5-47, 1994. | *biomass, chemicals, economics, hydrotreating, upgrading, zeolite cracking* |
| 15 | Di Blasi C. *Modeling and simulation of combustion processes of charring and non-charring solid fuels*, Progress in Energy and Combustion Science 19, 71-104, 1993 | *wood, chemical kinetics, transport models* |

***Continued on page 29***

# Reviews on biomass pyrolysis...continued

| | **Author, Paper, Publication** | ***Key words*** |
|---|---|---|
| **16** | Peacocke GVC. *Ablative pyrolysis of biomass*. PhD Thesis Aston University, Birmingham (UK), 1994. | *biomass, ablative pyrolysis, products* |
| **17** | Bridgwater AV, Elliot DC, Fagernas L, Gifford JS, Mackie KL, Toft AJ. *The nature and control of solid, liquid and gaseous emissions from the thermochemical processing of biomass.* Biomass & Bioenergy, 9, 325-341, 1995. | *biomass, thermochemical conversion, emissions, products, control, ash, char, wastewater* |
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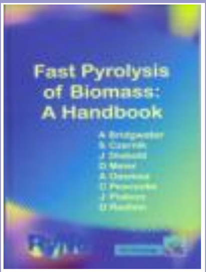
| **19** | Milosavljievic I, Suuberg E. *Cellulose thermal decomposition kinetics: global mass loss kinetics.* Industrial & Engineering Chemistry Research 34, 1081-1091, 1995. | *cellulose, pyrolysis, chemical kinetics* |
| **20** | Fagernäs L. *Chemical and physical characterisation of biomass-based pyrolysis oils. Literature review*. Espoo, VTT. 113 p. + app. 2 p. VTT Tiedotteita - Meddelanden - Research Notes; 1706. ISBN 951-38-4861-2. 1995. | *biomass, pyrolysis oils, characterisation* |
| **21** | Varhegyi G, Antal MJ, Jakab E, Szabo P. *Kinetic modeling of biomass pyrolysis.* Journal of Analytical and Applied Pyrolysis 42: 73-87, 1996. | *cellulose, biomass, pyrolysis, chemical kinetics, TG, DTG* |
| **22** | Gronli MG. *A theoretical and experimental study of the thermal degradation of biomass.* PhD. Thesis, NTNU, Trondheim, Norway, 1996. | *wood, pyrolysis, chemical kinetics, physical properties, particle model* |
| **23** | Meier D, Oasmaa A, Peacocke GVC. *Properties of fast pyrolysis liquids: status of test methods.* In: Bridgwater AV, Boocock DGB, editors. Developments in Thermochemical Biomass Conversion. London: Blackie Academic & Professional, pp. 391-408, 1997. | *biomass, pyrolysis, bio-oil, chemical characterization*  |
| **24** | Oasmaa A, Leppämäki E, Koponen P, Levander J, Tapola E. *Physical characterisation of biomass-based pyrolysis liquids. Application of standard fuel oil analyses.* Espoo, VTT. 46 p. + app. 30 p. VTT Publications; 306 ISBN 951-38-5051-X. 1997. | *pyrolysis, thermal decomposition, liquids, sampling, homogeneity, solubility* |
| **25** | Kantorovich II, Bar-Ziv E. *Heat transfer within highly porous chars: a review*. Fuel 78, 279-299, 1999. | *porous structure, chars, char oxidation, thermal conductivity, heat transfer* |
| **26** | Radlein D. *The production of chemicals from fast pyrolysis bio-oils,* in Fast Pyrolysis of Biomass: a Handbook, Vol. 1, Bridgwater AV (Ed.), CPL Press, Newbury, pp. 164-188, 1999. | *biomass, fast pyrolysis, bio-oil, chemicals*  |
| **27** | Diebold JP. *A review of the toxicity of biomass pyrolysis liquids formed at low temperature,* in Fast Pyrolysis of Biomass: a Handbook, Vol. 1, Bridgwater A. V. (Ed.), CPL Press, Newbury, pp. 135-163, 1999. | *biomass, pyrolysis, bio-oil, toxicity* |
| **28** | Diebold JP, Bridgwater AV. *Overview of fast pyrolysis of biomass for the production of liquid fuels.* In Fast Pyrolysis of Biomass: a Handbook, Vol. 1, Bridgwater AV (Ed.), CPL Press, Newbury, pp. 14-32, 1999. | *biomass, fast pyrolysis, products* |
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| **30** | Bridgwater AV. *Principles and practice of biomass fast pyrolysis processes for liquids*. Journal of Analytical and Applied Pyrolysis 51, 3-22, 1999. | *biomass, fast pyrolysis, pyrolysis technology, bio-oil* |
| **31** | Scott DS, Majerski P, Piskorz J, Radlein D. *A second look at fast pyrolysis of biomass - the RTI process.* Journal of Analytical and Applied Pyrolysis 51, 23-37, 1999. | *biomass, fast pyrolysis, bubbling fluidized bed, bio-oil* |
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| **33** | Burnham AK, Braun LR. *Global kinetic analysis of complex materials*, Energy & Fuels 13, 1-22, 1999. | *biomass, pyrolysis, kinetic modeling* |
| **34** | Lede J. *Solar thermochemical conversion of biomass*, Solar Energy 65, 3-13, 1999 | *slow pyrolysis, fast pyrolysis, gasification, concentrated solar energy* |
| **35** | Oasmaa A, Czernik S. *Fuel oil quality of biomass pyrolysis liquids - state of the art for the end users.* Energy & Fuels, 13, 914 - 921, 1999. | *biomass, pyrolysis, bio-oil, bio-oil applications* |
| **36** | Di Blasi C. *The state of the art of transport models for charring solid degradation.* Polymer International, 49, 1133-1146, 2000. | *wood, pyrolysis, chemical kinetics, transport models* |

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# Reviews on biomass pyrolysis...continued

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| 37 | Diebold JP. *A review of the chemical and physical mechanisms of the storage stability of fast pyrolysis bio-oils.* NREL/SR-570-27613, 2000. | *pyrolysis, bio-oil, storage stability* |
| 38 | Bridgwater AV, Peacocke GVC. *Fast pyrolysis processes for biomass. Renewable and Sustainable Energy Reviews* 4, 1-73, 2000. | *biomass, pyrolysis, pyrolysis technology, products* |
| 39 | Conesa JA, Marcilla A, Caballero JA, Font R. *Comments on the validity and utility of the different methods for kinetic analysis of thermogravimetric data*. Journal of Analytical and Applied Pyrolysis 58-59, 617-633, 2001. | *biomass, pyrolysis, TG, DTG, chemical kinetics* |
| 40 | Amen-Chen C, Pakdel H, Roy C. *Production of monomeric phenols by thermochemical conversion of biomass: a review.* Bioresource Technology 79, 277-299, 2001. | *biomass, pyrolysis, phenols* |
| 41 | Oasmaa A, Peacocke C. *A guide to physical property characterisation of biomass-derived fast pyrolysis liquids*. Espoo, VTT Energy. 65 p. + app. 34 VTT Publications; 450. ISBN 951-38-5878-2; 951-38-6365-4. 2001. | *biomass, fast pyrolysis, pyrolysis liquid, characterization* |
| 42 | McKendry P. *Energy production from biomass (part 2): conversion technologies*. Bioresource Technology 83, 55-63, 2002. | *biomass, energy conversion, gasification, pyrolysis* |
| 43 | Diebold J. *A review of chemical and physical mechanisms of the storage stability of fast pyrolysis bio-oils.* In Fast Pyrolysis of Biomass: A Handbook Vol. 2, Bridgwater AV (Ed.) pp. 243-292. CPL Press, Newbury, 2002. | *biomass, pyrolysis, bio-oil, bio-oil stability* |
| 44 | Bridgwater AV, Czernik S, Piskorz J. *The status of biomass fast pyrolysis*. In Fast Pyrolysis of Biomass a Handbook Vol. 2; Bridgwater AV (Ed.), CPL Press, Newbury, UK, pp 1-22, 2002. | *biomass, fast pyrolysis, pyrolysis technology, bio-oil* |
| 45 | Piskorz J. *Fundamentals, mechanisms and science of pyrolysis. In Fast Pyrolysis of Biomass:* a Handbook, Vol. 2, Bridgwater AV (Ed.), CPL Press, Newbury, UK, pp. 103-140, 2002. | *biomass, pyrolysis, fundamentals* |
| 46 | Czernik S, Maggi R, Peacocke GVC. *Review of methods for upgrading biomass-derived fast pyrolysis oils,* In Fast Pyrolysis of Biomass: a Handbook, Vol. 2, Bridgwater AV (Ed.), CPL Press, Newbury, UK; pp. 141-146, 2002. | *biomass, fast pyrolysis, bio-oil, upgrading* |
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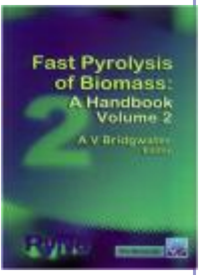
| 48 | Oasmaa A, Meier D. *Analysis, characterization and test methods of fast pyrolysis liquids.* In Fast Pyrolysis of Biomass a Handbook Vol. 2; Bridgwater AV (Ed), CPL Press, pp 23-40, 2002. | *biomass, fast pyrolysis, bio-oil, chemical characterization* |
| 49 | Meier D. *Summary of the analytical methods available for chemical analysis of pyrolysis liquids.* In Fast Pyrolysis of Biomass a Handbook Vol. 2, Bridgwater AV (Ed), CPL Press, pp 59-68, 2002. | *biomass, fast pyrolysis, bio-oil, chemical characterization* |
| 50 | Radlein D. *Study of levoglucosan production - a review*. In Fast Pyrolysis of Biomass: a Handbook, Vol. 2, Bridgwater AV (Ed.), CPL Press Newbury UK, pp. 205-241, 2002. | *biomass, fast pyrolysis, bio-oil, chemicals, levoglucosan* |
| 51 | Dobele G. *Production, properties and use of wood pyrolysis oil - a brief review of the work carried out at research and production centers of the former USSR from 1960 to 1990.* In Fast Pyrolysis of Biomass: a Handbook, Vol. 2, Bridgwater AV (Ed.), CPL Press, Newbury, UK, pp. 147-204, 2002. | *biomass, fast pyrolysis, bio-oil, chemicals* |
| 52 | Bridgwater AV, Toft AJ, Brammer JG. *A Techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion*. Renewable and Sustainable Energy Reviews 6: 181-248, 2002. | *biomass, pyrolysis, gasification, combustion, economics* |
| 53 | Antal MJ, Gronli MG. *The art, science and technology of charcoal production*. Industrial & Engineering Chemistry Research 42, 1619-1640, 2003. | *biomass, pyrolysis, flash carbonization, charcoal* |
| 54 | Bridgwater AV. *Renewable fuels and chemicals by thermal processing of biomass.* Chemical Engineering Journal 91, 87-102, 2003. | *biomass, fast pyrolysis, bio-oil, chemicals, gasification* |
| 55 | Czernik S, Bridgwater AV. *Overview of application of biomass fast pyrolysis oil*. Energy & Fuels 18: 590-598. 2004. | *biomass, fast pyrolysis, bio-oil, bio-oil applications* |
| 56 | Bridgwater AV. *Biomass fast pyrolysis*. Thermal Science 8(2), 21-49, 2004. | *biomass, fast pyrolysis, bio-oil* |
| 57 | Kersten SRA, Wang X, Prins W, van Swaaij WPM. *Biomass pyrolysis in a fluidized bed reactor. Part 1: Literature review and model simulations*. Industrial & Engineering Chemistry Research 44, 8773-8785, 2005. | *biomass, pyrolysis, chemical kinetics, particle models* |



**Continued on page 31**

# Reviews on biomass pyrolysis...continued

| | Author, Paper, Publication | *Key words* |
|---|---|---|
| **58** | Caballero JA, Conesa JA. *Mathematical considerations for nonisothermal kinetics in thermal decomposition.* Journal of Analytical and Applied Pyrolysis 73, 85-100, 2005. | *biomass, pyrolysis, TG, DTG, chemical kinetics* |
| **59** | Gronli M, Antal MJ, Schenkel Y, Crehay R. *The science and technology of charcoal production.* In Fast Pyrolysis of Biomass: A Handbook Vol. 3, Bridgwater AV (Ed.), CPL Press, Newbury, UK, pp. 147-178, 2005. | *biomass, pyrolysis, flash carbonization, charcoal yield, charcoal production*  |
| **60** | Di Blasi C. *Kinetics and modeling of biomass pyrolysis,* In Fast Pyrolysis of Biomass: A Handbook Vol.3, Bridgwater AV (Ed.), CPL Press, Newbury, UK, pp. 121-146, 2005. | *biomass, pyrolysis, kinetic models, transport model* |
| **61** | Czernik S, Bridgwater AV. *Applications of biomass fast pyrolysis oil.* In Fast Pyrolysis of Biomass: A Handbook Vol. 3 Bridgwater AV (Ed.), CPL Press, Newbury, UK, pp. 105-120, 2005. | *biomass, fast pyrolysis, bio-oil, bio-oil applications* |
| **62** | Oasmaa A, Meier D. *Characterization, analysis, norms & standards.* In Fast Pyrolysis of Biomass: A Handbook Vol. 3, Bridgwater AV (Ed.), CPL Press, Newbury, UK, pp. 19-60, 2005. | *biomass, fast pyrolysis, bio-oil, bio-oil characterization* |
| **63** | Gust S, McLellan RJ, Meier D, Oasmaa A, Ormrod D, Peacocke GVC. *Determination of norms and standards for bio-oil as an alternative renewable fuel for electricity and heat production.* In Fast Pyrolysis of Biomass: A Handbook Vol. 3, Bridgwater AV (Ed.), CPL Press, Newbury, UK, pp. 9-18, 2005. | *biomass, fast pyrolysis, bio-oil, heat and power production* |
| **64** | Oasmaa A, Peacocke C, Gust S, Meier D, McLellan R. *Norms and Standards for Pyrolysis Liquids. End-User Requirements and Specifications.* Energy & Fuels, Vol. 19, 5, ss. 2155-2163. 2005. | *biomass, pyrolysis, bio-oil, round robin test, characterisation* |
| **65** | Huber GW, Iborra S, Corma A. *Synthesis of transportation fuels from biomass: chemistry, catalysts and engineering.* Chem. Rev. 106, 4044-4098, 2006 | *biomass chemistry, gasification, syngas utilization, bio-oil production, bio-oil upgrading, biomass monomer production* |
| **66** | Mohan D, Pittman CU, Steele P. *Pyrolysis of wood/biomass for bio-oil: a critical review*. Energy & Fuels 20, 848-889, 2006. | *biomass chemistry, pyrolysis, bio-oil* |
| **67** | Fernando S, Adhikari S, Chandrapal C, Murali N. *Biorefineries: current status, challenges, and future direction.* Energy & Fuels 20, 1727-1737, 2006. | *chemicals, biorefinery, gasification, pyrolysis* |
| **68** | Moghtaderi B. *The state-of-the-art in pyrolysis modeling of lignocellulosic solid fuels.* Fire and Materials 30, 1-34, 2006. | *pyrolysis, wood, mathematical modeling* |
| **69** | Ni M, Leung DYC, Leung MKH, Sumathy K, *an overview of hydrogen production from biomass.* Fuel Processing Technology 87, 461-472, 2006. | *biomass, pyrolysis, gasification, supercritical water, fermentation, biophotolysis* |
| **70** | Chiaramonti D, Oasmaa A, Solantausta Y. *Power generation using fast pyrolysis liquids from biomass.* Renewable and Sustainable Energy Reviews 11, 1056-1086, 2007. | *biomass, pyrolysis, bio-oil, power, gas turbine, engine, co-firing* |
| **71** | Chiaramontia D, Oasmaa A, Solantausta Y, Peacocke C. *The use of biomass derived fast pyrolysis liquids in power generation: Engines and turbines.* Power Engineer, vol. 11, 5, ss. 3 – 25. 2007. | *biomass, fast pyrolysis, engines, turbines* |
| **72** | Di Blasi C. *Modeling chemical and physical processes of wood and biomass pyrolysis.* Progress in Energy and Combustion Science 34: 47-90, 2008 | *wood, biomass, pyrolysis, chemical kinetics, transport models* |
| **73** | Oasmaa A., Elliot DC, Muller S. *Quality control in fast pyrolysis bio-oil production and use.* Environmental Progress & Sustainable Energy 28, 404-409, 2009. | *bio-oil, norms and standards* |
| **74** | Elliott DC. *Historical developments in hydroprocessing bio-oils*, Energy and Fuels, 2007, vol. 21, (3), 1792-1815. 2010 | *pyrolysis, catalysis, hydrotreating, hydrocracking, upgrading* |
| **75** | Van de Velden M, Baeyens J, Brems A, Janssens B, Dewil R. *Fundamentals, kinetics and endothermicity of the biomass pyrolysis reaction.* Renewable Energy 35, 232-242, 2010. | *biomass particle, heat of reaction* |
| **76** | Oasmaa A, Peacocke C. *A guide to physical property characterisation of biomass-derived fast pyrolysis liquids*. Espoo, VTT. 79 p. + app. 46 p. VTT Publications; 731, ISBN 978-951-38-7384-4. 2010. | *biomass, fast pyrolysis, pyrolysis liquids, characterisation* |
| **77** | Bridgwater AV. *Upgrading biomass fast pyrolysis liquids.* Chapter 6 in: Thermochemical Processing of Biomass: Conversion into Fuels, Chemicals and Power. Brown RC. (ed.) Wiley Series in Renewable Resources. 2011. Wiley-Blackwell. ISBN: 978-0-470-72111-7 | *fast pyrolysis liquid, quality, upgrading, catalysts* |
| **78** | Bridgwater AV, *"Review of fast pyrolysis and product upgrading"*, Biomass and Bioenergy, (2011) 1-27 | *pyrolysis technology, liquid bio-oil, upgrading, catalyst* |

# Country Update — Finland

**VTT (Technical Research Centre of Finland)**
Anja Oasmaa of VTT is serving as the national team lead for Finland. At VTT, the biomass pyrolysis research is focused on two 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 involves also work on modelling of biomass pyrolysis.

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).

**ÅA (Åbo Akademi University)**
At ÅA, pyrolysis and gasification of black liquor (biomass bio-product from pulping industry) are 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 typically contain 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 zeolitie 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].

[1] Aho, A.; Kumar, N.; Lashkul, A. V.; 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)

**See the following pages for further updates from Finland**

| Article title | Contributor | Pages |
|---|---|---|
| The greenhouse gas emission saving of logging residue-based pyrolysis oil | VTT | 7-9 |
| Woody biomass catalytic pyrolysis research | Åbo Akademi University | 13-15 |
| Modelling an integrated fast pyrolysis process with Aspen Plus | VTT | 23-25 |

# Country Update — USA

**PNNL (Pacific Northwest National Laboratory)**
Upgrading by hydroprocessing remains a key component of the research into effects of operating parameters and catalyst composition on fouling of the catalyst bed by polymerization. PNNL leads the new project effort in developments in fixed catalyst bed processing to allow extended operation (>1000 hr) of hydrotreating fast pyrolysis bio-oil. PNNL is also involved in the Grace led effort to develop a new catalytic reactor system for hydrotreating bio-oil. Battelle (Columbus, Ohio) will lead a team to develop catalytic pyrolysis as a means to produce a more stable and more readily hydrotreatable bio-oil with the help of PNNL.

**NREL (National Renewable Energy Laboratory)**
NREL studies catalytic fast pyrolysis in both micro scale and bench scale and assesses alternative hydrotreating processes that are active at mild conditions. An analysis of preferred pathways from biomass to conventional oil refineries via pyrolysis was recently completed by a subcontractor, Global Energy Management Institute (GEMI), at the University of Houston in a collaboration with Valero.
NREL has been successfully demonstrating hot gas filtration of pyrolysis vapors in its Thermochemical Conversion User Facility as part of a bio-oil stabilization project in partnership with UOP and Pall Corporation.

**The University of Maine**
Metal oxides, metal nitrides, and supported metal catalysts for upgrading biomass-based fuels are all being developed by the University of Maine's Forest Bioproducts Research Institute and collaborators at Bates and Bowdoin Colleges using a rational approach that relies on understanding the relationships between catalyst structure and reactivity and selectivity. Novel pyrolysis schemes are also being studied using various biomass fractions such as lignin and hydrolyzed cellulose.  The latter has resulted in a high-yield, atmospheric pressure, non-catalytic method for producing completely-deoxygenated hydrocarbon oils.

**NABC (National Advanced Biofuels Consortium)**
This consortium is funded by the Department of Energy with industrial co-funding. The six advanced technologies being investigated include catalytic pyrolysis, hydropyrolysis, and hydrothermal liquefaction. Process research has been underway for almost a year and the technology teams are coming up on the "down select" in which two or three (or more?) of the technologies will become the focus of the consortium for two more years of R&D. The goal of the consortium is to have at least one technology ready for building a demonstration plant by the end of the three year life of the consortium.

**Mississippi State University** is fabricating a 4-ton per day pilot scale pyrolysis reactor with biomass receiving and processing capabilities.  Two fuels will also be produced in the pilot plant from the bio-oil produced in the reactor. The reactor is being built off-site and will be moved to the pilot facility upon its completion in early August 2011. MSU will produce fuels in the pilot facility for large-scale engine and boiler testing when all pilot-scale components are complete.

# Country Update — Germany

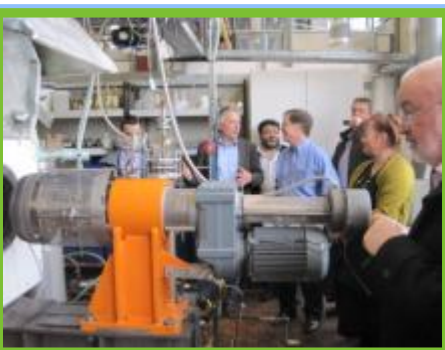
**KIT – Karlsruhe Institute of Technology, Karlsruhe** is developing the bioliq® process which comprises fast pyrolysis of straw in a twin screw reactor, slurry preparation by mixing bio-oil with char, slurry gasification to syngas in a pressurized entrained flow gasifier, and direct synthesis of DME (Dimethylether). Several test campaigns of the pyrolysis section have been successfully performed. Results of yields and overall composition of liquid, gaseous and solid products were comparable with laboratory tests Currently, the gas cleaning and the gasifier sections are under construction.

**CHOREN Industries GmbH, Freiberg**. CHOREN has carried out several successful operating campaigns to test the plant's synthesis gas production at the ß-scale. This includes: (1) start-up of low temperature gasifier with feeding of the multi-channel burner of the gasifier with pyrolysis gases, (2) test of chemical quench by feeding the pyrolysis coke to the endothermic reactor, (3) feeding the residual coke to the high temperature gasifier. Hot commissioning has started. Commissioning of gas conditioning, FT-catalyst, shift-catalyst and cracker catalyst is in progress.

**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 been continuing their activities in ablative fast pyrolysis. Tests of the injections system of the diesel engine using innovative new materials are underway. A new laboratory ablative pyrolysis system (15 kg/h) was commissioned and has been delivered for a client.

**vTI-HTB – Institute 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.



**Task 34 meeting in Germany**
See page 6 for a review of the recent Task 34 Pyrolysis meeting held in Hamburg, Germany which included a visit to:

- Johann Heinrich von Thünen-Institut for Wood Technology and Biology at the University of Hamburg *(photo top left)*
- PyTec laboratory, Hamburg *(photo top right)*
- PyTec ablative fast pyrolysis pilot plant Bülkau, near Cuxhaven, North Germany *(see photos bottom left and right)*

# Country Update — UK

**Cranfield University's** Centre for Energy and Resource Technology (CERT) operates a fixed bed reactor (up to 75 kWth) in both pyrolysis and gasification modes. This uses electrical trace heating to maintain the pyrolysis process temperature. The product gases are analyzed using infrared and thermal conductivity sensors with sampling of all other process streams and residues. This facility has been used to investigate slow and intermediate pyrolysis using different types of fuels, such as waste and biomass, with respect to efficiency and contaminant issues (e.g. tar recovery).

### North East Biomass to Liquid (BtL) project

A report has been published by the NNFCC which considers alternative thermochemical process routes from solid raw biomass to hydrocarbons or blendable alcohols, including biomass supplies, pretreatment by fast pyrolysis and torrefaction, preparation, gasification, direct and indirect synthesis of hydrocarbons and incorporation of products into transport fuel infrastructures.

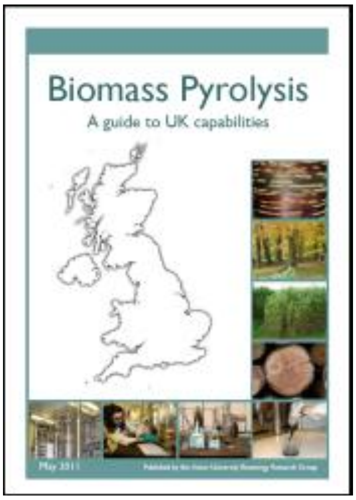
Particular attention has been paid to the trade off between pretreatment by fast pyrolysis and the impact on gasification showing that although there is a small increase in overall capital cost with addition of multiple decentralised fast pyrolysis units, these may be justified by the logistical and environmental advantages.

Visit the publications section of www.nnfcc.co.uk to download the report on 30 July 2009 (NNFCC08—18).

**University of Southampton** is working on a collaborative project with South Africa focusing on the development of computational models which work as effective tools for process design, optimisation and scale-up for biomass fast pyrolysis systems. The joint research program aims to form a constructive collaboration with UK expertise in computational modelling and South Africa experience in chemical process engineering.

**See page 5 for information about another South African collaboration with the USA**.

# Other UK news



### New guide on biomass pyrolysis capabilities in the UK

Aston University Bioenergy Research Group has produced a new guide, which summarises the range of biomass pyrolysis research and commercial activities currently being undertaken in the UK.

It has been devised to act as an aid to all involved in the expanding area of biomass pyrolysis including researchers, companies, policy makers, decision makers and stakeholders.

The guide contains a foreword from Professor David MacKay, Chief Scientific Advisor at the UK Department of Energy and Climate Change (DECC), plus contributions from a variety of organisations involved in pyrolysis activities.

**Visit the 'Newsletters and Publications' section on the PyNe website to download the guide.**

**www.pyne.co.uk**

# Country Update — Canada

**CanmetENERGY**
Fernando Preto of CanmetENERGY Ottawa is serving as the national team lead for Canada. CanmetENERGY is the science and technology arm of the Innovation and Energy Technology Sector (IETS) of Natural Resources Canada.

At CanmetENERGY Ottawa, current biomass pyrolysis research is focused on industrial partnerships to accelerate implementation of bioenergy technologies. 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 an automated package boiler typically fired with No.2 fuel oil or natural gas. The objective of the project is to demonstrate substitution of bio-oil for natural gas in an existing commercial scale (3 $MW_{th}$) boiler. It is expected that this demonstration could lead to full-scale implementation at CanmetENERGY's Bells Corners Complex heating plant in Ottawa.

# Canadian Event

**biofuels international**

co-hosted with
TANK STORAGE CANADA

**Canada expo & conference**

This year's conference will look in detail at those plants that are in production or construction and will help others in the industry learn from their success. Conference topics will also look at the impacts of regulations and how these are likely to evolve.

The event brings together biodiesel and ethanol producers, oil majors, regulators and investors to discuss how to support the market's continued development. Conference topics will include a clear explanation of the Federal Renewable Fuels Regulations, influences from the US regulatory environment, case studies of how ethanol can be produced from cellulosic feedstocks, information on future feedstock options such as algae, how facilities can secure the necessary finance and investment to grow and develop, the importance of plant design, how to ensure final fuel quality, and how to integrate biofuels into the supply chain

**3 - 4 October 2011**
**Telus Convention Centre**
**Calgary, Alberta, Canada**

### Attend the conference

For further information contact:
Rebecca Shears
Marketing & Event Manager
Email: rebecca@horseshoemedia.com
Tel: +44 20 8687 4138

**www.biofuelsinternationalexpo.com/canada**

*See Worldwide Events section on pages 37 and 38 for details of forthcoming conferences and exhibitions around the globe*

# *Worldwide Events*

## JUNE 2011

21st-24th
**International Conference 'Renewable Wood and Plant Resources: Chemistry, Technology, Pharmacology, Medicine'**
St Petersburg, Russia

22nd-24th
**Clean Energy Expo China**
Beijing, China

29th-30th
**AEBIOM European Bioenergy Conference & RENEXPO® Bioenergy EUROPE**
Brussels, Belgium

## JULY 2011

6th-7th
**UK AD & Biogas 2011**
Birmingham, UK

26th-27th
**Biomass 11**
Grand Forks, North Dakota, USA

26th—27th
**Biomass 2011—Replace the Whole Barrel; Supply the Whole Market**
National Harbor, Washington, USA

## AUGUST 2011

30th August—1st September
**ICPS—International Conference on Polygeneration Strategies**
Vienna, Austria

## SEPTEMBER 2011

5th-9th
**International Nordic Bioenergy 2011**
Jyväskylä, Finland

13th-15th
**International Biomass Valorisation Congress 2011**
Woerden, the Netherlands

14th
**Assises Nationales des Déchets**
Nantes, France

20th-21st
**7th International Conference on Biomass for Energy**
Kiev, Ukraine

22nd-25th
**RENEXPO 2011**
Augsburg, Germany

25th-27th
**8th Congress on Chemical Engineering, 1st European Congress of Applied Biotechnology**
Berlin, Germany

27th-30th
**tcbiomass2011**
Chicago, USA

28th-29th
**2nd Annual Lignofuels Summit**
Copenhagen, Denmark

28th-29th
**World Biofuels Markets Brazil**
São Paulo, Brazil

## OCTOBER 2011

3rd-4th
**Bioenergy International Canada Expo and Conference**
Alberta, Canada

4th-7th
**Catalysis for Biorefineries (CatchBio)**
Torremolinos, Málaga, Spain

5th-6th
**European Bioenergy Expo & Conference (EBEC)**
Stoneleigh Park, UK

10th-14th
**XIX ISAF International Symposium on Alcohol Fuels (including 2nd Lignocellulosic Bioethanol (2LB) Conference**)
Verona, Italy

## NOVEMBER 2011

7th–10th
**F.O. Licht's 14th Annual World Ethanol & Biofuels**
Barcelona, Spain

10th
**Bioenergy from Sustainable Forests**
Brussels, Belgium

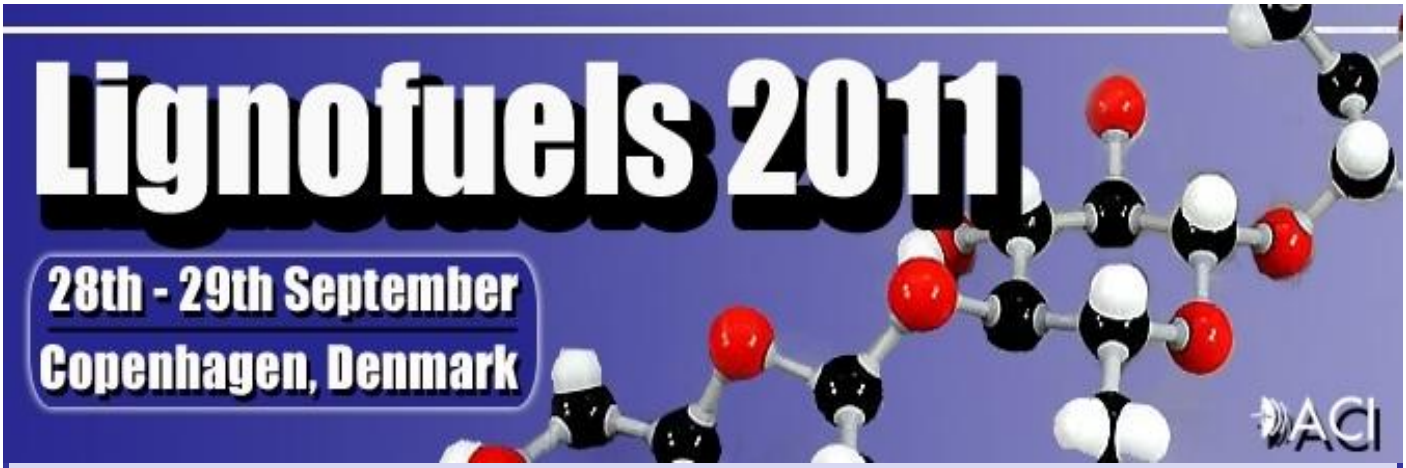
16th-17th
**Biofuels International Expo and Conference**
Antwerp, Belgium

24th-26th
**Renexpo International Trade Fair and Conference for Renewable Energy**
Salzburg, Austria

## DECEMBER 2011

7th-8th
**Bioenergy International Asia Expo & Conference**
Kuala Lumpur, Malaysia

# *Events...continued*



### Key Topics Include:

- Economic Challenges & Developments of Lignofuels
- European Market Outlook & Policy
- Feedstock Optimisation
- Biobutanol Production
- Pretreatment Technologies
- Gasification & Pyrolysis Pathways
- Fermentation & Hydrolysis Improvements
- Future Advancements to Meet Requirements of Transportation Industry

### Site Visit

BioGasol's Pretreatment and C5 Fermentation Pilots—Tuesday 27th September 2011

### For more information or to register contact

Dimitri Pavlyk on +44 207 981 2503 or email: dpavlk@acieu.co.uk

**Visit www.acius.net/aci/conferences/**

### 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.

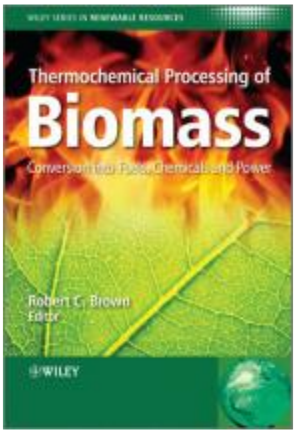
### Location

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

**Visit www.gastechnology.org for further information**

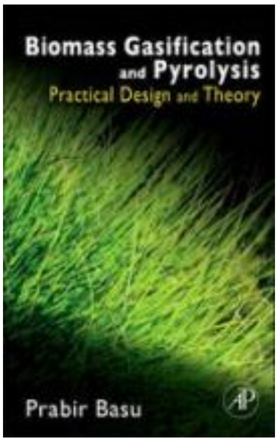
# Publications

## Books



**Thermochemical Processing of Biomass**
Conversion into Fuels, Chemicals and Power
*Edited by Robert C Brown*
Published by Wiley—www.wiley.com

Content includes:
1. **Introduction**—R.C. Brown
2. **Biomass Combustion**—B.M. Jenkins, L.L. Baxter and J. Koppejan
3. **Gasification**—R.L. Bain and K. Broer
4. **Syngas Cleanup, Conditioning and Utilization**—D.C. Dayton, B. Turk and R. Gupta
5. **Fast Pyrolysis**—R.H. Venderbosch and W. Prins
6. **Upgrading Fast Pyrolysis Liquids**—A.V. Bridgwater
7. **Hydrothermal Processing**—D.C. Elliott
8. **Catalytic Conversion of Sugars to Fuels**—G.A. Tompsett, N. Li and G.W. Huber
9. **Hybrid Processing**—D. Won Choi, A.A. DiSpirito, D.C. Chipman and R.C. Brown
10. **Costs of Thermochemical Conversion of Biomass to Power and Liquid Fuels**—M.M. Wright and R.C. Brown



**Biomass Gasification and Pyrolysis**
**Practical Design and Theory**
*Prabir Basu*
Published by Academic Press—www.academicpress.com

Content includes:
1. Biomass Characteristics
2. Pyrolysis and Torrefaction
3. Tar Production and Destruction
4. Gasification Theory and Modelling of Gasifiers
5. Design of Biomass Gasifiers
6. Hydrothermal Gasification of Biomass
7. Biomass Handling
8. Production of Synthetic Fuels and Chemicals from Biomass

## Newsletters

Past editions of the PyNe newsletter can be found in the 'Newsletter & Publications' section of the PyNe website at www.pyne.co.uk

# Further Information

If you require further information about the PyNe newsletter or would like to contribute to future editions, please contact the Editor, Irene Watkinson, at:

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IEA Bioenergy

Task 34 Pyrolysis

PyNe
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