Bioenergy carriers -
Integrated pyrolysis and
torrefaction concepts

‘Thermal pre-treatment of biomass for large-scale applications’
IEA Bioenergy ExCo 66, York, UK 12.10.2010

Kai Sipilä, Yrjö Solantausta, Carl Wilén
VTT Technical Research Centre of Finland

Esa Sipilä
Pöyry Management Consulting
Content

- EU policies and the 2020 targets will increase the market for renewable energy sources, especially for bioenergy. Currently ~ 65% of RES demand, 2 x current volumes?

- Ambitious target for 10% biofuels in transport and large scale green electricity production. Huge fuel demand.

- Lack of low price raw material sources, key focus to overall chain integration and efficiencies. Biomass trade.

- EIBI European Industrial Bioenergy Initiative call for new solutions in 7 value chains – bioenergy carrier is one.

- Pyrolysis and torrefaction integration to current forest biomass operation. Parallel to utility and refinery actions.

- Conclusions and recommendations
Is biomass availability sufficient?

Gross inland consumption

Final energy consumption

Source: Jean Marc Jossart, Aebiom
"Evaluation of the National Renewable Energy Action Plans"
Forest Bioenergy Conf, Tampere 2010
Renewable energy sources in Finland

Hydropower 14.5%, 48 949 TJ
Biodegradable fraction of waste 1.3%, (4 543 TJ)
Biogas 0.5%, 1 747 TJ
Heat pumps 1.8%, 6 560 TJ
Other bioenergy 0.2%, 814 TJ

Wind power 0.2%, 612 TJ
Solar energy 0.0%, 29 TJ

Wood fuels 81.4%
275 283 TJ (76.5 TWh)

Small-scale use of wood fuels 17.6%, 48 160 TJ
Industrial wood residues and by-products 34.5%, 94 996 TJ
Black liquor and other concentrated liquors 47.9%, 132 127 TJ

Renewable energy sources 338 537 TJ (8.1 Mtoe), 25% of total energy consumption
Advanced conversion paths based on thermochemical processes

1. Synthetic fuels / hydrocarbons from biomass via **GASIFICATION**
   - Main markets: renewable transport fuels for jet and diesel engines

2. Bio-methane and other gaseous fuels from biomass via **GASIFICATION**
   - Substituting natural gas and other gaseous fuels

3. High efficiency power generation via **GASIFICATION** of biomass
   - Power and heat

4. Bioenergy carriers via other thermochemical processes (e.g. **PYROLYSIS, TORREFACTION**)
   - Fuels for heating, power generation or intermediates for upgrading into transport fuels
Advanced conversion paths based on biological and chemical processes

1. **Lignocellulosic feedstocks**
   - SUGARS
   - Ethanol and higher alcohols from sugar via **FERMENTATION**
   - Main markets: Renewable transport fuels as gasoline components, E85

2. **Multipurpose sugar & starch crops**
   - SUGARS
   - Renewable hydrocarbons from sugar-containing biomass via **BIOLOGICAL PROCESSES** and/or **CHEMICAL PROCESSES**
   - Main markets: renewable transport fuels for jet and diesel engines

3. **Microbial biomass (e.g. microalgae, bacteria)**
   - SUGARS
   - Bioenergy carriers from CO₂ and light through **MICROORGANISM-BASED PRODUCTION** and upgrading into transport fuels and valuable bioproducts
### EBTP proposal for EIBI

#### Budget, timing & funding

<table>
<thead>
<tr>
<th>7 “generic” value chains</th>
<th>Estimated # of demo / reference needed</th>
<th>Total estimated budget M€</th>
<th>Public funding M€</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Synthetic fuels / hydrocarbons from biomass via gasification</td>
<td>1 D 2 R</td>
<td>1300-1700</td>
<td>650-850</td>
<td>50%/50%</td>
</tr>
<tr>
<td>2 Bio-methane and other gaseous fuels from biomass via gasification</td>
<td>1 D,2 R</td>
<td>500 - 800</td>
<td>250-400</td>
<td>50%/50%</td>
</tr>
<tr>
<td>3 High efficiency power generation via gasification of biomass</td>
<td>2 R</td>
<td>600 - 900</td>
<td>300-450</td>
<td>50%/50%</td>
</tr>
<tr>
<td>4 Bioenergy carriers from biomass via other thermochemical processes like pyrolysis, torrefaction etc.</td>
<td>2 R</td>
<td>300 - 400</td>
<td>150-200</td>
<td>50%/50%</td>
</tr>
<tr>
<td>5 Ethanol and higher alcohols from carbohydrates containing biomass [1]</td>
<td>1D 2 R</td>
<td>900 - 1200</td>
<td>450-600</td>
<td>50%/50%</td>
</tr>
<tr>
<td>6 Renewable hydrocarbons from carbohydrates containing biomass via biological and/or chemical process</td>
<td>2 D 1 R</td>
<td>400 - 500</td>
<td>200-250</td>
<td>50%/50%</td>
</tr>
<tr>
<td>7 Production of bioenergy carriers from CO2 &amp; sunlight through micro-organism based production (algae, bacteria etc.) and further upgrading into transportation fuels and valuable bio-products</td>
<td>2-3 D 1 R</td>
<td>1200 - 1500</td>
<td>600-750</td>
<td>50%/50%</td>
</tr>
</tbody>
</table>

#### Additional activities

| B | - Contribution to production and harvesting of biomass | 800 -1000 | 400-500 | 50%/50% |
|   | - Reserve for still unidentified value chains |

**Total** 6000 - 8000 3 000-4000

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*RSFF = Risk Sharing Finance Facility
Bioenergy Market Potential in European Forest Industry to 2G Biofuels and CHP by 2020

Kai Sipilä & Satu Helynen, VTT
Esa Sipilä & Jaakko Jokinen, Pöyry Forest Industry Consulting

17th European Biomass Conference
Hamburg 30.6.2009
There Are More Than 950 Pulp and Paper Mills in Europe – how large market potential by 2020, raw material demand?
BIOFUELS FROM FOREST INDUSTRY
- wood logistics and process integration benefit -

Forest biomass in future also urban waste and straw - Southern hemisphere plantations

Optional Biofuels:
- pellets
- bio oil
- EtOH/MeOH...
- FT Biodiesel
- DME

BioPower
Tax incentives and policies will prioritize long term business interest

< 500 MWf

< 400 MWf

Bark boiler

Biofuel production

Power Steam

Power

Heat

Steam

Refinery

Crude Oil

BioPower

Wood residues

Wood handling

Pulp & Paper Mill

Bark

Paper and Market pulp

Forest biomass

in future also urban waste and straw - Southern hemisphere plantations
Wood Flows by End Uses in EU-27

- **NATURAL FOREST, PLANTATIONS, PARKS**
  - SAWLOGS / PLYLOGS 236 million m³
  - PULPWOOD 162 million m³
  - HOUSEHOLD FIREWOOD 100 million m³
  - HARVEST RESIDUES 15 million m³
  - OTHER ENERGY WOOD 10 million m³

- **PROCESSING**
  - SAWNWOOD 114 million m³
  - WOOD PANELS 62 million m³
  - WOOD PULP 41 million t
  - PAPER & PAPERBOARD 100 million t

- **TRANSPORT**
  - PLANING
  - SOLID WOOD RESIDUES 180 million m³
  - BLACK LIQUOR 12 Mtoe
  - RECOVERED WOOD 20 million t
  - RECOVERED PAPER 50 million t
  - PELLETS, 8 million t
  - BIODIESEL / ETHANOL

- **WOOD BASED HEAT AND POWER** 61 Mtoe (2006)

- **NET IMPORTS**
  - RECOVERED WOOD 20 million t
  - RECOVERED PAPER 50 million t
  - HOUSEHOLD FIREWOOD 100 million m³
  - HARVEST RESIDUES 15 million m³
  - OTHER ENERGY WOOD 10 million m³

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- **WOOD BASED HEAT AND POWER** 61 Mtoe (2006)
Methods for VTT-Pöyry Bioenergy Market Potential Analysis

Analysed technologies in EU forest industry

- Wood fuel oil
- Green electricity
- FT-biodiesel from wood
- EtOH from waste fibre
- DME
- TOP torrefaction

- Process steam demand is limiting the industrial CHP+Fuel capacity.
Replacement potential of ~ 60 Solid Fuel Boilers in European Pulp and Paper industry by 2020

The basis for this market potential analysis is the replacement potential of old solid fuel boilers - 50% replacement for over 25 years old boilers and 25% for boiler over 15 years old.

Note: Number following the country’s name is the total number of solid fuel boiler in pulp and paper industry.
The total business potential of liquid biofuels in European pulp and paper industry with selected bioenergy technologies has a revenue potential of 2 500 - 5 000 MEUR/a and a investment potential 11 000 - 16 000 MEUR by year 2020.
Wood Bio-oil (Pyrolysis Oil) Market Potential

Business potential is calculated with the following predictions:

• Over 25 years old solid fuel boilers in European P&P industry will be replaced with new fluidised bed boilers and pyrolyzers with 50% penetration before year 2020.

• 25% penetration of fluidised bed boilers with pyrolysis for 15-25 years old boilers.

• Fuel input of the pyrolyzer was selected to be 25 MW in <50 MW boilers, 40 MW in 50-100 MW boilers and 80 MW in >100 MW boilers. Integration to main FB-boiler.

• Numbers of boilers in each country is based only on the boiler data with size and age known in the Pöyry’s database.

• Pyrolysis oil can be processed to transportation fuels in existing oil refineries in Europe (e.g. Biocoupe project).
Wood Oil Market Potential – 11 TWh/a

- Pyrolysis oil production potential is 11 000 GWh/a, ~ 0.95 Mtoe in 58 units, with the product value of 330 M€/a in selected countries.

- This pyrolysis oil production potential covers 130 % of fossil fuels used in European lime kilns!

- Solid wood fuel demand for pyrolysis is then 17 TWh/a which is 14 % of the European forest residue potential

- Main results were presented in details in the 15th European Bioenergy Conference
DECREASE IN ASH AND HARMFUL ELEMENTS IN PYROLYSIS

Potassium (K), Chlorine (Cl), and Sulphur (S)

More than 90% of total ash removed in pyrolysis
- Up to 95% decrease in K
- Up to 90% decrease in Cl
- Up to 80% decrease in S

Less ash sintering and melting
Less corrosion and fouling

<table>
<thead>
<tr>
<th></th>
<th>Forest residue Feedstock</th>
<th>Oil</th>
<th>Wheat straw Feedstock</th>
<th>Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>K, ppm</td>
<td>1500 - 1800</td>
<td>40 - 110</td>
<td>9000</td>
<td>900</td>
</tr>
<tr>
<td>Cl, ppm</td>
<td>100 - 300</td>
<td>20 - 40</td>
<td>2900</td>
<td>1100</td>
</tr>
<tr>
<td>S, ppm</td>
<td>400 - 800</td>
<td>90</td>
<td>1200</td>
<td>850</td>
</tr>
</tbody>
</table>

VTT results: solid content in the product < 0.5 m-%

Source: Anja Oasmaa, VTT
Metso, UPM, Fortum and VTT have developed an integrated biomass-based bio-oil production concept to provide an alternative to fossil fuel oil.

A 2 MW<sub>th</sub> fuel fast pyrolysis unit has been integrated with Metso’s 4 MW<sub>th</sub> circulating fluidized bed boiler, located at Metso’s R&D Center in Tampere.

- **Proof-of-concept has been done:**
  - More than 70 tons of bio-oil have been produced from sawdust and forest residues.
  - High availability, reliable process.

- **Bio-oil utilization has been proven:**
  - More than 20 tons of bio-oil has been used to replace heavy fuel oil at district heating boiler in Masala, Finland.
  - More than 50 MWh of district heating has been done by utilizing bio-oil.

- Demonstration plant is being planned.

Source: Jani Lehto, MetsoPower
Table 1. Summary of evaluated biotrade chains

<table>
<thead>
<tr>
<th>Export region</th>
<th>Feedstock</th>
<th>Traded commodity</th>
<th>Importing country</th>
<th>End-use</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-Western Russia</td>
<td>Forestry residues</td>
<td>Pyrolysis oil</td>
<td>The Netherlands</td>
<td>Co-firing in coal-fired power station</td>
</tr>
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<td>Pellets</td>
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<tr>
<td>Eastern Canada</td>
<td>Sawmilling residues</td>
<td>Pyrolysis oil</td>
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</tr>
</tbody>
</table>

Figure 14. Estimated delivered costs of biofuel and bioelectricity-generation costs for the Canada-Netherlands chains; zero cost for sawmill residues; large custom-built tanker used for shipping pyrolysis oil.
Table 8. Estimated performances and costs of producing pyrolysis oil from stemwood-derived wastes.

<table>
<thead>
<tr>
<th>Case:</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
<td>Stand-alone</td>
<td>Integrated with industrial CHP, &gt;100 MW heat</td>
<td>Integrated with heat &gt;10 h</td>
<td>Integrated with heat &gt;10 h</td>
<td></td>
</tr>
<tr>
<td>Dryer type</td>
<td>Flue-gas</td>
<td>Flue-gas</td>
<td>Flue-gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating time, h/a</td>
<td>7800</td>
<td>7800</td>
<td>5000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant performance:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedstock input, MW (LHV)</td>
<td>48.8</td>
<td>40.1</td>
<td>43.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity requirement, MW</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil produced</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– top phase, MW (LHV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– bottom phase, MW (LHV)</td>
<td>37.1</td>
<td>37.1</td>
<td>37.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LHV-efficiency **, %</td>
<td>79.3</td>
<td>92.5</td>
<td>94.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total investment, MEUR</td>
<td>11.6</td>
<td>10.2</td>
<td>12.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Defined as: 100*(LHV-energy output of oil products)/(LHV-energy input of feedstock).**

Figure 3. Comparison of estimated LHV-efficiencies of pyrolysis-oil production from forestry residues to those of pyrolysis-oil production from wastes derived from stemwood; feed-rate to pyrolyser same in both cases; oil production rates: 30 MW from forestry residues, 37.1 MW from stemwood-derived wastes; flue-gas drying.
Wood Torrefaction Products and European Forest Industry by 2020 – opportunities and constraints

Kai Sipilä & Carl Wilén, VTT
Esa Sipilä & Jaakko Jokinen, Pöyry Forest Industry Consulting
Jaap Kiel, ECN

18th European Biomass Conference, Lyon May 3-7, 2010, France
Pellet co-firing potential in existing coal fired power plants in Europe

The demand for wood pellets from the European coal based industry has grown steadily as co-firing is viewed as a necessity to reach CO₂ targets. In the US, the Renewable Portfolio Standard (RPS) programme requires electricity utilities to produce a minimum portion of their supply from renewable sources, including biomass.

European coal consumption by coal type, 2007

- Lignite: 54%
- Hard coal: 46%

54%* co-firing of coal with pellets

820 million t/a

Coal

5%* co-firing

Market growth in Europe would be 500%-

45 million tonnes/year

= ~ 4 times world pellet production in 2008

= ~ 5 times pellet production in EU-27 2008

Wood Pellets potential

Torrefied wood products to:

- cofiring in coal boilers due to good grinding properties in coal mills
- no high cost investments at power plants
- cofiring in cement kilns
- entrained flow gasifiers for transportation fuels or high efficiency power IGCC

Benefit in large volumes and long transportation distances

Ash content and properties?
Forest energy resources of the EU27

- Largest forest energy resources can be found in Germany, Sweden, Finland and France
  - Finland & Sweden: logging residues from current fellings
  - Germany and France: biomass from balance

1 Mm3 = 0.166 Mtoe

Source: Prof. Antti Asikainen
Global raw material availability and pellet production, 2008-2015

- European forest resources will be utilised for forest industry and its bionenergy production
- There are available woody biomass resources for import purposes connected to local forest industry operations in Russia, North and South America.

Production (million tonnes)
- 2008 - 11.8 Mt
- 2015 - 23.5 Mt

Woody biomass availability
- Increasing harvest potential
- Stable harvest potential
- Stable harvest potential but in high demand
- Raw material deficit
Woody biomass availability – outside Europe?

Availability and accessibility of raw materials suitable for torrefied pellet production is connected to existing wood chains

Russia
- Russian forest law determines that all wood residues have to be removed from the forest
- Sawmills utilise only the logs and waste wood is often unutilised
- Torrefied pellets production could be integrated to sawmills wood chains and processes

North America
- Wood use differs in North America by region but especially in West coast the wood flows go through sawmills
- Economic problems in pulp and paper industry can leave large amounts of wood unutilised
- Sawmills could be feasible sites to integrate torrefied pellets production by means of logistics and energy
- Pine beetle affected area require more harvesting than demand is for wood products and pulp&paper markets (thermal treatment required for pine beetle affected wood by torrefaction or pyrolysis)

→ At sawmill torrefied pellets and bio-oil production seems to be the most attractive option to import bioenergy carriers to European markets
New Sawmill Bioenergy Concepts – Bio-oil and Torrefied Pellets

Pöyry-VTT Sawmill case  30 – 80 MW and 0.2 – 0.5 TWh/a
Bio-oil Production Potential in North American Forest Industry by 2020
There are 515 pulp and paper mills in North America
Total paper capacity of 98 million tons and pulp capacity 87 million tons annually
Typical Wood Fibre Flows

In Europe, both sawmill chips and round pulpwood are utilized in industrial processing. In western part of North America, sawmill chips is a typical raw material for industrial processing, whereas in eastern/southern parts of North America also round pulpwood is utilized in industrial processing. There are regional differences in the utilization rate of wood residues.
USA – Softwood Sawmills with Annual Capacity over 50 000m³

Sawnwood production in 2008 73 million m³
Canada – Softwood Sawmills with Annual Capacity over 50 000 m³

Sawnwood production in 2008 42 million m³
Methodology of Mechanical Wood Industry Potential

The potential analysis is based on current capacities of sawmills from Pöyry’s databanks.

The sawmills are divided into 3 different classes that are based on size ( > 200 000 m³/a):
- Size categories: under 400 000 m³, 400 – 600 000 m³ and over 600 000 m³

The bio-oil or torrefaction investment potential by 2020 is estimated to be:
- 15 % for sawmills under 400 000 m³
- 25 % for sawmills between 400 – 600 000 m³
- 30 % for sawmills larger than 600 000 m³

The bio-oil production is estimated to utilise sawmill chips, bark and sawdust from the sawmilling as feedstock for bio-oil and process heat production.
Bio-oil Potential in Mechanical Wood Industry in this study

Bio-oil potential in North American mechanical wood industry is 69 units in this study. They have a production potential of 3.9 Mtoe annually.

The potential is almost equal in US and Canada.

Bio-oil potential in Canada is larger in mechanical wood industry than in pulp and paper industry.

<table>
<thead>
<tr>
<th>Raw material demand, 1000 m³sub/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
</tr>
<tr>
<td>USA</td>
</tr>
<tr>
<td>Total NA</td>
</tr>
<tr>
<td>Number of units</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>39</td>
</tr>
<tr>
<td>69</td>
</tr>
</tbody>
</table>

• The bio-oil potential in North American forest industry is 10 million tons of oil equivalent that has a value of USD 5 billion/a.
Conclusions

- Forest industry platforms offers significant benefits for future bioenergy carrier investments: logistics of wood and forest residues, multifuel operations, process integration and industrial CHP

- Current wood to energy 60 Mtoe/a in EU – additional raw material demand in this study 45 Mm3 ~ 9 Mtoe forest residues and 7 Mtoe ~ 20 Mt/a solid recovered fuels from MSW and CIW

- New green electricity and biofuels will have lowest production cost when integrated to global forest industry operations at saw, pulp and paper mills

- New technologies will increase the profit and market volume

- EU SET-Plan and European Industrial Bioenergy Initiative will accelerate the development the bioenergy market and market introduction of new technologies

- Collaboration within the IEA Bionergy member countries!