Energy production by thermochemical biomass valorization

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Biomass Energy Unit

A staff of 1800 persons, including 850 researchers

- 12 regional offices in the French overseas regions and abroad
- 700 staff members based outside metropolitan France

A scientific hub in Montpellier (France)
CIRAD's six priority lines of research

1. Ecological intensification

2. Biomass energy and societies in the South

3. Safe, diversified food

4. Animal health and emerging diseases

5. Public policy, poverty and inequality

6. Agriculture, environment, nature and societies

Biomass Energy Unit

- Non-food Biomass-to-energy processes -

- 7 researchers, 4 technicians, 1 assistant, 4 PhDs (Montpellier)
- 6 researchers, 4 PhDs (abroad)
- Topics: Process engineering, chemistry, economy, environmental evaluation, logistic
- 3 laboratories and 250 m² test platform
- 80% on contractual research (with various public french agencies, European union, private companies)

2013: merge of the Biomass Energy unit with Tropical woods unit
**Biomasses**

- Faveira
- Macaranduba
- Beech
- Pine
- Short Rotation Forestry
- Eucalyptus
- Short Rotation Coppice
- Poplar
- False Acacia
- Wheat Straw
- Triticale
- Tall Fescue
- Switchgrass
- Miscanthus

**Current research on lignocellulosic biomass conversion**

- **Example:**
  - Tests of torrefaction at lab-scale

- **Biomass conversion**
  - Torrefaction
    - Catalyzed, impregnated
    - Pelletization, grinding, ...
  - Gasification processes
    - Classification: lab, pilot (50, 200 kWth), and industrial plant (1.3 MWth, 8 MWth)
    - Gas cleaning (tar cracking/reforming)
    - New small gasifier for developing countries
  - Modeling (Fenvia, Consol, ...)
    - Understanding of phenomena involved in process
    - Data from experiments at particle- and reactor-scale
  - Physico-chemical analysis: solid, liquid, gas
  - Feedstocks: available feedstocks assessment, supply chain setup
  - Impact on environment: LCA
The process: from biomass to fuel

Biomass gasification in entrained flow reactor requires spherical particles ~200 µm

Technically difficult and expensive

Thermal pre-treatment: torrefaction

Grindability improvement

Biomass torrefaction

- Smooth thermal transformation under inert atmosphere
  - Between drying and pyrolysis
    - $T = 200-300^\circ\text{C}$
    - Residence time = 15 min – several hours
    - Atmospheric pressure

- Solid properties get more coal-like
  - Decrease of H/C and O/C
  - Hydrophobic nature
  - Higher energy content
  - Improved grindability and powder flowability

Volatile matter:
- Gas (CO, CO$_2$
- Condensable species (H$_2$O, acids...)

Raw  240°C  260°C  280°C  300°C

Biomass $C_6H_9O_4$ + moisture~20%
Torrefied biomass $C_6H_8O_3$ + moisture~3%
**TGA experimental results**

![Diagram showing mass loss over time for different biomass types.]

- Large differences in mass loss for agricultural by-products and wood.
- Impact on process control.

3 main families:
- Hardwood
- Softwood, Short Rotation Forestry
- Coppice and perennial crops

**Global mass balance**

![Bar chart showing mass balance for different biomass types.]

- Higher mass loss for agricultural by-products.
- For all biomass types: Volatile species are mainly condensable.

Closure: 97 - 101%
Mass balance: volatile species

- Similar CO / CO₂ for all biomass types
  - CO << CO₂ under the conditions explored
- Water and dry condensable: difference softwood/agricultural biomass

Mass balance: dry condensable species

- INVERTO project: INnovation in VEgetal chemistRy through TORrefaction
  - 3 years, 4 partners
- Acetic acid ~50% except for softwood (20%)
- Furanmethanol only in agricultural by-products
- Furfural only in softwood and agricultural by-products
- Glycolaldehyde only in softwood and perennial crops
- Formaldehyde and acetaldehyde only in softwood

Impact on torrefaction cleaning step!
**Bio-refinery**

- Better use of biochemical diversity (plant chemistry) to produce chemicals, biomaterials (fibers), fuels & power
- While keeping sustainability on environment, economy & society

BIO-REFINERY results from an innovative approach and brings new challenges & opportunities

![Diagram of Bio-refinery process]

**Current research on lignocellulosic biomass conversion**

- Biomass conditioning
  - Torrefaction
  - Flash pyrolysis and Carbonization
  - Catalysis impregnation
  - Pelletization, grinding, ...

- Gasification processes
  - Gasification
  - Gas cleaning

Example: Applications to industry

![Diagram of current research process]
Examples of applications to industry

Development of Rice husk gasifier coupled with a gasoil/gas dual-fuel generator

- Rice husk gasifier
- Developed in France
- Installed in Cimalaya (Indonesia)
- 60% of generator’s total power (60kW)
- Started in 2003

BIOVIVE Project

Vineyard biomass for glass furnaces via a gasification process - Demonstration of 1.5 MWth (7%) -
**TERREAL Project**
Substitution of NG by Syngas from wood gasification
in Heavy clay/brick industry
- Feasibility study / 50 kWth -

**GAYA (GDF-SUEZ project)**
- Synthetic Natural Gas production -
  Catalytic cracking/reforming in fluidised bed gasifiers

**GFE** Gasifier For Everyone
Small gasifier (20-100 kWe) for rural decentralised electrification
Forum PNRB Bioénergies – 21/01/10

Int. Workshop on the innovative uses of rice straw and rice husk – IRRI – December 11th-13th 2012

CIRAD
- 3 laboratories -
- A platform for pilots tests -

http://ur-biomasse-energie.cirad.fr/

Analysis laboratory

Thermochemical laboratory

Staged gasifier 75 kWth

Flash pyrolysis fluidized bed reactor

Continuous fixed bed reactor

Torrefaction reactor

Thank you for your attention
Wheat straw torrefaction for methanation

Pas de modification de la composition et/ou de la qualité en composants pariétaux

Zone à explorer

Augmentation de la teneur en ligne

Quantité de cellulose fortement affectée (90% de moins)

Quantité d'hémicellulose fortement affectée (70% de moins)

Les hémicelluloses et celluloses commencent à être affectées

Légère diminution de la teneur de cellulose et hémicellulose (10 à 15%)

Peace And Love project
**General methodology**

- Experiments + Modeling (Fortran, Comsol)
- Process evaluation
- Measurement "on-site"
- Objectives
- Optimisation
- Biomass identification
- Reactor
- Unit process

**Example:** Tests of pilot-scale rapid pyrolysis

**Our main research activities**

**Global issue:** Is fast pyrolysis a viable route for preconditioning biomass?

- No focus on specific application (defined in collaboration)

1. **Optimise mass and energy efficiencies**
   - Parametric study pilot scale / modelling
   - Implement fractionated condensation system

2. **Influence of biomass composition on yield and quality of bio-oils**
   - Impact of inorganic content (ashes)
   - Impact of organic extractives (triglycerides)

3. **Investigate bio-oil upgrading routes**
   - Gasification: mechanisms of thermal degradation
   - Catalytic pyrolysis of biomass

4. **Improvement of analyses methods**
Bench-scale fluidized bed pilot

- 1-1.5 kPa
- Mass balance
- Control

Char
Beech Spruce without bark Spruce with bark Straw
Product Yield (wt%)

Hot gas residence time: 1.5 s

- Impact of condensation conditions on yield and water content
- Energy efficiency: 65-70% wood; 50% straw

Typical mass balances and main bio-oil properties: impact of biomass

Reference conditions
Bed temperature: 500°C
Hot gas residence time: 1.5 s
Biomass pre-dried to 9-11 wt%
Particle size < 2-3 mm

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Beech</th>
<th>Spruce w/o bark</th>
<th>Spruce with bark</th>
<th>Wheat straw</th>
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<tbody>
<tr>
<td>Appearance</td>
<td>Homog</td>
<td>Homog</td>
<td>Homog</td>
<td>Phase sep.</td>
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<td>Water content</td>
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<td>29</td>
<td>32</td>
<td>20 / 48</td>
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<td>Solid content</td>
<td>0.1-0.3</td>
<td>0.1-0.3</td>
<td>0.2-0.4</td>
<td>0.5-1.1</td>
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<tr>
<td>Ash content</td>
<td>0.06-0.07</td>
<td>0.05</td>
<td>0.02-0.03</td>
<td>0.16</td>
</tr>
</tbody>
</table>

* Condensates = bio-oils (20°C) + light condensates

- Impact of condensation conditions on yield and water content
- Energy efficiency: 65-70% wood; 50% straw