Engine and turbine fuelled with bioliquids for combined heat and power production

Enhancing strategic international cooperation between EC and Russia in the field of power generation from biomass

David Chiaramonti
CREAR – Research Center for Renewable Energies
University of Florence, Italy

John Vos, Bert van de Beld
Biomass Technology Group
The Netherlands
Content

- Project background
- Project Objectives
- Project partners
- General Overview activities
- On going activities
Project background

- Combined heat and power (CHP) is a very efficient way of using energy sources.
- 2010 target: CHP to contribute 18% of European energy supply.
- In Russia, many CHP units are used, in particular in remote areas.
- Implementation of smaller scale, direct biomass CHP systems has been limited for various reasons e.g. high investment and running costs, poor reliability, low acceptance by end-user.
- At the root of these reasons: presence of contaminants in biomass, non-uniform appearance of biomass, low energy density, complicated operation, difficulty to operate on varying load.
- Using biomass derived liquids (in short: bioliquids) instead of direct biomass will overcome the main barriers hindering a wider use of biomass in smaller scale CHP systems.
Project objectives

Main objective:

- To adapt engines/turbines to enable operation on a variety of bioliquids for CHP systems in the range of 50-1000 kWₑ;

Specific objectives:

- To upgrade bioliquids or to prepare blends/emulsions of bioliquids to enable their use in engines/turbines;
- To find a technical and economic optimum between fuel upgrading and engine/turbine modification;
- To develop methods/techniques to control exhaust emissions (NOₓ, CO, particulates);
- To evaluate the complete chain (sustainability, economics, technology, environment, market opportunities) for application in EU & Russia.
General Project Data

*Full Title:* Engine and turbine combustion for combined heat and power production

*Acronym:* Bioliquids - CHP

*Call:* Enhancing strategic international cooperation with Russia in the field of power generation from biomass

<table>
<thead>
<tr>
<th></th>
<th>EC - part</th>
<th>Russian part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start-date</td>
<td>January 1, 2009</td>
<td>July, 2008</td>
</tr>
<tr>
<td>End-date</td>
<td>December 31, 2011</td>
<td>September 2011</td>
</tr>
<tr>
<td>Budget</td>
<td>1.6 MEur</td>
<td>~1.9 MEur</td>
</tr>
<tr>
<td>No of partners</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>
Project partnership

- BTG Biomass Technology Group BV (NL)
- EnConTech BV (NL)
- University of Florence, CREAR (Italy)
- Boreskov Institute of Catalysis, Siberian Branch of Russian Academy of Sciences (Russia)
- Federal State Unitary Enterprise 'Central Scientific Research Automobile and Automotive Engines Institute' - FSUE 'NAMI' (Russia)
- Aston University (United Kingdom)
- The Likhachev Plant (AMO ZIL) (Russia)
Bioliquids
- Pyrolysis oil from Pyne
- Pyrolysis oil from Straw
- Vegetable oil
- Biodiesel

Upgrading
- Filtration
- Dewatering
- Chemical treatment

Emulsions/Mixtures

Engines
- Diesel engine
- ‘Catalytic engine
- Syngas engine
(Russian project ?)

(Micro-) Turbine

Gas cleaning
- NOx
- CO
- Hydrocarbons

Heat
Electricity
Cooling
Clean flue gas
Bioliquid production, selection and analysis

- **WP-leader**: BTG

- **Partners involved**: ECT, UFL, Aston, BIC, NAMI

- **Objectives - activities**
  - Production of pyrolysis oil from different biomass feedstocks
  - Selection/purchase of other bioliquids, like e.g. vegetable oil
  - Characterisation/analysis of bioliquids
  - Characterisation/analysis of products from WP2 (upgraded oil, blends and/or emulsions)
Pyrolysis Oil Production

- Feedstock: pine & wheat straw
- Production of 1,100 kg of pyrolysis oil from pine completed
- Wheat straw derived oil will be produced in 2010

BTG’s Pilot-plant in Enschede
Selected Bioliquids

- Pyrolysis oil from pine
- Pyrolysis oil from straw
- Sunflower oil
- Biodiesel

Specifications:
- Diesel (40°C): 3.5 - 5 cSt
- Rapeseed (40°C): < 38 cSt
Bioliquids upgrading and blending

- **WP-leader:** BTG
- **Partners involved:** BIC, NAMI
- **Objectives - activities**
  - Filtration of bio-oil (solids removal)
  - (Partial) dewatering of oil
  - Mild (catalytic) treatment of pyrolysis oil
  - Catalytic pyrolysis of pyrolysis oil
  - Blending and emulsification of pyrolysis oil with other bioliquids
Filtration & partial dewatering of pyrolysis oil

- Different techniques are used for solids removal (filters, centrifuges, self-cleaning etc).
- Solids removal tested at labscale and pilot scale;
- Partial removal of water at low temperature and vacuum
Partial dewatering of pyrolysis oil

Kinematic viscosity as a function of the water content in the oil for different temperatures

- $T = 20 \, \text{C}$
- $T = 40 \, \text{C}$
- $T = 60 \, \text{C}$
- $T = 80 \, \text{C}$

`Bioliquids-CHP
Power generation from Biomass`
Development of Micro turbines

- **WP-leader:** UFL
- **Partners involved:** BIC, NAMI

**Objectives - activities**

- Modification of Micro Gas Turbines (MGT)
- Supporting CFD simulations
- MGT testing programme / MGT performance
- Evaluation and assessment of MGT for bioliquids fuelled CHP systems
Micro turbines - combustor

- Injector
- Swirler
- Deflectors
Micro turbines - combustor
Micro turbines - cold flow CFD

P & V fields, vectors of V

Velocity Magnitude

32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2

Pressure

3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
Micro Turbine - test bench

Fuel

Exhaust to stack

Nozzle

CC

Air

Generator

3~ 120/208V 400Hz

AC Load

T  P  Mc

T  P  T

T  Ma
Micro Turbine - test bench

START-UP AND SHUT-DOWN CONTROL PANEL

BATTERY PACK

LOAD CONTROL PANEL

FUEL TEMPORARY TANK

ALUMINIUM SKID
Development of Engines & components

- **WP-leader**: ECT / NAMI
- **Partners involved**: BTG, BIC
- **Objectives - activities**
  - to develop engine components that are tolerant towards the bio-liquids including fast-pyrolysis oils or mixtures.
  - Construction of experimental facilities
  - Lab-scale experiments
  - Engine modifications
  - Engine testing and emission measurement
Material testing – corrosion / abrasive wear

Material No 2 - New
After 400 hrs contact with pyrolysis oil

Material No 1 - New
After 27 hrs injection with water/diamond powder;
Material testing for sealings

Influence of biofuel on various elastomers

- **Volumetric change**
- **Hardness change**
- **Change of size**

- **Permanent deformation (compression)**
- **Tensile properties**
Engine development

Tested Engine at NAMI with an electric power generator.

View of the 120 kWt load testing bench for testing the engine with the generator.
Emission reduction and control

- **WP-leader**: BIC
- **Partners involved**: NAMI, ZIL
- **Objectives - activities**
  - Development of catalysts and a system for emission reduction and control – in particular NOx – for exhaust gases from engines and turbine for CHP units in the capacity range of 50 – 1000 kWe
  - Catalysts screening
  - Catalysts testing & selection
  - Catalyst manufacturing and system development
Schematic diagram and photo of NO$_x$ SCR reactor

- **Combustion chamber**
- **Exhaust gas**
- **DeNOx catalyst**
- **Temperature and gas composition measurements**
- **Flow mixer**
- **Exit gas**

**Biofuel** → **Air** → **Combustion chamber** → **Exhaust gas** → **DeNOx catalyst** → **Exit gas**

**Nitric acid** → **Biofuel** → **Cat** → **Syngas**

**Biofuel** → **Air** → **ATR reactor** → **Syngas**
Samples of Monolith Catalyts for ATR of Biofuel
DeNOx Catalyst (Ag/Al2O3)

<table>
<thead>
<tr>
<th>Name of Parameters</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalyst outwards:</td>
<td></td>
</tr>
<tr>
<td>- color</td>
<td>cream</td>
</tr>
<tr>
<td>- form</td>
<td>Spherical</td>
</tr>
<tr>
<td>Diameter, mm</td>
<td>2,5 - 2,8</td>
</tr>
<tr>
<td>Internal surface area, m²/g</td>
<td>190 - 210</td>
</tr>
<tr>
<td>Pore volume, sm³/g</td>
<td>0,55 - 0,70</td>
</tr>
<tr>
<td>Ag concentration, %</td>
<td>1,5 - 2,3</td>
</tr>
<tr>
<td>Density, g/l</td>
<td>500-600</td>
</tr>
<tr>
<td>GHSV</td>
<td>15 000 h⁻¹</td>
</tr>
<tr>
<td>Volume of catalyst preparation</td>
<td>40 liters</td>
</tr>
</tbody>
</table>
Conversion of NOx vs temperature during reduction by decane, and decane+syn.gas mixture.

Conditions of lab scale testing: catalyst Ag-18, GHSV = 13300 h⁻¹, [NOx]₀ = 460 ppm, [O₂] = 10%, [CO]₀ = 930 ppm, [H₂]₀ = 3200 ppm, [H₂O]₀ = 2 %, [C₁₀H₂₂]₀ = 160 ppm,
Techno-economic assessments and market opportunities

- **WP-leader**: Aston
- **Partners involved**: BIC, NAMI, ZIL
- **Objectives - activities**
  - Techno-economic and environmental assessment of CHP-units fuelled with bioliquids, and identification of market opportunities
  - State-Of-The-Art review on CHP-units in Europe and Russia
  - Performance and cost assessment
  - Environmental assessment
  - Identification of market opportunities for CHP-units in the capacity range of 50-1000 kWₑ for both Europe and Russia
Summary - Conclusions

- The project is exploring the production, upgrading and use of PO in engines and turbines through an International (EU-Russia) collaboration.
- Preliminary results have already given first insights on the topics.
- Larger batches of PO are under preparation, and technologies are currently being converted to biofuels (biodiesel, pure VO, PO).
- The next year full tests will be carried out.
Acknowledgement

This co-operative research project is financially supported by the Seventh Framework Programme (FP7) of the European Commission & the Russian Federal Agency of Science and Innovation (FASI).
Thanks for your attention!

www.bioliquids-chp.eu