Sixth Framework Programme

COOP-CT-2005-018080

Power-Grade Charcoal

Large-scale Production of Charcoal for Use in
Coal Fired Power and Co-generation Plants

Instrument Co-operative research

Thematic Priority Horizontal research activities involving SME's

Publishable Final Activity Report

Period covered: 1 September 2006 - 31 December 2007 Date of preparation: March 2008

Start date of project: 1 September 2005 Duration: 28 months

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Project coordinator organisation name: BTG Biomass Technology Group BV **Revision: Draft**

1.1 Summary: project objectives, contractors involved, work performed and end results, elaborating on the degree to which the objectives were reached.

Global aims of Power-Grade Charcoal

The overall goal of the Power-Grade Charcoal project is to develop a process for making charcoal that can be co-fired in coal-fired electric power plants. The carbonisation process should yield charcoal that complies with quality standards set by the electric power sector. The charcoal should also be competitive with alternative biomass feedstock and therefore the current production costs of the charcoal will need to be reduced by some 30%. This cost reduction is to be achieved by developing an innovative process design, optimising the extent of carbonisation, controlling the carbonisation process to achieve higher conversion yields and realising significant economies of scale.

Contractors involved

Project partners include 4 SME's. 3 RTD Performers and one other company, as follows:

- A.S. ENER EA (ENER, Estonia)
- GreenCoal B.V. (GreenCoal, The Netherlands)
- Insulcon B.V. (Insulcon, The Netherlands)
- P.P.H. "Centropol" (Centropol, Poland)
- BTG Biomass Technology Group BV (BTG, The Netherlands)
- Universität Kassel (UNIK, Germany)
- Swedish University of Agricultural Sciences (SLU, Sweden)
- Electrabel Nederland N.V. (Electrabel, The Netherlands)

Work performed

- Identification of minimum product specifications for charcoal that is suited for co-firing in coal-fired electric power plant (WP1);
- Definition, design, construction, debugging and commissioning of an experimental lab-scale test set-up for charcoal production (WP2);
- Completion of an experimental programme using this lab-scale test rig aimed at deriving optimal process conditions for large-scale wood carbonisation and for numerical model validation (WP2);
- Development of a mathematical model predicting the yield and quality of carbonisation products and by-products. Validation of the mathematical model using data from the lab-scale test rig and the real-scale production plant (WP3);
- Completion of an experimental programme involving *in situ* measurements at a real-scale charcoal production plant in Pärnu, Estonia (WP4);
- Determination of the (economically) optimal method of drying wood feedstock at a real-scale charcoal production plant in Pärnu, Estonia (WP5);
- Research into the suitability of various low-costs binders that can be used to produce briquettes from charcoal fines (WP6);
- Determination of the (economically) optimal method for drying briquettes produced from charcoal fines (WP6);
- Large-scale testing of the co-firing of lump charcoal and charcoal briquettes at a coal-fired power station in Poland (WP7);
- Development of a blueprint (design) and associated cost estimate for a large-scale charcoal production plant with a output capacity of 10,000 tonnes/year (WP8);
- Development of an implementation plan and a bankable business plan for the first of such large-scale charcoal production plants (WP9); and
- Completion of a plan for using and disseminating knowledge (WP9).

End results

Main results of the project include:

- Fundamental knowledge, practical understanding and a numerical model of the batch-wise charcoal production process that is applied by SME partner ENER;
- Improved drying process at the SME company ENER for woody raw materials for charcoal production by optimised utilisation of the residual heat of the carbonisation process;
- Identification of the potential to optimise the process and reduce the costs of (a) charcoal fine briquetting and (b) briquette drying at SME companies ENER (Estonia) and Centropol (Poland);
- Insight in the logistics and handling of large-scale charcoal transport and storage.
- Succesful co-firing of 200 tonnes of lump charcoal and charcoal briquettes at a coal-fired power station and quantitative data on the milling, combustion and emission characteristics;
- Insight that torrefaction (partial or mild pyrolysis/carbonisation, also know as roasting) is not possible in an indirectly heated carbonisation retort such as applied by ENER;
- Identification of the optimal heat integration and drying process for a scaled-up carbonisation plant;
- Identification of the economics and viability of scaling up the current charcoal production capacity by a factor 3 and 12 to 2,500 tonnes/year and 10,000 tonnes/year respectively; and
- A blueprint (detailed design), a cost estimate and a suitable location for a large-scale (10,000 tonnes/year) charcoal production plant.

The last of these results is considered an exploitable outcome of the project.

Degree to which the objectives were reached.

The envisaged *overall objective* was a 30% reduction in the costs of producing charcoal that meets the quality criteria of the power sector. As a matter of fact this objective is reached. The outcome of the project is a namely a design for a scaled-up 10,000 tonnes/year charcoal production plant that can produce charcoal for the power sector at 20-30% lower production costs compared to an existing plant with a capacity of 800 tonnes/year capacity.

Despite this success, producing charcoal for the co-firing market seems not an economically viable option for the short to medium term. It appeared not possible to reduce the charcoal production costs from approx. 200 €/tonne to 140 €/tonne. The main reason is that in the 28 months that the project was running the costs of the raw material for charcoal production (wood) increased by more than 10 €/m^3. As up to 8 m^3 (4 tonnes) of green forest residues (50% moisture content) are needed to produce 1 tonne of charcoal the wood price increase alone added 80 €/t to the charcoal production costs. Also the transportation costs, have risen steadily over the last few years. The bulk price of wood pellets (currently some 110 €/tonne or 7 €/GJ) constitutes effectively the ceiling of what power stations are willing to pay for biomass feedstock, and charcoal produced with the technology applied by the SME partners cannot meet this price.

The perspective for the SME partners are not bad, however, while the perspectives in their traditional (barbecue) charcoal market are excellent. Unlike the prices that electric power stations are willing to pay for co-firing feedstock, consumer prices for (barbecue) charcoal have grown steadily over recent years as a result of higher production and transportation costs on the one hand and market consolidation and capacity reduction on the other hand. In absolute terms producer margins have increased over the project duration (September 2005-December

2007). The increased producer margin and the potential to reduce charcoal production costs by scaling-up the production capacity render charcoal production for the consumer (barbecue) market a financially attractive option for the SME's. This is acknowledged by SME partner ENER which is seriously considering building a large-scale production facility near its existing production plant in Pärnu, Estonia.

Looking at the *specific objectives*, it is concluded that most of these were achieved, the only exception concerning the costs of charcoal densification. Field research in Poland suggests that these costs remain well above the target of 30 €/tonne charcoal. The specific objectives of the project include:

- Specification of minimum quality characteristics for charcoal for co-firing based on small scale tests at the power plant.
- A model for the simulation of the carbonisation process validated by the test results from laboratory experiments.
- A detailed design for a large carbonisation retort (envisaged capacity 8,000-10,000 tonnes charcoal per year), based on the model and supported by the pilot scale experiments with charcoal production.
- Optimised process for natural drying of the feedstock and integrated drying with the waste heat of the charcoal oven, without using external energy sources.
- Carbonisation plant design and cost estimation for the carbonisation retort and the whole plant (including drying section).
- Optimal process for large-scale charcoal densification in such a way that the quality criteria of the power sector are met and the densification costs remain below 30 €/tonne charcoal.
- Quantitative data on handling, milling, feeding, combustion and emissions of charcoal co-firing from a large co-firing test.
- Practical experience with storage and transport of large bulk quantities of charcoal.
- Exploitation plan to make optimal use of the result of the project.

1.2 Methodologies and approaches employed; relation between project achievements and the state-of-the-art.

WP Clusters

The nine central Work Packages can be clustered into five groups:

- WP1 concerns the detailed determination of the envisaged end-user's power grade charcoal (PGC) specifications;
- WP2-4 concern detailed research into obtaining fundamental knowledge of the central processing step in power grade charcoal production i.e. carbonisation;
- WP5-6 concern research into the cost reduction and process optimisation of auxiliary operations in power grade charcoal production;
- WP7 concerns research into the technical performance and logistical aspects of co-firing power grade charcoal in coal-fired power plants; and
- WP8-WP9 concern the development of a blueprint (detailed design) of a scaled-up charcoal production plant, and the commercialisation of this design.

For each WP cluster the methodology approached, the results achieved and the progress beyond the state-of-the-art is indicated below.

Determination of the power grade charcoal (PGC) specifications

Before the project started the SME partners had only a general insight in the relevant charcoal requirements for the co-firing market (see Table 4.4 of the DoW).

SME partner GreenCoal and RTD Performer BTG visited end-user Electrabel Nederland a number of times to jointly establish more detailed power grade charcoal specifications. The work started with the evaluation of an earlier exploratory test in which some 20 tonnes of charcoal briquettes were co-fired at Electrabel's 650 MW GC-13 power station in Nijmegen.

The deliberations resulted in a list of minimum power grade charcoal specifications. The most important technical requirements concern mechanical stability, water absorption and heating value (energy content). These requirements are likely to apply to any coal power station considering co-firing. Additional specifications are specific for the GC-13 power station. The specifications are in certain aspects (odour, appearance, fixed carbon content etc.) less strict than the requirements for barbecue charcoal briquettes, and in other aspects more strict (e.g. grindability).

Fundamental knowledge of wood carbonisation

Before the project started SME partner ENER had already acquired six years of practical experience operating a batch-wise charcoal production plant, and knew quite well how to operate the plant. Consortium members GreenCoal, BTG and UNIK had knowledge of different charcoal production techniques used around the world. UNIK had already elaborated a numerical model describing the time-dependent carbonisation process for a single wood particle.

To gain a more fundamental insight in the process of charcoal production three tracks were followed in parallel, feeding each other. BTG designed, constructed and operated a lab-scale test rig able to batch-carbonise wood in Enschede, The Netherlands. ENER ran several real-scale carbonisation experiments with different types of feedstock at its existing production plant in Pärnu, Estonia. UNIK expanded its existing numerical model to allow the simulation of various conceptual designs for large-scale charcoal production at its base in Kassel, Germany.

An important finding of the research was that in batch-wise charcoal production as applied by the SME partners it is not possible to control the degree of carbonisation adequately. Decreasing this degree was the second of six main innovations that the projects aimed to achieve, with a view of realising a higher energy yield. A fundamentally different technology would be needed to achieve this intended result.

Cost reduction and process optimisation of auxiliary operations

Large-scale production and export of charcoal for the co-firing market implies that green forest residues need to be used as feedstock and that the bulk density of the resulting charcoal need to be maximised. As neither of this aspects are relevant for their current (barbecue charcoal) markets and their scale of operation SME partners ENER and Centropol had little if any practical experience with these issues.

WP5 and WP6 therefore investigated the potential to optimise wood drying and charcoal briquetting respectively. The studies were very practically oriented and aimed at proposing a cheap and reliable method.

SME partner ENER and RTD performer SLU collaborated in the drying study which mainly shed light on the economic parameters of drying. In practical drying experiments it was found that the optimal drying method makes use of residual heat released during the carbonisation process. Currently ENER uses only some 30% of this heat for wood drying; the remainder goes lost.

In the briquetting study SME partner Centropol and RTD performer BTG (and later also SLU) mainly focused on finding a cost-effective industrial binder that would allow the production of sufficiently strong water-repellent briquettes. Building on the exploratory work of BTG Centropol identified two suitable potassium-based specialty binders. SLU found that mixing and pressurising charcoal fines with a blend of oil (linseed oil, tall oil, or used frying oil), lignin and either stearic acid or potato dextrose generated briquettes of satisfying quality. Total costs of briquetting charcoal fines amount to some 150 € per tonne, with some room for costs reduction.

Important lessons are that drying costs a lot of energy and thus money. Using waste heat or cheap biomass can reduce the drying costs somewhat.

Co-firing charcoal in coal-fired power plants

As charcoal is a high-quality household fuel and thus relatively expensive it has not been used at any significant scale as co-firing feedstock in co-firing plants to date. At the start of the project in September 2005 the largest charcoal co-firing test was the one held at Electrabel's 600 MW_e power station in Nijmegen in January 2005 (i.e. several months after the proposal for the Power-Grade Charcoal project had been developed and submitted). This test involved the co-firing of one container of charcoal briquettes i.e. the equivalent of the amount of hard coal fired in 3 minutes.

In WP7 a much larger co-firing test was held at one of the 225 MW_e units of end-user **Electrabel**'s coal power station in Polaniec. The test involved a total of almost 200 tonnes of charcoal (10% lump charcoal and 90% charcoal briquettes), supplied by SME partner Centropol. Relatively to the power station's capacity the scale of the co-firing test was 25 times larger than the earlier test held in Nijmegen.

The test looked at (a) charcoal transport and handling; (b) fuel blending; (c) co-milling charcoal and hard coal and (d) co-firing. The test proofed that there are few technical difficulties co-firing a large percentage of charcoal in a coal-fired power plant. The only real problem experienced is the occurrence of dust emissions when handling charcoal. This excessive dusting makes it necessary to handle charcoal in normal operation in closed transport and milling systems, much like other biomass (e.g. pellets). The separate handling of charcoal adds to its costs.

Blueprint (detailed design) of a scaled-up charcoal production plant

The results of the four proceeding WP clusters culminated in the design of a large-scale charcoal production plant with an output capacity of 10,000 tonnes per year, together with a plan how to implement such plant. The Estonian joint venture of SME partners ENER and

GreenCoal designs, constructs and installs twin-retort medium-scale charcoal production plants but has no direct experience producing designs for a scaled-up plant.

The design and engineering work was led by ENER. SME partners GreenCoal and Insulcon and RTD performers BTG and UNIK also contributed. ENER also consulted and visited the original designers of the twin-retort carbonisation plant and a experienced refractory specialist.

Under the guidance of ENER engineering drawings, material lists, overview drawings, construction labour requirements, control equipment specifications, construction time schedules etc. were prepared in an iterative process. The investment costs for a single carbonisation retort (2,500 tonnes of charcoal per year) and an integral carbonisation plant (4 retorts; 10,000 tonnes of charcoal per year) were also calculated.

In close co-operation SME partner GreenCoal and RTD performer BTG subsequently produced a comprehensive implementation plan including a business plan for scaling up charcoal production to 10,000 of charcoal per year. The implementation plan covers plant location, logistics of wood supply and charcoal delivery, feedstock price, economic feasibility, capital and operational costs assessment, risks strategies, etc.

The implementation plan shows that under current market conditions charcoal production for the traditional (barbecue) market is financially attractive, showing a healthy 14% internal rate of return. Producing power grade charcoal for the co-firing market is not financially feasible in the short-to-medium term.

1.3 Impact of the project on its industry or research sector.

As a co-operative research project an important goal of the project was to improve the market potential and competitiveness of the SME partners. The prime market targeted at is the electric power sector co-firing biomass in coal power plants. A second market is the traditional barbecue market.

As discussed above, it was found that under current market conditions it is not possible to produce power grade charcoal at an attractive price for the electric power sector. It is not realistic to consider any major sales, other than for research purposes, to this sector in the short-to-medium term.

Current market conditions for the SME's traditional barbecue market are much better. In this market, contracts are negotiated annually and charcoal producers have been able to pass on recent cost increases in raw material procurement and charcoal transport to their buyers (e.g. supermarket chains). The demand for barbecue charcoal in EU Member States is growing a few percent each year, and charcoal consumers pay increasing attention that the charcoal they buy is produced in a sustainable manner.

The Power-Grade Charcoal project has yielded a design, implementation and business plan for a large-scale charcoal production plant with an output capacity of 10,000 tonnes per year. This result enables the participating SME partners to better serve their traditional market, and offers them two distinct business opportunities. Firstly, charcoal producers ENER and Centropol now have the possibility to scale-up their charcoal production, and can achieve a healthy 14% internal rate of return. Secondly, the joint venture of SME partners ENER and GreenCoal have the possibility to sell scaled-up charcoal production technology.

Realistically, to be able to market the scaled-up charcoal production technology one of the SME partners should first demonstrate and proof its technical and economic viability. This demonstration plant can serve as a showcase and benchmark that would help the ENER-GreenCoal joint venture, or any other entity operating on behalf of the participating SME partners, to successfully market the technology.

1.4. Diagrams/ photos illustrating the work of the project, a project logo and a reference to the project website.

The figures below give an impression of the layout of an individual carbonisation oven (capacity 2,500 tonnes of charcoal per year) and a carbonisation plant based on 4 such ovens (total capacity 2,500 tonnes of charcoal per year). Within the project full AutoCad design drawings of these have been produced.

Figure 1 Various views and layout of layers of the scaled-up carbonisation oven

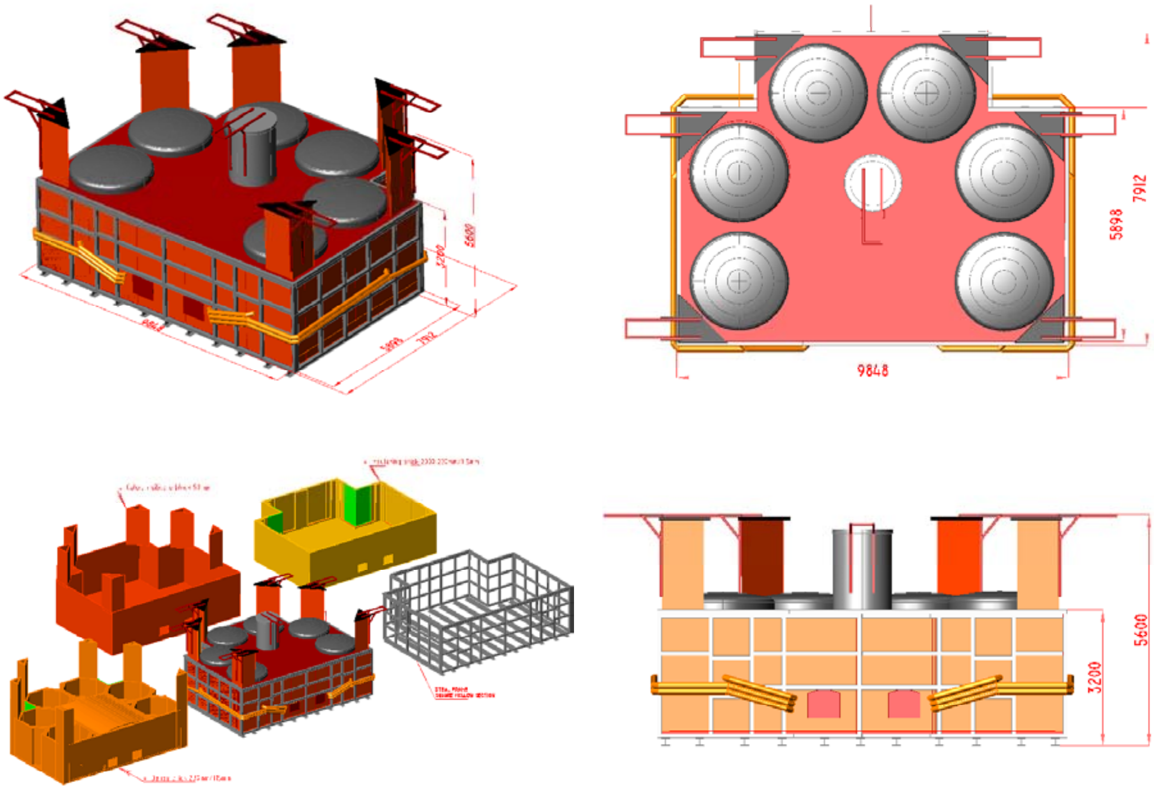
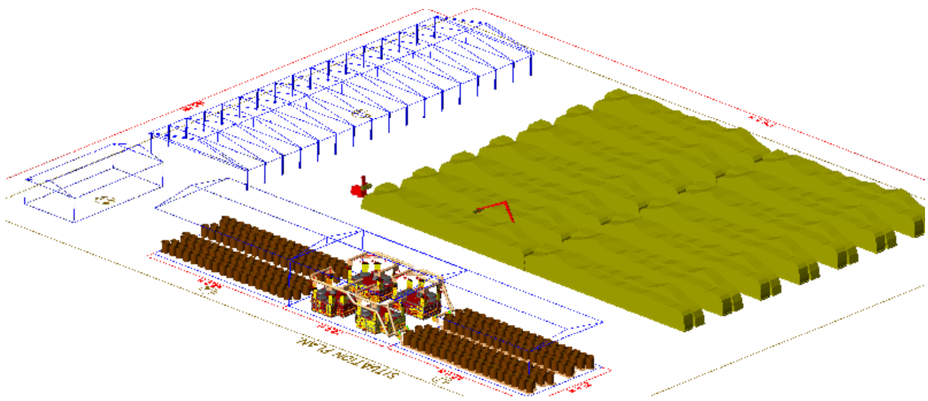


Figure 2 Top view (artist impression) of a scaled-up carbonisation plant (final design)



The project website can be found at URL:

1.4 Further information

As most of the Deliverables were of a confidential nature the communication beyond the project consortium of the project's progress, findings, outcome and results has been modest.

No project logo has been developed, and the developed project website was straightforward.

As the main outcome has only become available close to the end of the project the co-ordinator will continue promoting the project results for some time to come. An important dissemination activity will be the oral presentation at the 16th European Bioenergy Conference, to be held in Valencia, Spain from 2-6 June 2008.

For further information on the project please contact the co-ordinator.

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Section 2: Dissemination and Use

With the exception of the final report (Section 1 of this document) few other publishable results are available. However, giving one or more publications, to be presented at a large European bioenergy conference[1], is considered essential to reach the target audience, which include the electric power sector interested in co-firing biomass, as well as the charcoal sector (producers, customers, intermediaries, etc.).

Large biomass energy conferences considered suitable platform for dissemination project results include:

- World Sustainable Energy Days (scheduled for Wels, Austria, March 2008)
- World Bioenergy 2008 (scheduled for Jonköping, Sweden, May 2008)
- European Bioenergy Conference (scheduled for Valencia, Spain, 2-6 June 2008)
- 2nd European workshop of the Integrated European Network of Biomass Co-firing (NetBioCof) project, to be held in the second half of 2008.

Early February 2008 the coordinator received notice from the organisers of the 16th European Biomass Conference in Valencia that the abstract submitted in autumn 2007 had been accepted for an oral presentation.

[1] Preferably in an oral presentation, alternatively in a poster session. The decision how the project will be presented is normally made by the conference organisers, not by the project owners.