Conversion Of Biomass Residues To Transportation Fuels With The HTU® Process

Frans Goudriaan, Biofuel B.V.
Jaap Naber, Biofuel B.V.
Ed van den Berg , HVC Groep

CONTACT

Contactname: Ed van den Berg
Organisation: HVC Groep
Postal adress: Postbus 9199, 1800GD, Alkmaar
Telephone: +31 (0)72 541 13 11
Facsimile: +31 (0)72 541 13 44
E-mail: e.vandenberg@hvcgroep.nl

EXECUTIVE SUMMARY

HVC is a modern, innovative, public service waste company, committed to providing efficient, financially sound and environmentally friendly waste management services. The company is working together with Total France and Biofuel on developing te so-called Hydro Thermal Upgrading (HTU®) process.
The HTU® process for the thermochemical liquefaction of biomass offers excellent opportunities for conversion of biomass to a transportable form of energy. Suitable feedstocks include organic domestic waste, residues from agriculture and forestry, and also peat. Biomass is quantitatively and efficiently converted by treatment in liquid water at temperatures from 300 to 350°C and pressures from 100 to 180 bar. The product is 'Biocrude', a heavy organic liquid with 10-15%w oxygen and a heating value of 30-35 MJ/kg. It readily separates from water. Due to the low oxygen content it can be further upgraded cost-effectively by hydrodeoxygenation to a clean diesel-type fuel with high cetane number, that offers excellent prospects for direct blending with existing (conventional) automotive diesel fuels.

The development of the HTU® Process has reached a stage that a programme for commercial demonstration has been started early 2006. A consortium comprising TOTAL, the Waste Processing Company HVC and Biofuel is aiming at a demonstration unit (HTU®-1) of 25,000 tons biomass (dry basis)/year.

1 INTRODUCTION

This paper gives a description of the HTU® process for the conversion of biomass into a crude oil type product. This biocrude can be upgraded into a premium diesel fuel which can directly be blended with conventional diesel. The process is unique in its capability to convert *wet* biomass waste streams. The availability of waste streams with a price below 2 Euro/GJ is 0.2 billion dry tons in Europe and 5 billion tons worldwide. The HTU® process can, after the initial commercial applications, compete without subsidy with products from petroleum at crude prices of 30-50 $/bbl. A case study is discussed where the extraction of protein from grass is combined with the HTU® process. This provides ample synergy and it opens perspectives for a bio-based industrial complex. The economics of such a complex are shown to be very attractive.
Keywords: biomass conversion, wet residues, bio-energy complex

2 THE HTU® PROCESS

In chemical terms the key to biomass liquefaction is the removal of oxygen. Biomass contains typically 40-45%w (DAF, dry and ash free basis) of oxygen. Oxygen removal increases the heating value and it leads to a product with more hydrocarbon-like properties, ultimately causing it to be immiscible with water. In thermochemical liquefaction the oxygen is removed as carbon dioxide and water.
The HTU® (hydrothermal upgrading) process heats the feedstock in liquid water to temperatures between 300 and 350^{o}C, pressures 100-180 bar and a residence time ranging from 5 to 20 minutes. At these conditions up to 85% of the oxygen is removed from the biomass. It ends up in about equal proportions in carbon dioxide and water [3]. A typical product distribution is given in Table I.

Table I: Typical HTU® product distribution (mass units DAF)

Feedstock: Biomass	100
Products:	
Biocrude	45
CO_2	23
CO	2 (*)
Organics Dissolved (**)	12
H_2O	18

(*) Includes minor amounts of CH_4 and H_2
(**) Light organics such as acetic acid, ethanol

A very large variety of *feedstocks* has been tested in HTU® autoclave and pilot plant experiments. They include wood, waste streams from sugar, potato and other food industries, grass, olive waste, organic domestic waste and fractions thereof, peat, digestate from anaerobic digestion, frying fat, and slaughterhouse waste. Figure 1 presents a simplified process scheme.

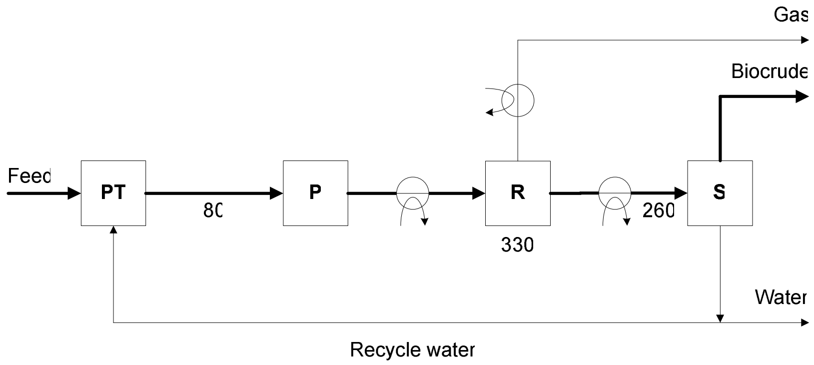

Figure 1: Simplified scheme of the HTU® process

PT = pretreatment, recycle water (only if water content of feedstock is low).
P = pump; R =reactor; S =separator; figures: temperatures in °C

The *biocrude product* is an organic substance that readily separates from water. At room temperature it is a solid, and it becomes a liquid at about 80°C. It contains 10-20%w (DAF) of oxygen. The atomic H/C ratio is generally 1.0–1.3 and the average molecular weight is around 400. The nitrogen and sulfur contents depend on those of the feedstock. The LHV (lower heating value) of the biocrude is 30-35 MJ/kg DAF. The thermal efficiency[1] of the HTU® process is 70-85%, depending on the degree of heat integration in the process scheme [3]. The water-soluble minerals present in the feedstock end up in the water phase and the insolubles collect in the biocrude.
The raw biocrude can be separated into a light and a heavy biocrude by either flashing or solvent extraction.
The light biocrude (LCR) is minerals-free. It can be used for high-efficiency electricity production. However, for large-scale applications it is preferred to upgrade the LCR by catalytic hydrodeoxygenation (HDO) to produce a premium gasoil and other high-quality fuel fractions. Exploratory experiments have shown that the gasoil fraction has excellent ignition properties [1]. It can directly be blended with conventional diesel fuel. No adaptations to engines or the existing distribution system are required.
The heavy biocrude (HCR) is a coal-like solid. It can be co-combusted in a coal-fired power station to raise green electricity. Alternatively, it may be gasified to produce 'green' hydrogen, part of which can be used for HDO.

[1] Thermal efficiency is defined as the ratio of (LHV in biocrude product) / (LHV in feedstock + external energy supplied to the process).

3 STATUS OF THE PROJECT

3.1 R&D Achievements

The most important achievements of the process R&D work are:

- Pressurising of the feedstocks in one step with a commercial proto-type pump, scaled down to pilot plant size, see also [4].
- A practical pre-treatment (cleaning and size reduction) of commercially attractive feedstocks, including organic household waste (GFT) and Public Garden Waste.
- Operation of the pilot plant in continuous shift for three weeks [5].
- The suitability of processing GFT has also been successfully verified.
- Definition of a demonstration programme for the diesel product [1].

- Basic design and cost estimate for a HTU® plant of commercial size (130 kton/a dry basis) by Jacobs Engineering Nederland.
- Predesign and cost estimate of a commercial demonstration plant HTU®-1 with a capacity of 25 kton/a db.

3.2 Economics

On the basis of the cost estimate we have made an economic analysis of the commercial-size HTU® process. Figure 2 gives the result.

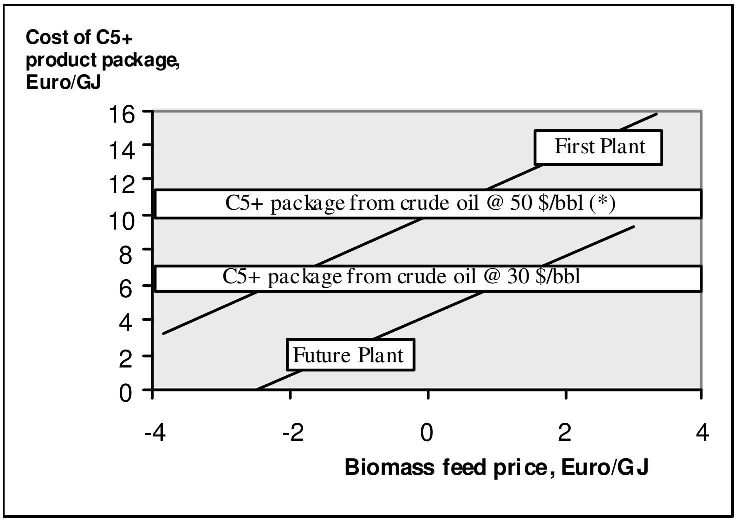

Figure 2: Cost of HTU® plus HDO
HTU capacity 200 kton/a db, 20%dm
(*) or 30$/bbl with tax reduction of 15 Euro cents/litre

HTU® can compete with a premium diesel made from petroleum at crude prices between 30 and 50 $/barrel when the biomass cost ranges from –1 to +2 Euro per GJ. No subsidy, tax reductions or CO_2 certificates were considered in this evaluation.

In view of the unique suitability of HTU® for the conversion of wet biomass streams and the price levels of such streams it is logical to start the commercialisation with such feedstocks. There is a massive availability of wet biomass waste at a price below 2 €/GJ. In *The Netherlands* these comprise organic domestic waste, road side grass, slaughterhouse waste, waste from agriculture and silviculture, and from food industry with a total of some 3 million tons (db). In *Europe* the total is 200 million tons (db), including 5 million tons of olive waste. *Worldwide* there is some 5 billion tons (db) of such streams from which 100 million tons (db) of bagasse.

3.3 First commercial plant (HTU® -1)

The development of the HTU process has reached a stag

A group of participants, among which the HVC groep and Total France, is about to start preparations for the commercial demonstration of the HTU® Process. The capital investment for the HTU®-1 plant is estimated at 15 to 20 million Euro. The main activities leading to the final decision point are:

- Definition of the commercial biomass feedstock mix, and perspective for supply contracts.
- Performing design runs with the feedstock mix in the HTU® pilot plant.
- Design of the anaerobic treatment for the waste water.
- Development and design of the extraction section for biocrude separation.
- Verification of the feasibility of the HDO upgrading.

- Basic process design and cost estimation by an Engineering Contractor.
- Preparation for the necessary permits.

4 INTEGRATION OF THE HTU® WITH PROTEIN EXTRACION

4.1 Principle

The HTU® process has excellent economic perspectives for a stand-alone situation, as pointed out in subsection 3.2. For any commercial application, however, one will consider whether integration with other operations can offer additional advantage. An example of such a cooperation is given in the sections 4 and 5.

It is well known that protein can be isolated from grass and other plants by pressing out the juice followed by coagulation [6]. In The Netherlands the so-called grass consortium has patented an improved process for extraction of protein with excellent properties as fodder [7]. The economics of a stand-alone application of the extraction are hampered by the lack of a suitable outlet for the by-products fibres and juice, and because a substantial amount of low-temperature heat is required for heating the juice to the coagulation temperature.

4.2 Case study

In cooperation with the Agrotechnology and Food Innovation (A&F) and Valorisation of Plant Production Chains (VPPC) groups of Wageningen UR we made a study into the integration of protein extraction from grass and the HTU® processing of the combined fibres and remaining juice. A technical and economic evaluation was made for an installation where about 200 kton/a (db) of cultivated grass is extracted. The feed stream to the HTU® installation is 130 kton/a (db). Maximum heat integration between the two installations is applied.

The heavy biocrude fraction (HCR) and surplus high-temperature heat are used to generate the electric power required for the extraction, the HTU® and the HDO installations. The yearly production is about 70 ktons of protein and 25 ktons of premium fuels.

The integration provides a considerable synergy. An outlet is created for the by-products of the protein extraction, and the HTU® obtains a feedstock which can be converted without pretreatment. Finally, the surplus low-temperature heat from the HTU® can be used efficiently in the protein extraction and the scheme is self-sufficient in its electricity consumption.

4.3 Economics

From the evaluation of the integrated scheme described in 4.2 it appears that the economics of the combined installation are very promising. The economy is dominated by the prices of grass and protein. The grass price is dictated by the local farming economy. The protein price is rather variable, since it is linked to the world soya price.

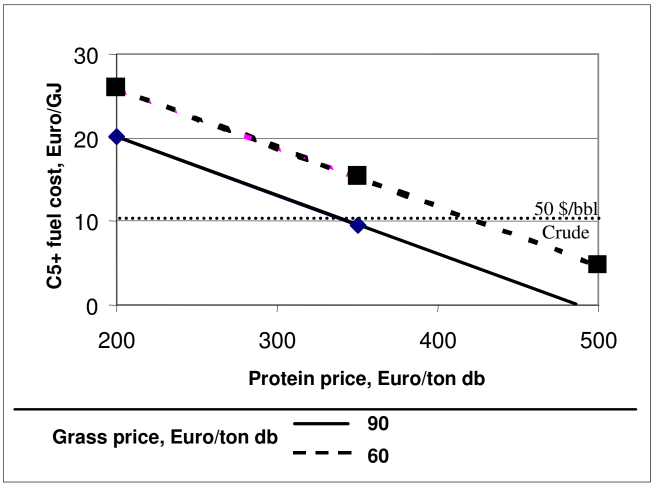

Figure 3: Effect of grass and protein cost on fuel product price

In Figure 3 the effect of the prices of grass and protein on the cost of the final hydrocarbon fuel mixture is shown. It demonstrates that at average prices for grass (75 €/dry ton) and protein (350 €/ton) the C_5^+ product is produced at a price of 12.5 €/GJ (LHV basis). This is competitive with premium products manufactured from petroleum at a crude price of 65 $/barrel.

It should be stressed that the result was obtained without any subsidy, tax reduction on green fuels, and CO_2 certificates. Introduction of any of these will render the present scheme competitive at crude prices of 30$/barrel or even lower.

5 HTU® - Based Bio-Refinery

5.1 Concept for case study

The example given in section 4 is further worked out here by the visualization of an industrial complex which is based on biomass as the raw material. A case study was made with the object of judging the economic potential of such a complex.

As depicted in Figure 4, the conversion processes are protein extraction and HTU®. The protein extraction is applied to 250 kton/a (db) of grass and beet leafs.

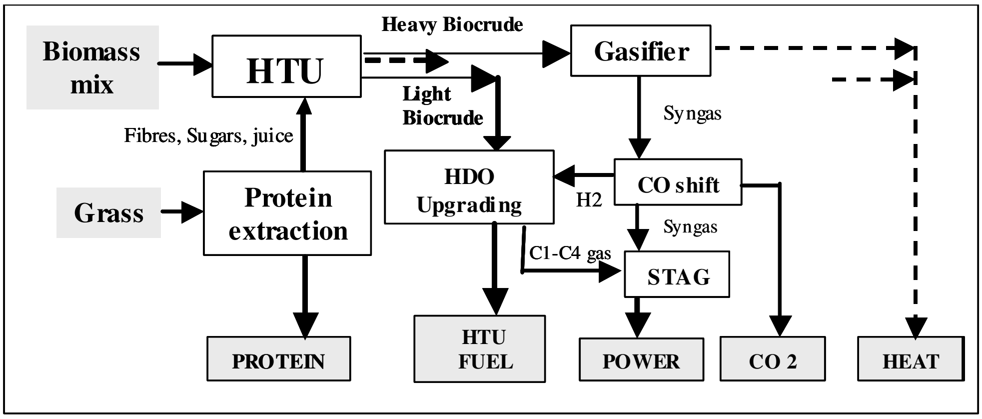

Figure 4: Layout of an HTU® based biorefinery complex.

Feedstock to the HTU® is the juice and fibres from the protein extraction, and 235 kton/a (db) of a “Biomass Mix” composed of biomass streams which are available in the area. These may be residues from agriculture, food industry (e.g., a sugar producing factory), or from households. For the study we selected as an example a mix of sugar beet residues, sugar beet pulp, road side grass and organic domestic waste.

The light biocrude fraction (LCR) is upgraded into diesel fuel by HDO as described earlier. The HCR is converted in an entrained-flow gasifier. The resulting synthesis gas supplies the hydrogen required for the HDO upgrading of the LCR. The remainder of the synthesis gas and the surplus high-temperature heat is used for the generation of electric power. This serves for the own electricity consumption in the HTU®, HDO and protein extraction installations. The surplus electricity is exported. Thus, the products from this biorefinery are:

- Protein as a premium cattle fodder component.
- HTU® diesel of premium quality
- HTU® kerosine as a green aviation fuel
- HTU® naphtha as a green chemical feedstock to existing chemical plants
- Electric power
- Carbon dioxide, either for greenhouse horticulture or for sequestration
- Export heat

This makes this biorefinery very attractive as a partner in a larger bio-based industrial complex with extensive exchange and integration of utilities like electricity, steam, carbon dioxide, hydrogen, etc. The sequestration of CO_2 would make the HTU® complex even CO_2-positive, i.e., it withdraws CO_2 from the atmosphere.

5.2 Economics

The economic potential of the biorefinery complex was assessed with a discounted cash flow calculation. Total capital investment was estimated to be 280 million Euro, including 20% project overhead contingency. A project life time of 15 years was assumed. CO_2 certificates afford 20 Euro per ton of avoided CO_2 emission. Feedstock prices are 65 Euro/dry ton for the protein extraction feed and 30 Euro/dry ton for the Biomass Mix to the HTU®. The selling price of the premium fuel products was derived from the crude oil price for two cases, viz., 30 and 50 $/barrel.

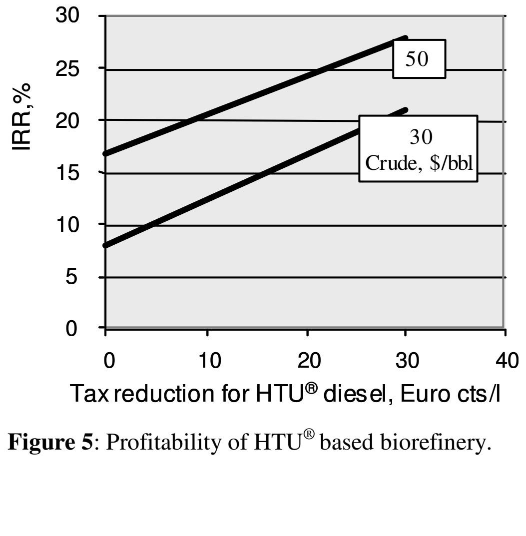

Figure 5: Profitability of HTU® based biorefinery.

The result is shown in Figure 5, where the internal rate of return (IRR) is plotted as a function of the tax reduction on green diesel. The conclusion is that the project is already viable without a tax reduction. With a moderate tax reduction of 20 Euro cents per litre the (IRR) ranges from 17 to 25% per year. No tax reduction or other incentive was assumed for green electricity, and the proceeds from the exported heat were neglected. If these effects are considered, the attractiveness would even further increase.

6 CONCLUSIONS

- HTU® converts all types of biomass into biocrude.
- The biocrude can be upgraded into a premium diesel fuel, which can directly be blended with conventional diesel.
- HTU® is unique for conversion of wet biomass streams into diesel fuel.
- After the initial commercial applications HTU® is competitive without subsidies with products derived from crude oil at a price of 30-50 $/bbl.
- Preparations for a first commercial demonstration installation of 25 kton/a (db) have been started.
- Integration with protein extraction from grass shows promise.
- Integration of HTU® in a bio-based industrial complex with extensive exchange of utilities has a very attractive economy.
- HTU® is CO_2-neutral and with sequestration even CO_2-positive.

REFERENCES

[1] Naber, J.E. and Goudriaan, F., "Transportation fuels from biomass via the HTU® process", Paper 5b of the 4th European Motor Biofuels Forum, Berlin, 24-26 November 2003 (Europoint).

[2] Naber J.E., Goudriaan F., Zeevalkink J.A. and Berends R.H., The HTU® Process is ready for Commercial Demonstration", Proceedings of the 2nd World Biomass Conference - Biomass for Energy, Industry and Climate Protection, (2004) 1894.

[3] F. Goudriaan, B. Van de Beld, F.R. Boerefijn, G.M. Bos, J.E. Naber, S. van der Wal and J.A. Zeevalkink, "Thermal efficiency of the HTU® process for biomass liquefaction", Proceedings of conference "Progress in thermochemical biomass conversion", Tyrol, Austria, 18-21 September 2000 (A.V. Bridgwater, ed.) pages 1312-1325 (ISBN 0-632-05533-2).

[4] Beld, L. van de, Boerefijn, F.R., Bos, G.M., Goudriaan, F., Naber, J.E., and Zeevalkink, J.A., "Process for the production of liquid fuels from biomass", Chinese Patent 01818289.5 (2005) (to Biofuel B.V.)

5] Berends R.H., Zeevalkink J.A., Goudriaan F., and Naber J.E., "Results of the first long duration run of the HTU® pilot plant at TNO-MEP", Proceedings of the 2nd World Biomass Conference - Biomass for Energy, Industry and Climate Protection, (2004) 535.

[6] Kamm, B. and Kamm, M., Appl Microbiol Biotechnol 64(2004) 137-145;
Reske, J, Kamm, B., and Kamm, M., Umweltwirtschaftsforum, 10 (2), June 2002 (Springer Verlag) 21-25.

[7] Hulst, A.C., Ketelaars,J. and Sanders, J.P.M., "Separating and recovering components from plants", US patent 6740342 (1999)