



Integrated Biomass Utilisation System

PUBLISHABLE FINAL REPORT

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Doc. no. 486762
Project no. E001123.02

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9 November 2006
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1. Executive Summary

1.1 Objectives

The overall objective of the project is to develop cost and energy effective production systems for co-production of bioethanol and electricity based on Integrated Biomass Utilisation Systems (IBUS). The IBUS concept integrates utilisation of lignocellulosic feedstocks, which produce ethanol, animal feed and a surplus of solid biofuel, with starch-sugar feedstocks, which produce ethanol and animal feed but consume fossil fuels.

Furthermore, the concept integrates production of electricity and bioethanol by using the low value low pressure steam from the power plant to cover the steam consumption of the bioethanol process.

1.2 Results

The project has achieved very useful results of which the most significant are:

- Development of a low cost continuous pressurised hot water pre treatment process for lignocellulosic feedstocks producing a liquid fraction with more than 90% of the straw's alkali-chlorides and a part of the hemicellulose sugars and a fibre fraction with 30-45% DM and more than 90% of the straw's cellulose and lignin content together with the remaining hemicellulose. The key component of the process – the Particle Pump – is protected by patent.
- Development of a high gravity liquefaction process capable of converting the fibre fraction with 30-45% DM to a pumpable liquid within few hours at moderate enzyme concentration (3-4 FPU/g). It has been demonstrated that the liquefied fibre fraction (including the lignin) can be fermented by means of yeast using simultaneous saccharification and fermentation (SSF). Patent Pending.
- Development of a thermophilic organism that produces ethanol from all sugars found in biomass hydrolysates under controlled pH and temperature. These results indicate that the thermophilic fermentation process is feasible, and the organism will be used to develop a full-scale commercial process.
- Development of an integrated process and process equipment for conversion of lignocellulosic feedstocks comprising: particle generation, pretreatment, liquefaction, fermentation and product recovery. The integrated process is characterised by 100 % utilisation of the raw material, no waste water and no emission of volatile organic compounds. Full sustainability is achieved by recycling of the plant nutrients contained in the raw materials to the soil via the animal feed produced. Pilot plant equipment with capacities of 10 kg/h, 100 kg/h and 1000 kg/h has been constructed. Patent pending.
- Pilot-scale trials with biomass from household waste have demonstrated that it is possible to conduct liquefaction and fermentation (SSF, yeast) after pretreatment at temperatures as low as 100° C. A low-cost fractionation process for household waste with the capacity to isolate the biomass at low cost has been developed. Patent pending.
- The feasibility studies of the project demonstrate that wheat straw can compete with a wheat grain price of 120 EUR/t when the cellulase cost is 0.16 EUR/l ethanol and the straw price is below 30 EUR/ t. If the cellulase price can be reduced to 0.03 EUR/l ethanol, which is anticipated by No-vozymes and Genencor, a straw price around 60 EUR/t can compete with a grain price of 120 EUR/t.

If the hemicellulose sugars are used in animal feed as a C5 molasses (70 % DM) and sold at a price of 86 EUR/t they can compete with C5 fermentation using thermophilic organisms or genetically modified yeast. The economy of scale favours units producing more than 150 000 t/y of ethanol which requires about 1 million t/y of straw (without C5 fermentation) or about 0.75 million t/y with C5 fermentation. Collection of such quantities in Europe will be costly, and this makes the integration of 1st and 2nd generation bioethanol beneficial.

The results will be used for design and construction of the first industrial IBUS plant for about 150 000 t/y of bioethanol.

2. Synthesis report

The work performed under the project: Co-production of biofuels was organised in 6 work packages addressing the following main scientific technical and financial objectives related to the conversion of ligno-cellulosic raw materials to bioethanol, animal feed and solid biofuel.

- WP 1A Pretreatment investigations with different raw materials using different catalysts, temperatures and residence times. Risoe (section 2.1)
- WP 1B Enzymatic hydrolysis and C6 fermentation with yeast (RVAU) (section 2.2)
- WP 2 C5 and C6 fermentation with thermophilic organisms (TMO) (section 2.3)
- WP 3 Development of process equipment to create an integrated pilot plant for conversion of wheat straw delivered in bales. The process comprises:
- Particle generation and cleaning
 - Pretreatment
 - Enzymatic hydrolysis
 - Ethanol fermentation
 - Ethanol recovery (Elsam, Sicco)
- WP 4 Feasibility studies based on data from trials on the integrated pilot plant and relevant external data. Focus was placed on the combinations of straw, whole grain and biomass from Municipal Solid Waste (MSW) as raw material (Elsam)
- WP 5 Feasibility studies focussing on whole crops as raw material (Elsam, Sicco)
- WP 6 ICT-based implementation system (Elsam).

2.1 WP 1A Pretreatment investigations

2.1.1 Laboratory experiments

Pretreatment (wet oxidation) of several different raw materials was performed in lab-scale experiments using 6% DM. Wet oxidation was tested by means of enzymatic hydrolysis of the fibres (using 30 FPU/g DM) and (for some experiments) by means of SSF with baker's yeast. **Wheat straw** was optimised, and it was found that addition of 2 g/L of Na₂CO₃ or NH₃ resulted in a high sugar recovery and high amounts of soluble sugars (17-19 g/100 g straw). The enzymatic conversion of cellulose was 100 % and of hemicellulose 80 %. The potassium content was decreased from 1.7 % in the raw material to 1 ‰ in the wet oxidized wheat straw. Pretreatment of **sugarcane bagasse** at 185 °C for 5 minutes and with acidic pH gave the highest yield of hemicellulose-derived sugars in the liquid fraction, 14.4 g/100 g. The highest enzymatic convertibility of cellulose in bagasse (65 %) was achieved after pretreatment at 195 °C for 15 minutes with alkaline pH. **Municipal solid waste** (MSW) was enriched with straw fibres to 8 % DM. For all wet oxidation conditions tested, total carbohydrate recoveries were high (> 89 %), and SSF of the treated waste showed compatible conversion yields of 60-65%. For **woody yard waste**, enzymatic cellulose convertibility to glucose was most optimal after wet oxidation for 15 minutes at 185 °C with addition of 12 bar oxygen and 2 g/L Na₂CO₃ (58-67 %). **Maize silage** was pretreated at optimal conditions for corn stover (195 °C, 15 minutes, 2 g/L Na₂CO₃, 12 bar O₂). After pretreatment very high hydrolysis yields could be obtained (90%), and in SSF, 91 % of the theoretical ethanol yield was obtained after only 40 h of fermentation.

2.1.2 2-step experiments (100 kg/h scale)

Several trials were carried out with 2-step pilot-scale hydrothermal pretreatment with varying parameters of temperature (190 °C, 195 °C, 200 °C, 205 °C), residence time (3 min, 6 min, 12 min), water flow (100 l/h, 250 l/h, 500 l/h, 0 l/h (steam pretreatment)), and addition of catalysts. Experiments with catalysts were made with Na₂CO₃ (2 g/l and 6 g/l), NH₃ (1 g/l), H₂SO₄ (0.7%), and some experiments were carried out as

wet oxidation experiments by adding 0.5 % H₂O₂ to the water. The best hemicellulose recovery was found at 190 °C (87 %), and extraction of hemicellulose in the hydrothermal treatment was improved at longer residence times of the straw in the reactor (12 min). In this experiment 32 % was extracted. The best total hemicellulose yield was found at 190 °C with H₂O₂ addition (68 %). In this experiment approximately 30 % of the hemicellulose was extracted during pretreatment, and approximately 40 % was obtained in the enzymatic hydrolysis. In most experiments at higher temperatures a significant degradation of the hemicellulose fraction was found independent of other reaction conditions. The convertibility of the cellulose fraction was improved at higher temperatures (up to 71 % at 200 °C and 205 °C) under hydrothermal conditions without catalysts added, and it was in these experiments that the highest glucose yield was found. In SSF of straw pretreated at 200 °C, ethanol yields of close to 100 % of theoretical was obtained. Addition of H₂O₂ decreased the convertibility compared to no addition, but the inhibitor level in the liquid fraction was reduced. The highest lignin recovery was found in experiments at hydrothermal conditions using the shortest residence time (3 min) and high temperatures (200 °C-205 °C). For an optimal 3-step process, as suggested for the 1000 kg/hour plant, and based on the maximum obtained sugar yields from these 2-step trials (68% for hemicellulose and 71% for glucose), the expected total ethanol production (theoretical) was 223 kg ethanol/tonne of straw.

2.1.3 3-step experiments

The pilot plant was expanded during the summer holiday 2005 from a 2-step pretreatment with a max capacity of 100 kg/h to a 3-step pretreatment with a maximum capacity of 1 tonne/h. The 3-step pretreatment was expected to enable both high hemicellulose recovery and cellulose convertibility. Five optimisation trials were performed on this plant. All trials were performed with the same parameters in the third reactor step (195 °C for 3 minutes) with varying parameters in the second step and varying water flow. The parameters in the second step and the water flow in the three trials were as follows: **Trial (1)** 180 °C for 7.5 minutes with a water flow of 420 l/h, **Trial (2)** 170 °C for 7.5 minutes with a water flow of 420 l/h, **Trial (3)** 180 °C for 15 minutes with a water flow of 600 l/h, and **Trial (4)** was performed with low water addition (0-200 l/h). The water flow in reactor 2 had positive effect on the hemicellulose extraction. Thereby high hemicellulose recovery (83%) and the highest total hemicellulose yield (69%) were obtained with a water flow of 600 l/h. The hemicellulose recovery was lower when low water addition was used (0-200 l/h) due to sugar degradation and inhibitor formation. The highest enzymatic cellulose convertibility (~70%) was found in experiments with low water flow (0-200 l/h), resulting in ethanol production (in SSF) of 90% of the theoretical yield. The pretreated straw became more fermentable when it was filtered to remove the liquid phase containing inhibitors. After subsequent washing in water, the resulting ethanol yields from glucose were 100%. The theoretical ethanol production from convertible fibres and hemicellulose sugars in the pretreated samples was 118-136 kg/tonne of straw, and in the experiments the highest production was reached where low water flow was used (0-200 l/h) due to the higher cellulose convertibility obtained in these experiments.

2.1.4 Detoxification

Detoxification of the most toxic liquid fractions from the 2-step pretreatment was performed using three different methods: Adjustment of pH to 10 with addition of Ca(OH)₂ followed by neutralisation with CO₂ and subsequent removal of precipitated compounds. The same method was applied only with addition of NH₃. The third method was wet oxidation of the liquid at 190 °C with 6 bar O₂ for 10 minutes. SSF of the detoxified liquids with added cellulose was performed with baker's yeast and compared to SSF of cellulose in the buffer. The best results were obtained with the Ca(OH)₂-detoxified liquid. SSF of this liquid gave an ethanol yield comparable to that of SSF in the buffer. After 140 h of fermentation the yield was close to 100% of theoretical. With NH₃ the ethanol yield after 140 h was 88 % of theoretical, and with wet oxidation, the yield was 85% of theoretical.

2.1.5 Removal of potassium during pretreatment

One of the objectives in IBUS was to produce a low-alkali solid fuel for incineration. The aim was to obtain a 95 % reduction of the potassium content in the pretreated straw. Different process configurations were tested, and the influence of e.g. the counter-current water flow in the reactor was investigated. In the 1000 kg h⁻¹ pretreatment plant, a substantial part (up to 60 %) of the potassium was already removed in the stone trap and the pre-soaking reactor. Operating the pretreatment with a straw-water ratio of 1:5.6 resulted in 95 % removal of potassium. It was therefore possible, even at low water flow rates, to ensure an efficient wash out of potassium. After subsequent fermentation of the pretreated material, the potassium content remained unaltered. It has been demonstrated that potassium is effectively washed out of the straw thereby producing an excellent solid fuel for combustion.

2.2 WP 1B Enzymatic hydrolysis and yeast fermentation

The pretreatment produced a solid fraction of pretreated straw and a liquid fraction containing alkali salts, dissolved hemicellulose and soluble degradation products. The ability to hydrolyse polysaccharides in both these fraction with enzymes was studied.

2.2.1 Hydrolysis of liquid fraction

The liquid fraction from the pre-treatment in general contained below 10 % of sugar of which xylose and arabinose constituted 80 %. Only 10-15 % of the sugar in the liquid is present as monosaccharides, whereas the remaining sugar is present as soluble oligosaccharides (arabinoxylan).

A variety of commercial enzyme preparations were tested alone or in mixtures in order to evaluate the possibility of releasing the monosaccharides. The best results revealed that up to 70-75 % of the sugar from the oligosaccharides could be liberated within 24 h using enzyme loadings of 0.5-1.0 % (v/v). The resulting liquid produced after enzymatic hydrolysis contained up to 8 g l⁻¹ of total monosaccharides. Using thermophilic bacteria capable of fermenting the xylose would preferably require that the enzymes could be used at temperatures of 60 °C or higher (the growth temperature of the microorganism). For all tested enzymes the yields were around 10 % lower at 60 °C compared to 50 °C. It is therefore not beneficial to design the process as a simultaneous saccharification and fermentation (SSF).

2.2.2 Hydrolysis of solid fraction at high dry matter

To improve process economics of the lignocellulose-to-ethanol process, a reactor system for enzymatic liquefaction and saccharification at high solids concentrations was developed. The technology is based on free-fall mixing, employing a horizontally placed drum with a horizontal rotating shaft mounted with paddlers for mixing. Enzymatic liquefaction and saccharification of pretreated wheat straw was tested with up to 40 (w/w) % initial DM. In less than 10 h the structure of the material was changed from intact straw particles (length 1-5 cm) into a pumpable paste/liquid. Tests revealed no significant effect of mixing speed in the range 3.3 to 11.5 rpm on the glucose conversion after 24 h or the ethanol yield after subsequent fermentation for 48 h. Low power inputs for mixing are therefore possible. Liquefaction and saccharification for 96 h using an enzyme loading of 7 FPU (g DM)⁻¹ and 40 % DM resulted in a glucose concentration of 86 g kg⁻¹. Experiments conducted at 2 to 40 (w/w) % initial DM revealed that cellulose and hemicellulose conversion decreased almost linearly with increasing DM. Performing the experiments as simultaneous saccharification and fermentation also revealed a decrease in ethanol yield at increasing initial DM. *Saccharomyces cerevisiae* was capable of fermenting hydrolysates up to 40 % DM. The highest ethanol concentration, 48 g kg⁻¹, was obtained using 35 (w/w) % DM. Liquefaction of biomass with this reactor system unlocks the possibility of 10 (w/w) % ethanol in the fermentation broth in future lignocellulose-to-ethanol plants.

2.2.3 Improving enzymatic hydrolysis of solid fraction and recycling of enzymes

Unproductive and irreversible adsorption of enzymes onto lignin in pretreated lignocellulosic materials is a well-known problem and a barrier for an efficient hydrolysis of cellulose. Furthermore, the adsorption hinders recovery of enzyme after hydrolysis, as a substantial part of the enzyme can be bound onto the lignin. Various compounds like non-ionic surfactants (e.g. Tween 80), poly(ethylene glycol) (PEG) and also proteins (e.g. BSA) have been shown to improve the performance of enzymes on hydrolysis of pretreated softwood materials. The hypothesis is that these compounds reduce the adsorption of enzymes onto lignin.

Initial screening of a number of these compounds clearly showed a positive effect of adding surfactants or PEG. Irrespective of pretreatment conditions applied there was a positive effect of addition of surfactants, PEG or BSA. In general PEG showed good effect on the hydrolysis performance and on average the cellulose conversion was increased by 15 %. The positive effect was also observed on ethanol yield in SSF studies. Furthermore PEG is non-toxic and can be purchased at a relatively low price.

Optimisation studies employing PEG 6000 revealed that the optimum effect of PEG was obtained around 10 g per kg of DM, resulting in 16 % higher final yield of ethanol. This corresponds to a 30 % reduction in enzyme loading. With the current enzyme costs, the cost of PEG addition seems feasible.

Studies verified that addition of PEG did indeed result in higher enzyme activity free in solution, and therefore less enzymes were unproductively adsorbed onto lignin. Addition of PEG could thus be used to recover more enzymes after the hydrolysis. As the process is most likely going to be operated as an SSF process, the ethanol has to be removed before the liquid can be recycled. The enzymes are susceptible to rapid loss of activity at temperatures above 50 °C. Therefore, the ethanol has to be removed at lower temperatures employing vacuum. After stripping of ethanol, the liquid can be separated from the solids by either a decanter centrifuge or a filter press. The liquid with enzymes can then be added to the pretreated substrate together with fresh enzyme.

Recycling experiments revealed that after 24 h of liquefaction at 50 °C and SSF for 72 h at 32 °C in the hydrolysis reactor, 9 % of the enzyme activity could be recovered in the liquid when operating at an initial DM content of 20 % (w/w). Addition of PEG proved to be favourable. Using 10 g per kg DM of PEG 6000 increased the enzyme recovery to 10.5 %, and in addition 11 % higher final yield was obtained.

2.2.4 Removal of soluble lignin

During pretreatment some lignin is dissolved and some lignin degradation products are formed. These low molecular phenolics might act as inhibitors of enzymes and/or fermenting organisms. Removing these compounds from the liquid fraction and using them in the combustion might be beneficial.

Laccase is an enzyme catalysing oxidation of phenolic compounds in the presence of oxygen. The oxidation will result in formation of free radicals, which can then react and result in cross-linking of the phenolic compounds. This can either be between two soluble phenolic compounds or between a soluble phenolic compound and insoluble lignin. This polymerisation will result in formation of larger insoluble compounds that will precipitate. Laccase treatment can therefore be used to remove some phenolics.

The laccase treatment was tested on both wheat straw hydrolysate (pretreated straw after hydrolysis) and on a mixture of liquid and solid fraction from the pretreatment. In both cases it was proved that laccase treatment was able to remove phenolic compounds present in the material. The removal was measured by UV-VIS measurements after centrifugation of the material. The results were confirmed by GC-MS measurements, where the level of a range of low molecular phenolics was reduced significantly.

2.3 WP 2 Thermophilic Microorganisms

A thermophilic *Bacillus* sp. that naturally produces large quantities of lactic acid has been modified to eliminate the formation of this metabolite and has been shown to produce significant amounts of ethanol

from both C5 (xylose) and C6 (glucose) sugars commonly found in biomass hydrolysates. Long-term continuous culture studies have demonstrated that this modification is stable, and the strain continued to produce ethanol over a period in excess of 1500 hours with no reversion to the lactate-positive phenotype. Fermentation studies with feedstocks derived from hydrolysed straw demonstrated ethanol formation and the consumption of all sugars present. These results will form the basis for the development of a full-scale commercial process for the production of biomass-derived ethanol.

2.4 WP 3 Pilot Plant development

In the course of the project, a pilot plant demonstrating the complete process from straw to ethanol has been built on Fynsværket (a power plant owned by Elsam until 1 June 2006). The plant has been operated for more than 600 hours in the project period.

Figure 1 shows the process in schematic form and defines the different (interim and end) products in the process. Figure 2 is a birds-eye view of the pilot plant.

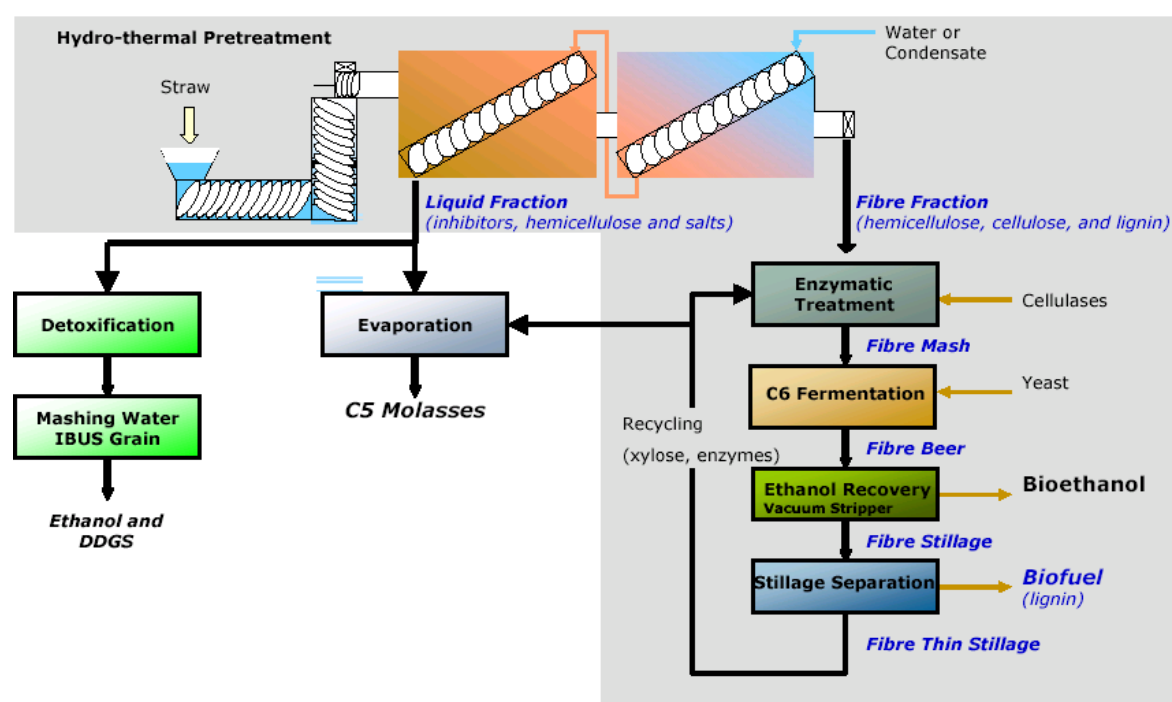


Figure 1 The IBUS process (principle)

The pilot plant includes the following parts:

- Straw reception
- De-baling
- Stone trap
- Cutting
- Pre-soaking
- Thermal treatment (2 reactors)
- Hydrolysis reactors/fermentation tanks
- Stripping and rectifying columns
- Control system



Figure 2 Pilot plant 1000 kg/h (straw reception, mechanical treatment and thermal pretreatment)

2.5 WP 4 Feasibility studies: straw + grain, MSW

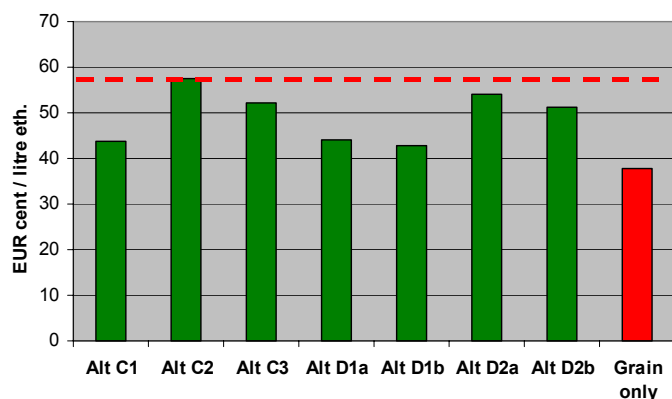
The objective of the feasibility study is to show the main process and economic data for the commercial-size straw, grain and municipal solid waste-based IBUS system outlined in seven alternative configurations. The data are based on own experimental data and current commercially available processes. All calculations are based on estimations on the 2nd plant, which means that special costs of developing, building and commissioning the first plant of a kind are not included.

Through experiments, modelling and analytical work in the project period, the following inputs/outputs for the seven alternative IBUS configurations in WP4 (Table 1), are reached. Case 1 is treated in WP 5, but has been included in Table 1 for comparison (for configurations handled in WP 5, see section 2.6).

	Unit	Alt. C1	Alt. C2	Alt. C3	Alt. D1a	Alt. D1b	Alt. D2a	Alt. D2b	Case 1
Input:									
Straw	t/year	150,000	945,000		150,000	150,000	683,000	645,000	
Grain	t/year	403,000	0		374,000	368,000	0	0	479,000
MSW	t/year			200,000					
Fermentation		C6, yeast	C6, yeast	C6, yeast	C6, 5, TMO	C6, 5 yeast	C6, 5, TMO	C6, 5 yeast	C6 yeast
Raw water	t/year	96,500	66,900	3,000	81,500	80,886	8,688	11,400	102,000
Steam	GWh	567	957	183	558	540	782	692	486
Cooling	GWh	390	948	186	405	388	799	703	293
Electricity	GWh	70	158	30	73	67	143	112	51
Output:									
Ethanol (from straw)	t/year	140,000 (22,200)	140,000 (140,000)	22,400	140,000 (30,800)	140,000 (32,600)	140,000 (140,000)	140,000 (140,000)	140,000
Biofuel	t/year	52,400	330,000	26,800	55,200	52,900	251,300	227,500	0
DDGS	t/year	149,700	0		138,800	136,500	0	0	178,000
C5 molasses	t/year	67,000	422,000		38,600	38,100	175,600	163,900	0
Total investment	kEUR	156,400	335,700	87,000	154,400	154,600	264,600	259,500	101,800
Investment per litre/y ethanol	Euro/litre	1.12	2.40	3.88	1.10	1.10	1.89	1.85	0.73

Table 1 Input/output for the feasibility study

Figure 3 shows that the highest cost of ethanol (from C2, straw only) is 53 % higher than the lowest (from case 1; grain only). The (red) dot-and-dash line indicates the market price of ethanol in the EU (May 06).



Input prices:

Straw: 60 Euro/t
 Grain: 120 Euro/t
 Cellulases: 0,16 Euro/l ethanol

Output prices:

Solid biofuel: 4.46 Euro/GJ
 DDGS: 98 Euro/t

Figure 3 Ethanol production costs (WP 4)

Fig. 4 shows that mainly the high cost of enzymes and the high capital cost are responsible for the difference.

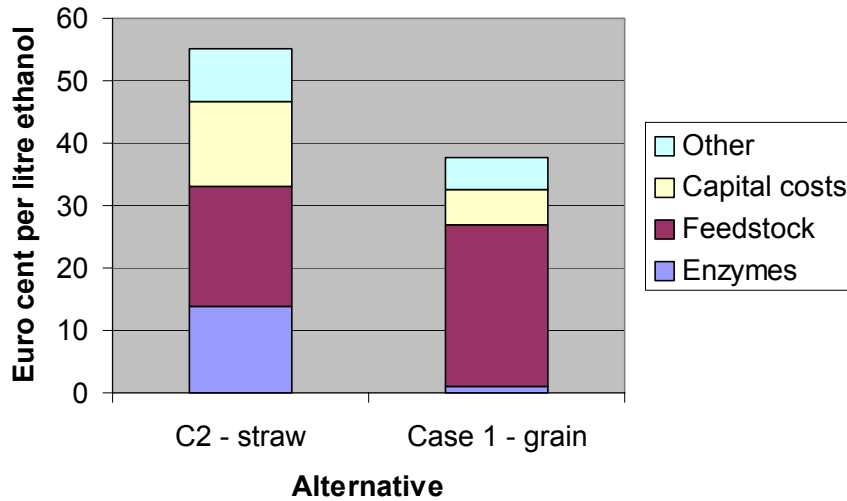


Figure 4 Split of major costs for ethanol production from straw and grain

The cost of enzymes used in Fig. 3 is 0.16 EUR/l ethanol but according to Novozymes and Genencor this cost is expected to decrease to about 0.03 EUR/l ethanol. The cost of straw used in Fig. 3 is 60 EUR/t reflecting Danish prices. Straw prices around 30 EUR/t are more realistic in most of Europe.

Fig. 5 shows the impact of the lower prices of straw and enzymes.

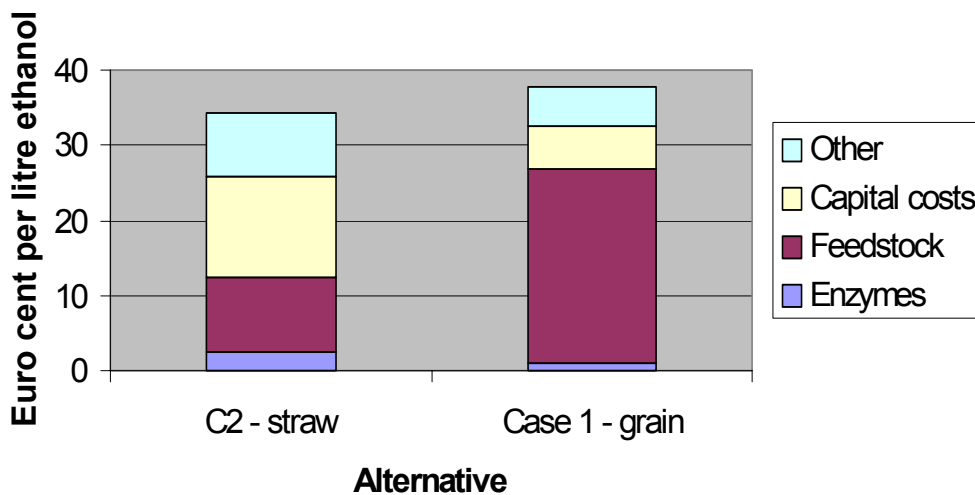


Figure 5 Split of costs for ethanol production (plant size 140.000 t/y ethanol)

The capital cost for case 1 (grain only) is only 30 % of the capital cost for C2 (straw only) reflecting that the specific investment cost for C2 is 2.40 EUR/l ethanol against 0.73 EUR/l for case 1.

Based on the trials on the 1 t/h pilot plant for pre-treatment of straw the project has identified several process steps where substantial reductions in investment costs could be achieved in the coming industrial scale IBUS plants.

Integration of the production of bioethanol with an existing power plant has provided cost reductions (total cost minus feedstock cost) amounting to 18 %, mainly deriving from lower investment cost and from lower energy cost by using the low value steam from the electricity generation.

2.6 WP 5 Feasibility studies: Whole crops

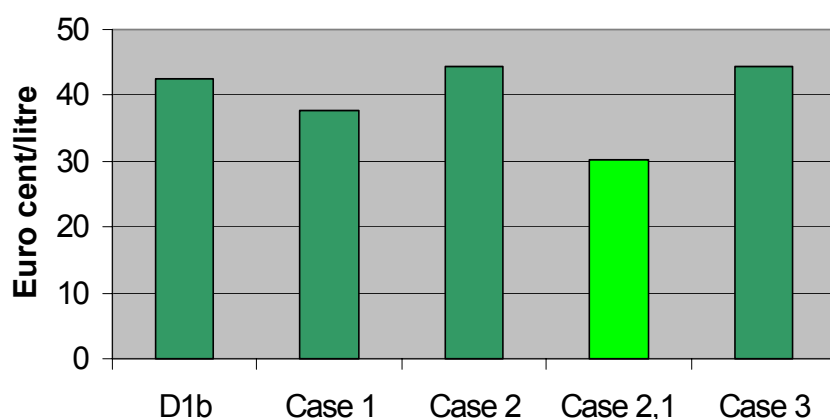
In Work Package 5 the feasibility of ethanol production based on whole crop wheat has been compared to grain-only based ethanol production. Furthermore, the possibility of utilising the DDGS fodder product from the grain process for further ethanol production is analysed.

This part of the feasibility study deals with three different IBUS configurations. Furthermore the most feasible of the configurations in WP4, the Alternative D1b (see above), is used for comparison. The four cases described are:

- 1: WP4 – Alternative D1b: 150,000 t straw + 368,000 t grain, C5+C6 fermentation by yeast, 140,000 t ethanol/year
- 2: WP5 – Case 1: 479,000 tonnes of grain, standard dry milling ethanol process, 140,000 t ethanol/year
- 3: WP5 – Case 2: 530,000 tonnes of whole crop wheat, C5+C6 fermentation by yeast, 140,000 t ethanol/year
- 4: WP5 – Case 3: As WP5 – Case 2 but with DDGS added to straw line, 160,000 t ethanol/year

The ethanol production costs resulting from the three cases in WP5 are shown in Figure 6.

Figure 6 shows that a straw price of 60 EUR/t and enzyme costs of 0.16 EUR/l ethanol gives about 15 % higher ethanol cost for D1b, case 2 and 3 compared to case 1 (grain only).



3

Figure 6 Total ethanol production costs for different IBUS processes (WP5)

If the straw price is reduced to 30 EUR/t and enzyme costs to 0.03 EUR/l the cost of ethanol in case 2 (whole crop) will be reduced with 32 % (from 0.44 EUR/l to 0.30 EUR/l) as shown in case 2,1. Thereby the whole crop system produces ethanol at 20 % lower cost than grain-to-ethanol system.

The lower harvesting and transport costs for whole wheat crop compared with separate handling of grain and straw have not been applied in these calculations because the savings were neutralized by the higher cost of the in-house storage of the whole crop bales found necessary to minimize losses from germination of grain.

It is expected that an in-field anaerobic storage system for whole crop in big bags can be developed to improve the savings by exploiting the whole crop system.

The ethanol from case 2 and 2.1 can be produced without using fossil fuel for processing by using the solid biofuel in the power plant.

Case 3 surprisingly shows that utilising the DDGS feed from the grain line is economically interesting when DDGS market prices are decreasing slightly. Figure 7 shows the ethanol production costs at decreasing DDGS market prices:

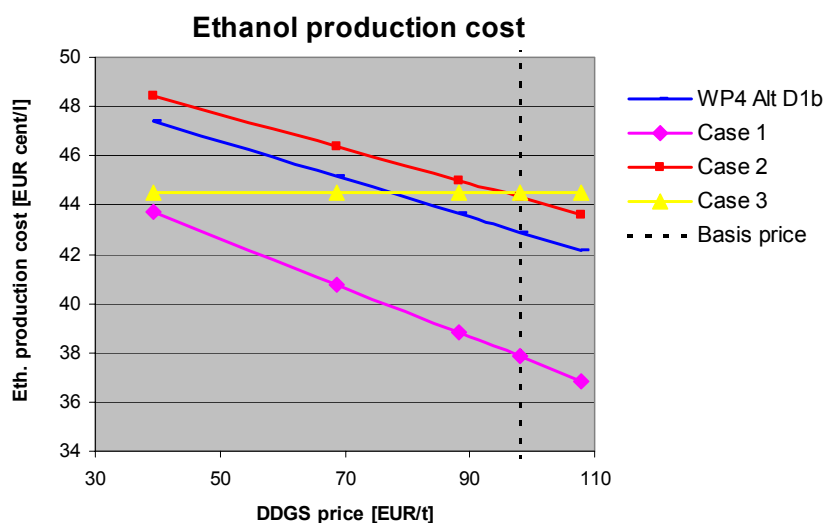


Figure 7 Ethanol production costs - sensitivity to DDGS prices

2.7 WP 6 Website and interactive model

A public website with information about the project, the process and the partners has been established at <http://www.bioethanol.info/> (alternatively <http://www.ibusystem.info/>). The website has resulted in 24 contacts from universities and industrial parties from around the globe (e.g. Europe, Canada, Indonesia).

The work carried out in Work Package 6 also comprises the development of a programme that is able to estimate the financial aspects and used quantities of biomass, steam and energy as well as output of ethanol and fibre fraction. The programme is intended for power plant engineers who want insight in the IBUS process and an estimate of financial and technical aspects of building an IBUS plant at their respective power plants.

The programme is developed in MicromediaFlash 8.0 and is accessible to the public on the website, <http://www.bioethanol.info/>. To find the programme on the website and start the model, click on this title on the main page:

**How the process works:
See Interactive model**

The user of the programme can type in different input: straw flow, production year, straw cost, steam cost, green power sales price and labour cost. Standard values always appear in the field where the value can be typed - the column in the middle. These values are based on Danish experiences. Figure 8 shows the user interface of the Flash programme.

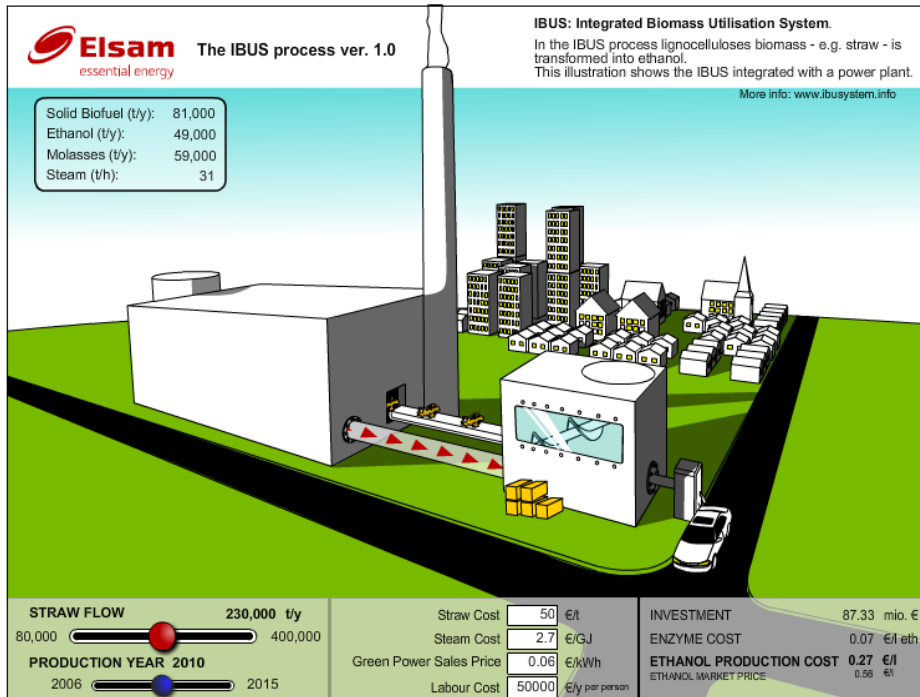


Figure 8 User interface of the Flash programme

When the pointer is placed on the input or output fields, a short explanation appears. The same happens when the pointer is placed on the graphics, e.g. the power plant. Clicking on the process plant will expand the view of the process, as illustrated in Figure 9.

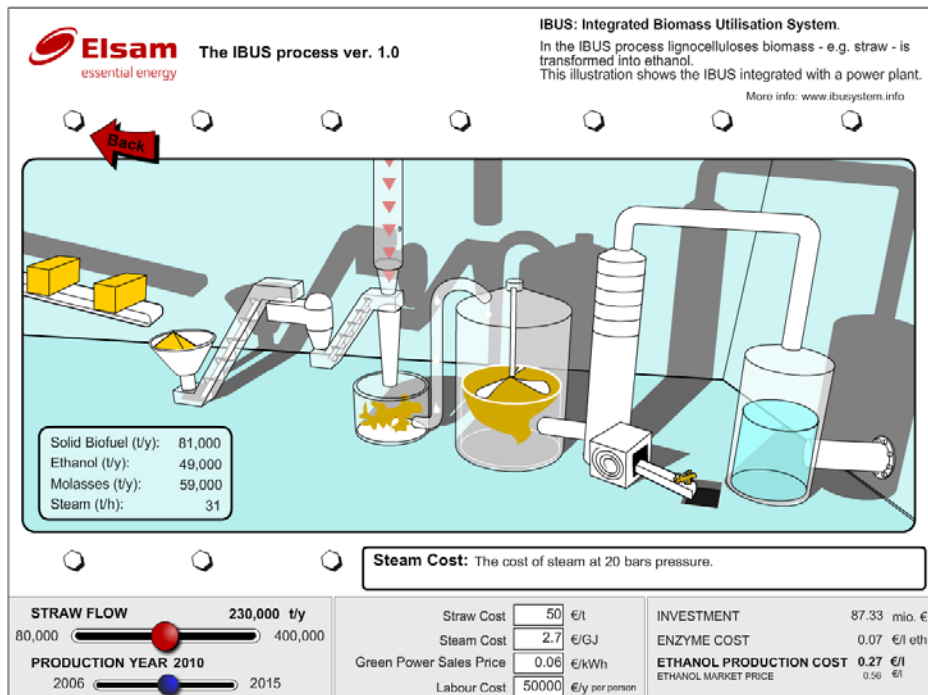


Figure 9 Expanded view of the process

The equations behind the calculations are derived from the feasibility study.