CPD NR 3295
Basis of Design

Process Systems Engineering
DelftChemTech - Faculty of Applied Sciences
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Subject

Basis of Design for a process to refine green plants.

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Summary

This basis of design report details about the process options and design decisions made on the CPD3295 project. The original assignment was the design of mobile units that convert grass into pig feed and liquid fuels. Due to size considerations on equipment, harvesting and flow considerations the concept of mobile units has been put on hold, and an alternative was chosen.

A design will be worked out on the following: Small biomass conversion units located in small farming communities in Zambia. These units are stationary, and will produce pig feed, fuel grade ethanol and electricity. The objective will be to produce enough of these three products per unit to fulfil the needs of decently sized (sets of) communities. Each individual unit will produce in the order of magnitude of feed for 2100 pigs, 140 tonnes of ethanol per year and electricity for several western standard households (which should be ample for the small communities).

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Appendices

1 Project description

1.1 Background of the design

In Zambia there are about 350 000 pigs and 25 million chicken. This is relatively little compared to the 3.5 million cows and the 600 000 goats in the country. This is mainly caused by the high price of feed components as they now are imported from e.g. Argentina (310 dollars/ton for Soy cake at a protein concentration of 47%). In the Netherlands in the last 5 years a pilot factory has been build to fractionate leaf material into a protein fraction, an energy fraction and a fiber fraction. This pilot factory operated with a capacity of about 4 tons of fresh weight grass per hour for a continuous period. The protein and the energy fraction has been fed to groups of pigs and the feed conversion was as good as traditional proteins on the market.

The pigs had no preference for either the traditional or the grass proteins when they were given the choice. The fibre fraction can be used to generate electricity by burning the fibers. In Zambia the growth of leaves like grass can be abundant. Forty tons of dry weight are reported when Star grass and legumes are grown together. This and the fact that labor is a lot cheaper in Zambia than in the Netherlands, enables a small and a technologically spoken simpler unit to be economical feasible in Zambia while in the Netherlands only large scale units will be cost effective. The idea in this CPD project is to design and to investigate both the technical and the economical feasibility of a mobile green plant refinery that can process the grass into the protein, the energy and the fiber fraction.

Sustainability:
The above production of feed components can be done in a very sustainable way if the manure from the pigs is taken back to the soil where the gras/legume is grown. Thereby most of the phosphate and potassium comes back. The nitrogen is being added to the system by the nitrogen fixation capacity of the legume while most of the energy is being added by the abundant solar in this country.

In a later stage the more complex process can supply the fibres that can be burned centrally to electricity or can be converted to ethanol by a fermentation process. In the past 3 years it was shown that also ethanol can be produced using the sugars that are present in the juice. A trade off decision can be made to use the juice for growing pigs and/or for ethanol production.[1]

1.2 Problem definition

Prepare a conceptual process design (CPD) for a process to refine green plants.

Demands and design conditions maintained by the project principles

- Installation should recover at least 50% of the proteins present in the feed (simple option 1, e.g. using filter press) and preferably more than 90% (option 2, using refiner patented by Avebe).
- The remaining liquid fraction or fiber fraction after refining should be processed to generate the fuel for the refining process and the transport/harvesting vehicles. This fuel production process may be carried out elsewhere, e.g. ethanol via fermentation of remaining liquid.
- The liquid fuel production unit is part of the CPD.
- Evaluate the process for 3 locations: the Netherlands, China and Zambia.
- Local greens should be used as the main raw material.

- Minimize the use of added fertilizer. The protein will be used to feed pigs.
- Pig manure can be recycled to the fields as long as sustainability criteria apply (e.g. no build-up of heavy metals).
- Determine the number of pigs that can be fed using 1 mechanical refining installation.
- Determine the number of hectares needed to grow the green plants for 1 refiner.
- Excess fuel, if any, can only be sold as a liquid fuel having generally accepted specifications.
- Assume the installation will be owned by a cooperation of pig growing farmers that try to become self sufficient in energy for transport and electricity.
- Investigate different usages for fibers: Electricity, building material etc.
- Investigate different usages for protein: pig, human, other kinds of animals, use as silage
- A pilot plant for the patent exists with a feed capacity of 4 tons per hour of grass; we should look into the use of different plants and mixtures.
- Investigate what to do with leftover juice, it contains a lot of biochemicals and minerals
- The process should be sustainable. CO2 sustainability is the easiest part, but the process should also be sustainable in K, Na, P, S etc. These products should all be recycled to soil.
- Since we produce proteins which contain a lot of nitrogen; we have to find a way to get it back in the system, for example with Alfalfa (legumes in general). A solution is to define systems and calculate the amount of N crossing the borders of the systems.
- Plants should be processed within 12 hours because of loss of turgor.
- A future view to 2020 needs to be implemented into the report.

Reporting issues

- Find arguments in favor and against the use of "economy of scale" for the process.
- Make a risk assessment early in with chance AND impact, and only focus on the largest onces.
- Keep in mind that the situation in The Netherlands is really different from Zambia/Chinese cities/ Chinese country side.
- Make a (dis-)advantages list for the 3 countries.
- The process must be able to process leftovers from all kinds of plants.
- A consumer approach might be smart, check how many pigs a community can actually sell/eat during a year, and keep that in mind while designing the unit.

Tips and reminders from principles

- Aids is a serious problem, there is a huge loss of know-how.
- After grinding the grass, the juice has about the same composition as the juice from potatoes with the starch taken out.
- In Zambia it might be possible to use wild plants, instead of cultivated plants.
- As long as grass is fresh enough during the dry season it can be used for the process, but expect lower protein content.
- Wild plants instead of cultivated grasses/crops could be used, but keep in mind that some plants are toxic.
- Zambia is 20 times bigger than the Netherlands, 10 million inhabitants; the capital city is Usaka with 1 million inhabitants
- Communities hold 50 – 100 persons; they are a group of farmers.
- Wageningen collaborates with all kinds of groups in whole Africa.
- The biomass production of grass in Zambia is 30 (sure) to 40 (high) tons of dry weight per hectare per year. Growth mainly during rain season.

- There is a lot of water in Zambia, but no irrigation. Make a study of it, but keep in mind that irrigation is not easily made sustainable.
- Composition of protein cake: 45% protein, 15% fat.
- Do not use high tech and delicate equipment in Zambia, factors i.e. sand can destroy expensive equipment (rotating disk) easily
- The fibers in the Zambia process will most likely contain a lot of protein, this can be used as silage that has no value in The Netherlands, but does have in Zambia.
- At the moment the 1st generation of bioprocesses uses microorganisms that produce ethanol, and vegetable oils (the esters) for diesel. The 2nd generation will be able to convert cellulose (and other fibers) into a sugar soup which can be used to make fuel.
- For technology about patent (which is boiling water and than proteins will coagulate) use data from the paper industry.
- Realize that the investment in plants is less than the investment in photovoltaic cells, especially in 3rd world countries

Limitations by legislation

1. Safety and health (ARBO legislation)
2. Environmental legislation
3. Legislation for road transportation
4. Legislation for transportation of dangerous substances
5. Design of pressure equipment according to "Stoomwezen"
6. Zambian laws

2 Process definition

2.1 Process options

Figure 2.1 gives a simple representation of the separation steps as they were mentioned in the project description. As there were many solutions found for these functions, a decision was made to separate the feasible options from the other alternatives. Both the feasible and the alternative options are displayed in tables in appendix Ia and Ib. The advantages and disadvantages of each option will be shortly described in these tables as well. The paragraphs 2.1.1 up to paragraph 2.1.4 describe the working principles of the feasible process options. The working principles of the alternative solutions are displayed in appendix Ic.

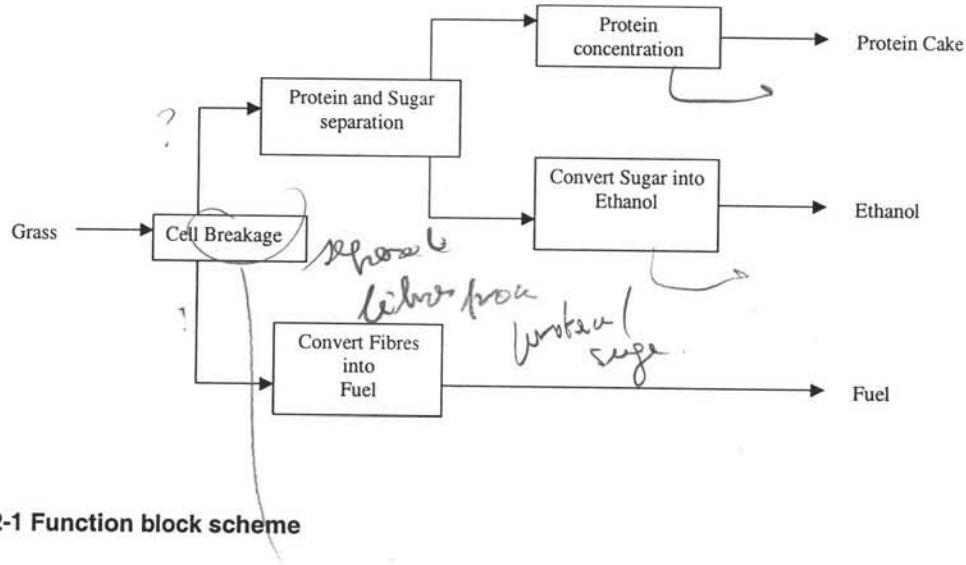

Figure 2-1 Function block scheme

2.1.1 Options for cell disruption

Bead mill [1-3]
The bead mill incorporates a cylindrical container with a central shaft on which discs of various shapes and sizes are mounted. The cell suspension and beads are added to the container, with the beads usually accounting for 50% to 60% of the total mixture volume. Optional parameters: bead size, bead volume, agitator speed and milling time. The bead mill is suitable for all countries as it is low tech, and doesn't require much service.

One of the advantages is the ease with which the equipment can be scaled from the laboratory to industrial scale. The bead mill is a high performance closed grinding and dispersing system, which can be automated perfectly.
Used for tough to disrupt cells like yeast, spores, and micro algae, and for large-scale disruption of fungi.
A disadvantage is the considerable heat generated, through friction. It also has longer residence times than high-pressure homogenizers do. Cells are not extensively disintegrated.

Homogenizer [1,2,4]
The slurry is pumped through a restricted orifice valve, after which the high pressure is followed by instant expansion through a special exiting nozzle. The sudden pressure drop

upon discharge causes an explosion of the cell in a first order process. The homogenizer is suitable for all countries as it is low tech, and doesn't require much service.

An advantage of high-pressure homogenizers is their suitability for large-scale operation. In addition, homogenization has proven to be effective on large-scale processes. Moderate cost/harsh press on cell is another advantage.
Disadvantages are that the cells will not be extensively disintegrated, and risks of clogging.

Chemical addition
By adding chemicals the cell walls can be destroyed. This can be done by high concentrations of salts to use osmotic pressure, or by adding an acid in which the walls dissolve. The process can be applied in all countries, due to is simplicity.

The advantage is that this is a relatively simple process and is easy to control.
The addition of chemicals is a disadvantage, especially when the products will be used in food preparation. The denaturation[1] of the proteins is another disadvantage.

2.1.2 Options for sugar protein separation

Salt [5]
The proteins will denaturate and precipitate due to the addition of the salts. A solid liquid separation step will separate the sugars from the proteins. (i.e. centrifuge or sedicanter). This process can be used in all countries because it is a low tech and relatively simple process.

Advantages of this process are low costs and relative simplicity in lab scale. A disadvantage is reproducing the precipitation of proteins by addition of salt on a large scale. The concentration of saturated salt solutions varies with temperature, which requires strict control to avoid lot-to-lot variation. Problems with the mixing of large volumes also make precipitation more difficult than for small volumes, due to local variations in salt concentration. Such variations may lead to precipitation of more (and different) proteins at different locations within the tank. Small density differences make separation by centrifugation difficult.

Temperature
Exposing the proteins to heat will lead to denaturation of the proteins. The proteins will take a solid phase after which a solid liquid separation step will separate them from the sugar (i.e. centrifuge or sedicanter). Due to the simple techniques used in this process it is possible to use it in every country.

The process is relatively simple and cheap. The process is also easy to scale up. In contradiction to the addition to salts no density problems will occur.
The denaturation[1] of the proteins is a disadvantage of this process.

Ultra filtration [5-7]
Ultra filtration (UF) is a separation technique using membranes. UF membranes can have a rejection rate of 90%.

The membrane separation process is easy to scale up. Another advantage is the fact that no phase change will occur.
The major disadvantage of membrane separation techniques is the fact that these techniques are usually very expensive. Fouling of the membranes is another disadvantage.

[1] In fact this is not a problem as long as the protein does not become poisonous.

Centrifuges [5]
Separation by centrifugation is based on the difference in densities. Several options are available, such as sedimentation or filtration centrifuges. The centrifuge is sensitive to dust. Application in Zambia could result in mechanical problems / failures, but when good care is taken with respect to dust it is a good option.

Centrifugation processes have relatively low operational costs, and have short residence times. Centrifuges are usually relatively compact apparatus, so easy for transport.
A major disadvantage is the sensitivity of the disks spinning at high velocity to dust and dirt. Problems could occur by the small density difference between sugars and proteins. Another disadvantage of the centrifuge is the heat produced by friction, resulting in possible protein denaturation.

2.1.3 Options for sugar ethanol conversion

Microorganisms
For the conversion of sugars into a useful fuel, the use of microorganisms is by far the most logical choice. The microorganisms use the sugar as a feedstock for growing and making alcohol. Depending on the substrate and other needed components the microorganism either only (by approximation) grows or only produces some alcoholic compounds. The use of microorganisms is not a problem for the Dutch situation because of the high tech possibilities of process control and asceptic work. In China and Zambia this can cause some problems, but because the process itself is very easy and well known, it is possible to use this option in those countries as well.

The advantage of using microorganisms is that they use almost all components in the sugar feed, resulting in a very clean fuel leaving the process. Because there are a lot of different microorganisms that can make for example ethanol or methanol, it is not that difficult to find a good one for this process.
The disadvantages are that the process must be in good control, not only temperature, but also the amount of alcohol in the process, because of its toxicity to the microorganisms. Another disadvantages is that the produced ethanol must be separated from the water which is an azeotropic distillation (multiple steps are necessary) .

2.1.4 Options for fiber usage

Dumping and conversion to fertilizer
The easiest option is to dump the fibres on the land so the natural microorganisms on the land can convert it into some sort of fertilizer. Because this option is very easy, it is an option for Zambia (or China), but only as a last resort. In the Netherlands this is no option because it already has too much fertilizer.

The advantages of this option are cheap and easy, just dump the fibers and the rest of the conversion is done automatically.
Of course by using this option a lot of useful energy is thrown away and the plants do not really need this fertilizer because there is a lot of fertilizer coming from the pigs already.

Sell to paper industry [8-10]
A more useful option is to sell the fibers to the paper industry. In Zambia and China this option should be considered. Maybe for the first few years until other options are more developed.

The main advantage is useful use of the fibers which function as replacement for tree fibers so fewer trees are needed. Also by selling the fibers, some profit is made.
The problem is that it is not known if fibers of plants are as good as fibers from trees. In addition, Zambia is not (yet) a paper consuming country and there is already enough paper in the rest of Africa (they have a higher capacity than they need on this moment).

Direct combustion [11]
Preferably dry biomass (high energy density) is burnt to generate heat, which is converted to electricity using a Rankine cycle. Direct combustion can also be used for heating, both in domestic and industrial (heating processes, producing steam) situations. This process fits in al countries, but in the Netherlands better options are available.

The advantage is that this process is well known and used globally and on large scale. Another advantage is the high efficiency of this process.
There are also some disadvantages. First is that the process produces heat and electricity instead of liquid fuel. The process is only efficient if high energy density cheap biomass is used. This is not a big problem because the fibres are waste from another process step.

Gasification [11-13]
Heating under oxygen deficient conditions. Reactions produce char, tar and gas. Gas yields increase with temperature, while the tar yield decreases. Temperatures from 800K-1000K are commonly used. Opportunities ($C + H_2O$, Boudouard: $C + CO_2 \rightarrow 2CO$) exist to increase useful gas yield (simultaneously reducing the amount of char), which work by shifting the thermodynamic equilibrium (favoured by high T, low P). Because in the neighbourhood of Zambia a very big Fischer – Tropsch plant (Sasol in South Africa) is located, the knowledge for the gasification is nearby. In China this is not the case, so it is more difficult to implement this process over there. In the Netherlands this process shouldn't give any problems.

The advantage is the production of Syngas, which can be used in many different ways. Disadvantages are the high temperatures and the need for further processing (complex process).

MO bio fuel [14,15]
It is possible for certain MO's to convert the fibres into ethanol or methane. Because it is a very easy process, which doesn't need too many high tech controllers, it could possibly be used in Zambia.

The MO's are not very expensive and give a high conversion rate on glucose (but not on fibres). Because it is an exothermal process, heat is produced which can be used in other process steps.
The disadvantages are the 5-carbon sugars that are not as easily fermentable as 6-carbon sugars, and that the enzyme is sensitive to the change of temperature and PH. Also, the microorganisms mainly convert sugars (which are usually obtained from (hemi-)cellulose by acid hydrolysis, and convert fibre only in extreme cases (and even then very slowly). Because of this, it is limited to laboratory scale on this moment.

Silage [16-19]
Silage is a way of storing grass without losing too many important compounds. Because the fibres do not contain any useful components for feedstock any more, this silage is not very useful. It can only be useful if the fibers should be stored before they enter a process (rain season debottlenecking). To store the fibers temporally before conversion into something else, in Zambia and China this is a very good option. In the Netherlands there are better and easier ways to store the fibers (and it is possibly not necessary either).

The advantages of this option are very cheap and easy process. But because it has no value, it is still a waste product and a waste of potential energy.

2.2 Process selection and block schemes

From all the options mentioned in the past paragraph, choices were made to compose the complete block schemes which roughly display the process.

The assignment was to design a concept for usage in the Netherlands, a concept for usage in Zambia and concept for usage in China. After several discussions the project team determined that the concept for China was very difficult because the country is very big and has so many regions. The team decided to use the concept for the Netherlands in the more developed areas of China and to use the design for Zambia in the remote (less developed) parts of China.

The block scheme for the process in Zambia is displayed in appendix 3-1, the process block scheme for the process in the Netherlands is displayed in appendix 3-2.

The choice for each option is explained below.

2.2.1 Cell disruption

Three feasible options were available here, viz. the bead mill, the homogenizer and chemical addition. Heat integration (boiling) was also an option but the team decided to move boiling to the alternative options, because of the fact that a difficult solid/solid separation had to be included after the boiling process. This seemed to be unreasonable to do on a mobile unit.

After investigation the bead mill seemed to be the best option for the Dutch process as well as for the Zambian process. Chemical addition is not desirable when processing food, so that one was the first to be omitted. The homogenizer seemed to be a good alternative, but using this machine means that some sort of grinder has to be included in the process.

After all, the simplicity of the machine, the production rate and the product quality of two bead mills in series were decisive. The disadvantages of the bead mill are small compared to the disadvantages of the homogenizer and the addition of chemicals.

2.2.2 Protein and sugar separation

Four options were mentioned here, viz. addition of salt, precipitation by temperature, ultra filtration by membranes and the of centrifuges. The methods of salt addition and temperature are based on the same principal: precipitation. After precipitation a solid/liquid separation step is executed. Precipitation by increasing temperature does not have the disadvantage of the addition of extra materials so this option is preferred. Using centrifuges is another option but the small difference in density could be a problem. Ultra filtration is a very delicate and good method for protein and sugar separation, but the membranes used are expensive. The team decided to use the separation method of precipitation by heating in both the process for the Netherlands and the process for Zambia. The membrane option is a very good alternative for the process in the Netherlands. It isn't an option for Zambia as it can be considered as a high tech option.

2.2.3 Ethanol production

The options for sugar to ethanol conversion are actually very simple as there are very limited options for that process. The fermentation process is widely used and simple to execute, so it will also be used in this process.

2.2.4 Fibre usage

Several methods have been considered to be an option for the usage of the produced fibres. Very simple options are dumping or usage in paper industry. The fibres, on the other hand, have the potential to deliver energy. Three possible options to convert the fibres into useful products are direct combustion in a furnace, gasification to produce syngas and a conversion of fibres into sugars using microorganisms. This last option is very sensitive for contamination, resulting in useless products.

The team decided to use the option for direct combustion for the process in Zambia making the communities self-supporting by producing electricity on small scale. As small-scale electricity production makes no sense in the Netherlands, the team decided to use gasification to convert the fibre cakes into syngas, which is in fact a valuable product in the Netherlands. Although syngas production is also feasible in Zambia, the team thinks that the communities would take more advantages out of the electricity production.

Several options are possible for further processing the syngas viz. production of methanol or ammonia. Another option would be the production of fuels using the Fischer Tropsch process. The team decided that the further processing of the syngas is beyond the scope of this project.

2.3 Thermodynamic properties and reaction kinetics

2.3.1 Thermodynamics Models [1-5]

Phase equilibrium data are needed for the design of all separation processes. Experimental data have been published for several thousands binary and many multi-component systems. However no universal equation is available for nonideal mixtures to compute values of the thermodynamic properties such as density, enthalpy, entropy, fugacity and activity coefficient as functions of temperature, pressure and phase composition. Instead, there are two types of models to calculate phase equilibrium: (1) P-V-T equation-of-state models (2) activity coefficient or free-energy models. These are based on constitutive equations because they depend on the constitution or nature of the components in the mixture.

PVT model equation-of-state

The equation-of-state method is used to describe both liquid and vapor phase behavior. A large number of such equations have been proposed, mostly for vapor phase. It is recommended to apply it for weak non-ideal solution, such as most hydrocarbon and light gas mixture systems at high, moderate or low pressure (at least not below atmospheric pressure). This method is applicable for systems where the interaction of the components in the liquid phase is assumed to be minimal.

In the process of the Netherlands, biomass (fibre) will be converted to synthesis gas, which consists primarily of carbon monoxide (CO), carbon dioxide (CO_2), and hydrogen (H_2), via the gasification process. The PVT equation of state model is applicable to the gas mixture. Appropriate choices of the models depend on the components in the system, temperature, pressure, and the availability of parameters. It can be assumed that gasification process is operated at low or moderate pressure (below than 5 bar). According to the limitation of the

models appliances, the following models are most applicable.
If the operating pressure is 1-2 bar, ideal gas model will be adopted.

$$PV = nRT$$

If the operating pressure is 2-5 bar, the Virial equations model will be adopted.
Virial equation is:

$$Z = 1 + \frac{B}{V} + \frac{C}{V^2} + \frac{D}{V^3} + \ldots$$

For non-ideal species, at low pressures

$$\frac{PV}{RT} = 1 + \frac{BP}{RT}$$

B is needed as a function of T and species.

Activity coefficient model
Activity coefficient models are based on Gibbs free-energy models and used to predict liquid properties such as activity coefficient and other excess functions.

In our design, ethanol is produced in fermentation. After fermentation, the residual ash, substrate, biomass, sugar, and water go into the separation stage together with ethanol. It is a liquid-solid mixture, but the solids are removed before the distillation step. Sugar takes an effect in separation of ethanol and water. However, the amount of sugar in outlet flow would be very small, to the extent that it can be neglected. Therefore it is assumed that only ethanol and water present in the distillation column. Because polar molecules are present (ethanol), the equation of state should not be used, instead, activity models are more applicable for the liquid phase.

The following table shows and compares five models.

	Margules	VanLaar	Wilson	NRTL	UNIQUAC
Binary	OK	OK	OK	OK	OK
Azeotropic	OK	OK	OK	OK	OK
Polar	NO	NO	OK	OK	OK

Table 2-1 Activity Model Applicability

Ethanol/ water is non-ideal, polar and azeotropic mixture. According to the table, it is obvious that Wilson/ NRTL/ UNIQUAC models are the proper ones for the separation process of ethanol and water. Wilson and UNIQUAC both have 2 parameters and NRTL has 3.

2.3.2 Thermodynamic data

Reaction enthalpy data
The reaction enthalpy can be calculated from the heat of formation of each component at reaction temperature. All the data needed is in the table of pure component properties as appendix 2-1. From that, whether the reaction is exothermic or endothermic can be determined.

Specific heat data
Typical constant pressure specific heat (at 1atm, 25°C or different temperature) for each component can be obtained from ASPEN PLUS simulation engine or from literature.

Comparison of the data:

T/x and x/y at constant pressure diagrams are produced for the key components. The graphs are for the *Wilson model*, obtained from ASPEN PLUS simulation engine. From these graphs, separation of ethanol from water can be done by distillation.

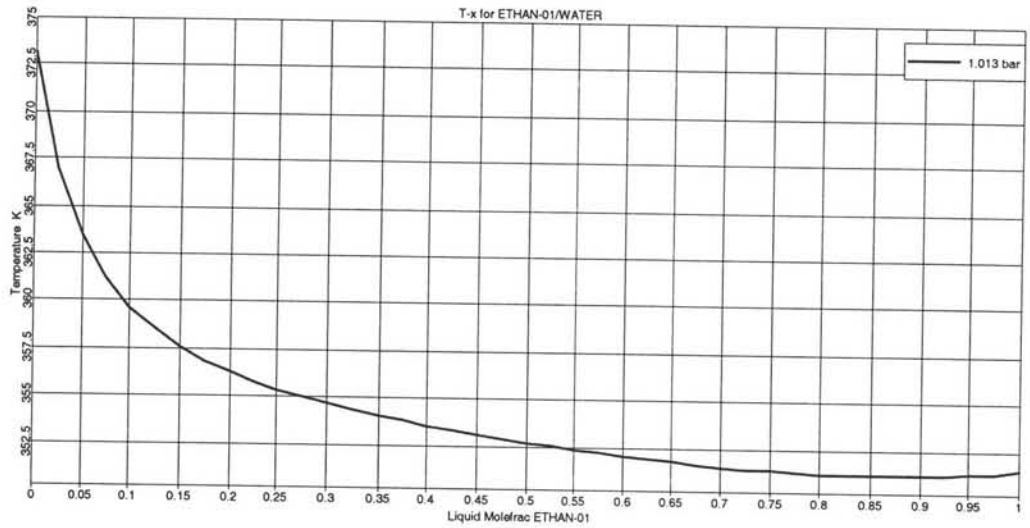

Figure 2-2 T/x diagram of an ethanol/water mixture at p=1.013 bar

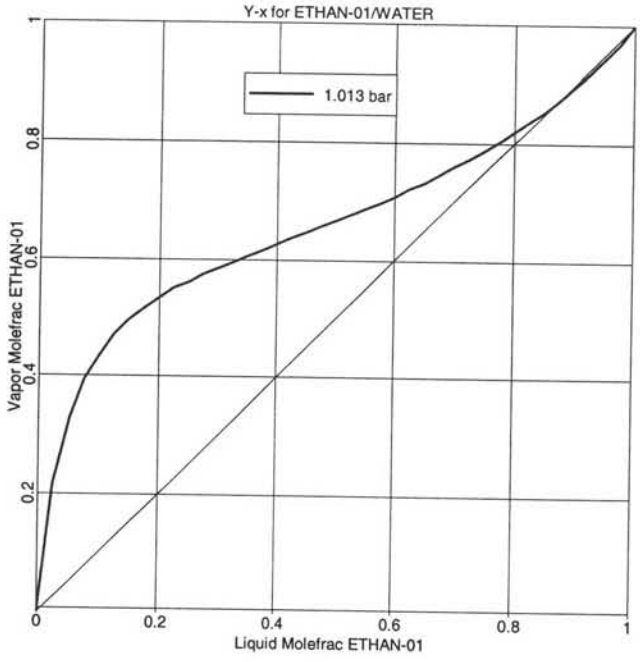

Figure 2-3 x/y diagram of Ethanol/ water mixture at p = 1.013bar

2.3.3 Validation of Method [4]

Comparison of the data from the literature and the Wilson model using ASPEN.

Experimental data			Data from ASPEN Plot		Difference	
T(c)	X1	Y1	T(c)	Y1	Diff T	Diff Y1
94.90	0.0180	0.1900	95.19	0.1742	0.29	-0.0158
94.40	0.0190	0.2050	94.98	0.1813	0.58	-0.0237
89.30	0.0530	0.3640	90.02	0.3383	0.72	-0.0257
87.10	0.0820	0.4300	87.59	0.4089	0.49	-0.0211
84.20	0.1520	0.5000	84.39	0.4990	0.19	-0.001
82.50	0.2250	0.5450	82.65	0.5495	0.15	0.0045
78.20	0.8000	0.8380	78.05	0.8183	-0.15	-0.0197
78.00	0.9160	0.9140	78.01	0.9105	0.01	-0.0035

Mean diff T=0.285, Min diff T=0.01, Max diff T=0.72
Mean diff Y1=0.485, Min diff Y1=-0.0035, Max diff Y1=0.0197
Difference of data from literature and Wilson model is acceptable thus Wilson model for Ethanol/ Water separation is valid.

2.3.4 Reaction kinetics

The reactions of ethanol fermentation and gasification are complex. Moreover, the reaction conditions, such as the temperature and pressure, haven't fixed until now. Thermodynamic data on bio reactions is limited and the gasification process is an option. So no time is used to find information on those subjects.

2.3.5 Pure components properties [6-11]

For pure components properties, data are obtained both from websites and handbooks as shown in the references.
For the toxicity data of chemical components, since all the components present in our process do not have high toxicities, data such as LD50 or LC are not available. There are no experiments done for it currently or if LD50 or LC is available, the data is for the animals, such as rats, but not for human beings.
Data of bio-component properties and composition, such as grass, protein, fiber and other components in the cell are not easily found. During calculation, we make a rough assumption for ash, protein, other stuffs content for the grass composition. But the accurate data are needed. To know the plant composition such as protein content is of great help to determine which kinds of protein they have and to determine at which temperature and what pH value they will aggregate in the protein/ sugar separation.

We do hope the student from Wageningen can join us and help us solve those kinds of problems.

2.4 Process stream summary and mass balances

In appendix 3-1 the Zambian process block scheme is shown. Why this scheme and not the Fischer Tropsch process has been chosen is described in the process description and the basic assumptions. The simplified block scheme of this process alternative is inserted in appendix 3-2.

In this chapter the amounts of the different components in the different streams are described and only the most important values are given. All the other values can be found in appendix 4-1 up to appendix 4-5 in the process stream summary. The numbers in this appendix refer to the numbers in appendix 3-1. The stream numbers in 3-2 are not used for reference, but only to make it more readable.
Since no or unreliable thermodynamic data is found for the grass and it components, no data is given on molar composition and total enthalpy of the streams in the stream summary. No increase in pressure is needed in the system, although sometimes pressure differences will be needed to get a flow of mass. Since no serious pressure differences are present, all pressures of the streams are 1 bar for now.

2.4.1 Determination of the amount of grass needed

For the current number of pigs, 35,625 tonnes of proteins are needed (see basic assumption). With an estimated protein recovery of 95% in the protein cake production steps, 37,500 tonnes of proteins are needed to go into the protein cake production.
To obtain a proper protein recovery the fibres must be cleaned thoroughly (if only C/H/O remain it becomes a good fuel-feedstock). An overall protein recovery of 100% in the cell breaking and fibre cleaning steps is required. Since the protein content of grass is 1.25%(rough estimate, see basic assumptions), the total amount of grass that must get into the process is 3,000,000 tonnes of grass (includes water) per year.

Cell breaking
The grass will enter the system at the temperature of the air in Zambia. There is a tropical mountain climate [20], which results in an average temperature of 25 °C.
During the cutting of the grass, no composition changes will take place. But after that it is needed to add water to get a slurry that can be processed by the bead mill. The first estimate of the water that needs to be added is 10%; this gives a total water stream of 300,000 tonnes per hour. At this point it is assumed that fresh water is used, to be on the safe side for the design. Most likely it will be possible to recycle water from either the protein separation or the ethanol purification, but the design of that will be done later.
The total amount of cells broken by the bead mill is a design parameter, but for this stream summary it is set at 80%. During the separation of grass cell and fibres from the rest, there must be water left in the cell and fibre stream to make sure that it can be processed further. The water content is set at 10% on mass basis of the left grass cells and fibres. The mass of fibres and cells is 1,050,000 tonnes per year; so 105,000 tonnes of water is needed. The total amount of water is 2,100,000 tonnes per year. With the assumption that all soluble components are evenly distributed over the 2 streams, 5% of all fibre, ash, protein and substrate that have been recovered from the cells will be in the cell and fibre stream. Since the cells and fibres are much larger in size, no cells and fibres will be in the water stream, because separation is relatively easy.
During the cell breaking a lot of friction is involved, which generates heat. Since an increase in temperature will increase the chance of deformation of the protein, the temperature raise should be optimized. The temperature raise has been set at 15 degrees for this moment, resulting in an outgoing temperature of 40 °C.

Fibre cleaning
During the cleaning of the fibre, all grass cells must be broken, and all non-fibres must be separated. To assure full protein recovery, the stream must be processed to break all the cells. After this is done, the fibres must be washed. No additional water is needed, because a part of the water used for washing must be removed to prevent large amounts of water in the protein cake production. This water can then be used again to clean the fibres etc. After this water removal, the grass is pressed into fibre cakes with an estimated water content of 5% on mass basis left.

During the cell breaking, the temperature will increase once again, but the fibres are also washed with cooler water, so overall there will be no temperature changes.

Protein cake production

During the protein cake production, a lot of water must be separated. At this moment this has been set at 60% water removal. This results in an about 10% concentrated stream of substrates which will be used to make ethanol from.
The temperature for this evaporation has been set at 80 °C, but it is a design value. This temperature must be high enough to make sure that the proteins denaturate and precipitate, and that the water-evaporation rate is high enough. The temperature should also be low enough to prevent protein losses.
The amount of protein that can be recovered in the protein cake has been estimated on 95%. The purity of the cake is also a design parameter, and is for the time being set at 75%. This gives a total protein cake production of 47500 tonnes per year. It is important to get the water content as low as possible to be sure that the proteins will not rot during storage. But it is almost impossible to get all water out, so for the time being the water content is set at 5%. The rest of the protein cake will be ash and substrates in the same ratio as they are in the water stream. The temperature of the proteins entering the press will be 80 °C, and during pressing the temperature will even get higher. But in the end the protein cakes will be stored at the same temperature as outside, which is 25 °C.

Ethanol production

The temperature of the streams entering the ethanol production will be 80 °C. This is too hot for the microorganisms, so cooling is needed to around 40 °C. Not all substrates will be converted, but since all substrates are from grass, most will be. This value is set at 95%. The proteins that are left in this stream provide all nitrogen needed for the growth of biomass, and full protein conversion is assumed.
The maximal amount of ethanol that can be made from glucose is 44% on mass basis [21]. But the substrates do not consist of glucose alone, in fact it will only be a very small part of it. The total yield of ethanol from converted substrates on mass basis has been set at 20% in the basic assumptions. This gives an ethanol production of 20k tonnes per year.
During glucose fermentation as many moles of ethanol as of CO_2 are formed. Since the efficiency of ethanol production is halved in this case, the amount of CO_2 will be doubled. Since the molar weights are about the same, it is reasoned that 40k tonnes of CO_2 are formed.
Average biomass yields under anaerobic conditions are around 0,1 C-mol biomass per C-mol substrates [21]. Since the exact composition of grass substrates for microorganisms is unknown, the average composition has been estimated to be the same as glucose.
Furthermore the ash content is 5% of biomass dry weight and the water content around 75% of the total weight.
This results in a biomass stream of 35k tonnes each year. This biomass can be used as a low quality animal feed.
All substrates that are not converted to ethanol, carbon dioxide or biomass are assumed to be turned into water.

Ethanol purification

The outgoing stream of the bioreactor contains gas (carbon dioxide, ethanol and water), liquid (water and ethanol) and solids (yeast and non converted substrates).
The particles can easily be removed by using for example a rotary drum filter. For now it is assumed that all particles can be removed and that no ethanol is lost. The total amount of water in this stream is set at 10% on mass basis of the total amount of this stream. The temperature of this stream will be at room temperature.

Since CO_2 is much more volatile than ethanol, this can be easily flashed off, so the separation is set at 100%. The exact flash conditions are not known right now, so the outgoing temperature of this stream is set at 25 ^{o}C.
Assumed is that all ashes (minerals) are still present in the water and ethanol stream entering the ethanol purification. Since we have decided to use a distillation column, and minerals have the tendency to precipitate during heating, this could cause a lot of trouble. A solution could be the use of a flash vessel to get all ethanol in the vapour phase, and the minerals in the liquid stream exiting the system.
The optimal conditions for the distillation are design variables. For now the recovery of ethanol is set at 99%. This ethanol is used as a fuel, and too much water can damage engines, as well as lower the heating value. According to [22], less than 1% of water is found in current used ethanol fuels. The amount of water in the ethanol is set on 1% for now, but in the actual design it might be needed to further reduce the water content. During the distillation heat must be transferred to the distillation column (maximum temperature around 80 ^{o}C, the boiling point of ethanol), but to get usable product streams (ethanol and waste water) they need to be cooled to 25 ^{o}C.

2.4.2 Electricity production

The temperature of the clean fibre is 40 ^{o}C. The optimum temperature for conversion is a design variable, but for the time being set at 600 ^{o}C. This high temperature of the exhaust gasses will be used to evaporate water in the protein sugar separation step, for now the temperature of the exhaust gasses has been set at 50 ^{o}C.
In the basic assumptions the electricity production is described. Since completely clean fibres are used, the only off gasses will be water and carbon dioxide. The oxygen needed for the combustion will be taken from the air.
The estimated composition of one C-mol of fibres is CH_2O. This requires 1 mol of oxygen per C-mol to convert all the fibres to CO_2 and H_2O. With an oxygen amount of 20% on mol basis in air, 2.7 million tonnes of air are needed per year.

3 Basic assumptions

The feedstock used throughout this design consists mainly of fresh leaves or stems of different plants. The plants will be harvested from natural grounds, which means that feed composition will vary with location, time of year and method of harvesting. For simplicity's sake this biomass feedstock will be called 'grass'. In more industrialised areas, grass is less abundant, and agricultural residues (leaves from food crops) are suitable. Products formed are pig-feed in the form of protein cakes, fuel-grade ethanol and diesel or electricity. The main waste streams are water and gas exhaust. Gas exhausts consists of CO_2 and H_2O. Wastewater is recycled into the process where needed. Minerals leave the system either in protein cake or in wastewater. In the later case it can be recycled to the grass.

The process will be carried out in Zambia. It is a country in southern Africa, approximately $7.5 \cdot 10^5$ sq.km in size (a bit more than 22 times the size of the Netherlands) with some ten million inhabitants. Main employment is in agriculture, where pigs take a relatively small niche (some 300,000 animals). The primary focus of this design is on small farming communities, which are scattered across the land.

The target is to produce 50 ktonnes of protein cake at 75% protein purity (enough to feed some 300,000 pigs), while maximizing fuel production at the same time. Assumed average grass composition is shown in table 1. This results in a grass requirement of 750 ktonnes DW/annum (694 ktonnes/hr for 180 day/year production). 113 ktonnes/annum of sugars, lipids and other digestibles (from now on called substrate) are available for use in for example fermentation to produce ethanol. 563 ktonnes/annum of fiber are available for fuel production.

Table 3-1 Grass Composition

Component	composition
Water	75.00%
Fibre	18.75%
Protein	1.25%
Ash	1.25%
Sugars, lipids and other digestibles	3.75%

In Zambia 30 ktonnes DW grow per hectare per annum, which means that 25,000 hectares are needed. To ensure sustainability, the grass should be only partly harvested, or harvested using crop rotation. This will mean a larger required area, say 100,000 hectares, an area approximately 18 km in radius. In the centre of this area a central fuel production plant would be located.

The process would be partly executed in this central, stationary unit and partly in mobile units. The function of the mobile units is then to process fresh grass, and convert it into protein cakes, dry fibre cakes and concentrated substrate. Water is cleaned to environmental standards, and sequestered or recycled into the terrain to avoid transportation costs. After processing the local area the mobile unit relocates and processes grass at the new location. Fibre and substrate are brought to the central processing unit with trucks for fuel production. Ethanol production through fermentation could be done on the mobile unit, but will likely be too large (or the protein production too low) to be realistically mobile.

The substrate (113ktonnes/annum of digestible sugars and lipids) will be used in anaerobic fermentation to produce ethanol. Ethanol is chosen because it is the best-known form of fermentation, reducing the requirement of high-tech facilities.

The fibres are gasified at high temperature (1100+K) to form CO, CO_2, H_2, char and traces light hydrocarbons and tar. CO and H_2 are converted to liquid fuel using Fischer-Tropsch, while carbon dioxide will be used to further gasify the char (Boudouard). Any heat required will be generated from the direct combustion of excess char and biomass.

Alternatively, the fibres could be combusted, or gasified and then combusted, with the objective to produce electricity.

Location

The battery limits of the mobile units will be defined dynamically. For safety considerations battery limits are restricted to several meters, since the mobile units might need to enter residential areas. Inside battery limits = inside/on the mobile unit itself. Streams entering the mobile unit: grass and fuel (ethanol). Streams leaving: protein cake, fibre cake and substrate.

Battery limits of the stationary units

In case of centralised gasification/Fischer-Tropsch, the plant will not be located in or too near a residential area. Inside the battery limits lie offices, reactors, piping, material handling facilities. Streams entering are fibre cake and substrate; streams leaving are ethanol and fuel (or, synth gas in case of off-site F-T). Availability of outside facilities in Zambia is assumed non-existent.

Deciding on mobile units

Several factors are important in the decision to build mobile chemical plants. The main problem in this particular case is the following: The plant should be mobile if one can't import enough biomass from the direct vicinity. However, when such large volumes of biomass need to be processed by that plant, the plant automatically becomes large, heavy and cumbersome, making it unadvisable –or even impossible- to move the plant around.

When considering stationary units, conversion to electricity becomes more and more attractive. Due to the absence of a power grid it can become economically viable to produce power locally even at low efficiency. Then one plant produces feed, fuel (ethanol) and electricity, which add to the self-sufficiency of the community it is situated in.

Streams

All streams entering and leaving battery limits do so at ambient P and T. Incoming streams, intermediary streams (from protein separation to fuel production facilities) and outgoing streams are all at ambient pressure, although the temperature can change. In case of local self-sufficiency units, the streams syngas and fuel are replaced by produced electricity.

Table 3-2 Stream compositions

Stream	Composition	V/L/S	Mode of transportation	Location
Grass	75.00% H_2O 18.75% fibre 1.25% protein 1.25% inorganics 3.75% 'substrate'	S	Manual labour, oxen	Incoming
Feed (protein cake)	75% protein 25% sugars, fats etc.	S	Trucks	Outgoing
Substrate	Sugars, fats, other digestibles, water	L	Trucks, rail	Intermed.
Fibre	(hemi-)cellulose and lignin	S	Trucks, rail	Intermed.
Ethanol	99% C_2H_5OH <1% H_2O	L	Trucks, rail	Outgoing
Syngas	45% H_2 20% CO 30% CO_2 rest light HC	V	Pipeline	Intermed/Out
Fuel		L	Trucks, rail	Outgoing
Water	Clean H_2O	V/L	Local sequestration	Outgoing
Ash	Surplus minerals	S/(aq)	Local sequestration	Outgoing
Off gas	CO_2, H_2O	V	Chimney	Outgoing

When using Fischer-Tropsch (due to size and complexity per definition a single, immobile, large unit), only a small area is needed to supply enough biomass to easily feed all Zambian pigs. It becomes a lot more efficient to produce the protein cake at this facility, and transport the protein cakes to the farming communities. The fibre streams are immense (see Process Block Scheme appendix 3-1), and it would cost a small fortune (not to mention a sizeable amount of motorized transport) to transport this from all over Zambia (=the mobile units).

Using direct combustion in combination with a Rankine cycle, or gasification combined with a gas engine to produce electricity is very promising. It is also more in the spirit of the assignment, with the benefits to populace being more easily recognisable when compared to a big plant.

4 Margins

In this chapter a root estimation of the maximal total investment costs will be made.

To make these calculations, the Net Cash Flow for the production years is needed. Because nothing is known about the labour costs and all other sorts of costs, all other than raw materials costs are not taken into account.

Under the assumption that the process is sold to the local people, nothing has to be paid for the grass feed, because the farmers already own this. The other two incoming streams, water and air, also don't cost anything. Air is not buyable and water is produced in the process and can partly be recycled. This means that there are no raw material costs.

Table 4-1 Costs of raw materials

	Amount	**Costs**	
	Ton/year	EUR/ton	EUR/year
Grass	3000000	0	0
Air	2700000	0	0
Water	300000	0	0
Total			0

Because the farmers use the products, no money is made from the products. But because they have their own fuel and protein cakes, these things needn't be bought any more, so they save money on this. For this calculation, the common prices of protein cakes and gasoline in Zambia are used (the exact calculations are described in appendix 6-1). In this calculation it is not taken into account that the energy density of ethanol is much lower than the energy density of gasoline. The electricity produced depends on the final energy efficiency of the design. A safe assumption is that we produce little value in excess electricity compared to the rest.

Table 4-2 Product revenues

	Amount	**Costs**	
	Tons/year	EUR/ton	EUR/year
Ethanol	20000	1390	27,826,087
Protein Cake	47500	263	12,485,375
Exhaust steam	3300000	0	0
CO2	40000	0	0
H2O (clean)	1500000	0	0
Waste water with minerals	1050000	0	0
Solid waste (biomass)	44000	0	0
Total			40,311,462

The Net Cash Flow is defined as: product revenues - raw material costs.

With the Net Cash Flow and an interest percentage of 25% (last years inflation in Zambia) the maximal investment costs can be calculated (see appendix 6-1). The maximum total investment costs are EUR 115 million.

Because there are no raw material costs, it is impossible to reduce on these costs to increase the Net Cash Flow. Many costs are not taken into account, so the actual Net Cash Flow will be lower as the one calculated. This means that the investment costs also will be less than calculated.

The biggest problem is the high interest costs. If Zambia can control the devaluation of the money, this will already help because the interest percentage will decrease and thereby the investment costs can rise.

Because Zambia is a country in development, it may be possible to get some loan from Western Countries at more favourable rates. This possibility and also the effect on the investment costs should be investigated.

5 Planning Update

The scheme of the project planning can be found in appendix 7-1. Only the group work has been plotted. At this moment there is still communication between the group and Jenny Ordonez on the how and what of her entering the group. She is a student from Wageningen and has a background very different from the rest of the group. Whether she joins or not, what her available times will be and what her fields of knowledge/interests are will determine the task distribution for every person. The moment that this information is available, a timetable for every person will be created.

As can be seen in the figure, explicit time is reserved for reporting after all parts. During the strengths and weaknesses analysis it was found that reporting was a very weak point in the group. The importance of reporting while working has already been noticed during the creation of this BOD. After this reporting all team members will check what has been written and search for wrong assumptions and all other kinds of errors. Only when everybody agrees on the information and the results it will be placed in the final report.

If in any situation substantial initial errors are found in the design, a crisis meeting will be held. During this meeting what should be done next will be discussed. If there is enough time to start redesigning, that will be done. But if there is not enough time, the principals will be notified, and the group will make a proposal of what to do. Together will be decided what the best thing to do is.
Every week a creativity meeting will be held to be sure that no good solutions go to waste. During this meeting all kinds of problems found during the design will be discussed and with the help of creative methods new solutions might be found.
The order of the tasks described in the project planning is self-explanatory. If at any moment it is found that earlier decisions are impossible, time will be made free to make new decisions. If there is not enough time, we will discuss together with the principals what the best options are.

6 Creativity and group process tools

6.1 Creativity in the process design

Throughout the development of the basis of design, much room was left to apply creativity. Both good and bad ideas sprang forth from brainstorms, illegible notes on napkins, attempts to solve impassable boundaries and heated discussions. Most of the bad ideas found a use in determining limits in less extreme situations (hiring individual Zambians to cut open the *cells* of grass is not an option, but it forces you to look at the available workforce, and to look for methods that can physically cut open single cells).

Some of the ideas that were not incorporated into the design, but are deemed somewhat relevant or new for this field of technology.

Protein-sugar separation

Some ideas to solve the protein-sugar separation came from rephrasing the original question (how to get protein out of the protein mixture). Instead we focused on trying to get the sugar out of the protein mixture. For example, if we could polymerise the sugars and lipids to form some starch-like product if might become easier to separate the protein from the substrate (S/L separation or by centrifugation).

Another idea is to just ferment the lot. If an anaerobic culture is used to produce yeast and ethanol from the protein and substrate, we can make a solid/liquid separation. The solids can be dried and used as pig feed, while ethanol can be distilled from the water/ethanol phase. This way protein separation and ethanol production are combined. The disadvantage is limited protein content (defined by the dry weight protein content in the yeast cells), although protein recovery will be very high. This option remains as a fallback option if we conclude that too little gain is obtained from producing more concentrated (75%) protein cake.

Fibres

A solution to the fibre problem was also needed: fibres are difficult to process into something useful. Using fibre cakes as 'construction' material (euphemism for dumping) is actually one of the most promising options. But there are better places to dump the fibre. Zambia has a large lumber industry, and quite some paper and fibreboard industry are located in it, and in its vicinity. By applying the fibre into local lumber industry one can lower the burden on the (rain) forest ecosystem.

A different option came from interaction between disciplines. Since fibre consists of sugar polymers ((hemi-) cellulose and lignin) it could be possible to depolymerise them, if we'd find the right enzyme. This enzyme exists, but is hard to apply, since bacteria have to excrete it, which means that the decomposition occurs outside the cell, allowing other organisms to consume the formed sugars, fouling and/or disabling the process.

In a different discussion (about starch) a biotechnologist explained to a chemist how enzymes tend to work in both directions: amylase is used both in formation and decomposition of cellulose, and that the direction is governed by thermodynamics.

Now the chemist starts about how the plant cell is able to produce the fibre polymers, thus is also able to decompose them using the same enzyme. If the right thermodynamic conditions are found, it could in theory be possible to decompose the lignin. There is however a big practical consideration: de-polymerisation is entropically unfavourable, partly due to the large amount of monomer that will be formed.

So you could try to re-polymerise the fibres into a more easily digestible substance (starch) during the de-polymerisation (using enzyme that is present in the grass itself). By re-polymerising the monomers, their concentrations remain low, perhaps allowing the switch from cellulose and lignin into something like starch from a thermodynamic point of view.
All this is however purely theoretical, and was deemed too abstract to apply in design without at least some serious research into it. For future developments fibre decomposition using cell-native enzymes looks interesting.

Alternatives
Due to transportability issues, converting fibre into electricity was not a good option. Once it became more and more obvious that viability of the mobile units wasn't very likely, power production in the form of electricity gained in applicability. Especially in the case of a large, central plant power production becomes reasonably efficient, but then there is a logistics problem: A large part of the communities we focus on will not have access to a proper power grid.

The solution lies in thinking about the mobile units: If the production facility is located at its market the product logistics become a lot simpler. Huge investments in a countrywide power grid can be avoided (be it at the cost of fuel efficiency). Many small units, located in the communities (or in a collection of small communities) can produce electricity to comply with any energy demands of that community which, in combination with the fuel and feed, helps in strengthening the community.

6.2 Group process tools

Group Profile Sheet
Every group member filled in the Personal Profile Sheet to show his or her background and characters. By combining the data from the Personal Profile Sheet into the Group Profile Sheet, it is easier to pick out the different potentials of each person and what he or she can do or which part he/she can take care of in our CPD assignment.
For example, Christa is good at economics, planning, cooperation and leadership, while her weaknesses are English language and self-criticism. According to this profile sheet, she is more suitable to be our group leader. By doing this for every team member, everybody knows his/her own duty for our group work.

Another advantage of using the Group Profile Sheet is that we know very clear at which factors we are stronger and which ones we are weaker. Such as, we have three people good at long-term vision, two people good at hard working, and five people are good at coordination. This means there will be no problem in these factors in our group work. The weaknesses warn us what we should really pay attention to them in our work.

It is obvious that our weakness lies in our different education background and different culture, but we can also turn them into an advantage. We met with many problems at the beginning, such as misunderstanding of what should be done now and what should be done in the future. Chinese students are less expressive than Dutch students; they used to keep quiet during the group discussion. These weaknesses really slowed down our design process. Fortunately, this problem was tackled in time, and group work is changing to the positive direction with all members' effort.
By using this method, there is a big potential to improve our group work.

PIQUAR

Our group members chose 41 criteria from hundreds of criteria given in a list. Our principals pointed out the 19 most important ones from those 41 criteria. Then everybody evaluated them and gave 10 of them a number (from 1 to 10) to show how important they are. After arranging them in sequence, the weight factors were calculated by using an interaction factors matrix. With the weighting factor, we can transfer the quantity of our work into a quality. This value helps to determine which parts of the project need more attention.

PIQUAR is a good tool for us to manage our group process work. With only one performance figure, everything related to our design is combined and analyzed.

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Appendix 1-1: Tables of feasible process options

2 N ??

1. Cell breakage

Number	Sort	Advantages	Disadvantages	Z	N	References
1.1	Bead mill	- Easy scale-up - Lots of choice types - High performance - Low costs	- Heat generation - Not extensively disintegrated	X	X	[1, 2, 3]
1.2	Homogenisers	- Effective large scale process - Moderate cost/ harsh press on cell	- Cells are not extensively disintegrated - Clogging	X	X	[1, 2, 4]
1.3	Chemical addition	- Simple - Easy to control	- Chemicals in food making - Denaturisation proteins	X	X	

2. Protein – Sugar separation

Number	Sort	Advantages	Disadvantages	Z	N	References
2.1	Salt	- Low costs - Simple	- Difficult to reproduce on a large scale - Protein and salt solution density same	X	X	[5]
2.2	Temperature	- Simple - Easy to scale up - Low cost		X	X	
2.3	Ultra filtration	- Easily scaled up - No phase change	- Keep membrane wet - Fouling of membranes - High investment costs	X	X	[5, 6, 7]
2.4	Centrifuge	- Short retention times - Relatively compact - Low operational costs	- Heat generation - Fouled by rapidly settling particles - Density sugar and proteins is same, difficult separation	X	X	[5]

4. Fibre usage

Number	Sort	Advantages	Disadvantages	Z	N	References
4.1	Dumping and conversion in fertilizer	- Cheap - Easy	- Waste of energy	X		
4.2	Sell to paper industry	- Profitable - Easy (existing industry) - Less wood needed	- Already enough paper - Maybe lower quality fibres? - Don't use much paper in Zambia	X	X	[8 – 10]
4.3	Direct combustion	- Well known process - High efficiency	- Produces electricity, not liquid fuel - Requires high energy density biomass. - Economy of scale	X	X	[11]
4.4	Gasification	- Produces synthgas: many different products possible	- High temperatures: (far) over 1000K - Requires further processing (F-T)	X	X	[11 - 13]
4.5	MO biofuel (ethanol or methane)	- Low costs - Exothermal reaction, lower energy needed - High conversion rate - Normal yeast, cheap and used in the industry	- 5-carbon sugars are not fermentable - Limited to laboratory scale - Need extra acid to convert hemi-cellulose to glucose - Enzyme is sensitive to the change of temperature and PH.	X	X	[14, 15]
4.6	Silage	- Cheap - Easy	- No value, still waste - Waste of energy	X	X	[16 – 19]

Appendix 1-2: Tables of alternative process options

1. Cell breakage

Number	Sort	Advantages	Disadvantages	Z	N	References
1.4	Micro organisms	- Combine ethanol prod with cell breaking	- Consume P + S - Contamination		X	
1.5	Enzymatic lysis	- Low energy consumption - Enzymes attack specific components	- Temperature, pH and cofactor - No large scale		X	[1, 2, 3]
1.6	Disk Refiner	- High yield - Relative less power - Easy in use	- Low conversion		X	[4 - 6]
1.7	Heating	- Very simple process	- Denaturisation proteins - Solid-solid separation		X	
1.8	Ultrasonic sound	- Complete cell breaking	- Lab-scale use - High energy use - Tested on weak cell walls - High costs			[1, 2, 7, 8]
1.9	Radiation		- Heating water inside microwave - Higher wavelength less energy - Lower wavelength destroy all			[9]
1.10	Freezing		- Only lab scale - High costs - Very slow			[1, 2]
1.11	Osmosis	- For those cells lack a cell wall can be easily lysed	- Not well suited for large-scale - Only usable for animal cells - Not very efficient			[1, 2, 8]
1.12	French Press		- Lab scale - Temperature increase → cooling			[1, 2]
1.13	Stone ground wood process		- No cell breaking - Contains slivers of wood → fouling			[4, 5, 6, 10, 11]

2. Protein – Sugar separation

Number	Sort	Advantages	Disadvantages	Z	N	References
2.5	Micro organism	- All useful components used	- Micro organisms maybe harmful - Produce toxic compounds		X	
2.6	Organic solvents	- Relatively compact - Preparation and start-up times relatively short Automation easily achieved. - Operational costs low	- High equipment and maintenance costs - Lines fouled by rapidly settling particles		X	[1, 2, 12, 13]
2.7	Extraction	- High recovery rates - Low capital costs - Simple operation - Low power requirement	- Extra separation - Add new chemical - Expensive - Large recycle stream of organics - Cost of waste treatment is large		X	[12, 14]
2.8	Crystallization	- Simple technique	- Scale-up		X	[14]
2.9	Electrostatic precipitation		- Only gas phase			
2.10	Electrophoresis		- Only analytical			[15]
2.11	Non-ionic polymers	- No denaturing the proteins - No interacting	- Introduce new chemicals - Expensive - Extra separation step			[12]
2.12.a	Gellation methods		- Separation gel and proteins			
2.12.b	Gel filtration	- Separate very sharply	- Enormous amount needed - Expensive			[16, 17]
2.13	PH		- introduce new chemicals			
2.14	Radiation		- High wavelengths have not enough energy - Microwaves will only heat the water			[17]
2.15	Freezing		- Solid-solid separation			[1, 2, 18]
2.16	Micro Membrane Filtration	- Energy savings - Environmentally benign - Clean technology - Produces high quality products - Greater flexibility in designing systems	- Expensive - High Tech - Clogging			[12, 14, 19]
2.17	Chromatography		- Viscosity can not be too high, must be diluted - Flow rate can not be too high or too low			[14]

4. Fibre usage

Number	Sort	Advantages	Disadvantages	Z	N	References
4.7	Pyrolysis	- Simple, but still many optimisation options - Produce high energy density pyrolytic oils	- Mainly suitable for producing coal/char - Low yields on liquid hydrocarbons		X	[20, 21]
4.8	Hydro-gasification / liquefaction	- Main product is liquid - Wide product range determined by P, T, solvent, cat, additional reactants	- Requires further processing: deoxygenation - High pressure		X	[20, 22]
4.9	Chemical biomass conversion	- Produces different sugars, which can be used in many ways - Pre-hydrolysis can also be applied as cellulose softener in other conversion strategies	- Large amounts of acids (and bases for neutralizing) - Strong acid results in glucose degradation → yeast poisoning - Corrosion		X	[20, 23, 24]
4.10	Methane and CO	- Is profitable - Biological, no chemicals used	- CO converted into CO2 - Desulfuration necessary - Not sure if it works with fibres		X	[25]
4.11	Photo biological	- Hydrogen production efficiency could reach 24%; - The ability of elimination from power plant flue gas	- Must overcome the limitation of oxygen sensitivity of the hydrogen-evolving enzyme systems - Low efficiency of lipid produced - Need separate lipid from cells		X	[26, 27]
4.12	Biochemical Fuel Cell		- Low yields and low fuel storage capacities. - Not commercial			[26, 27]
4.13	Bio plastics	- Can be profitable - Biological, no chemicals used	- Degradation - Expensive - Long process times		X	[28 - 30]

Appendix 1-3: Description of alternative process options

Alternative options for cell disruption

Microorganisms

Since microorganisms exist that can destroy cell walls it is an option to use those to break the cell walls. This option is only suitable in the Netherlands as it can be seen as a high-tech biotechnology. It also requires very good sterilizing between the processes.

The advantage is that the cell-breaking step and the ethanol production step can be combined into one process by using yeast which has the ability to produce cellulases. Disadvantage is that the microorganisms will consume at least part of the protein and sugars that come free when the cells break. Contamination with other microorganisms will lead to an even higher unwanted conversion of sugar and protein.

Enzymatic lysis [1-3]

Enzymes attach and degrade specific components of the cell wall, leaving the products unaffected in most cases. It is usually followed by sonication, homogenization or vigorous vortexing in a GITC lysis buffer. (Cellulase can lyse plant cells.) This option is only suitable in the Netherlands as it can be seen as a bio high-tech option. It also requires very good sterilizing between the processes.

Advantage is it requires low energy consumption, damages the product less and is very specific 'Gentle' technique since the enzymes attack specific components of the cell wall. Frequently used with bacteria and yeast to dissolve a coat, capsule, capsid or other structure not easily sheared by mechanical methods alone
Disadvantages are temperature, pH and cofactor availability can influence enzymatic lysis. There are too many factors to influence the lysis process.Despite the gentleness of the technique and its efficiency, there is no widely utilization at the industrial scale because of the high cost of the enzymes.

Disk Refiner [4-6]

This process, developed in the late 1950's, originally uses wood chips as its main input. The chips are fed between two large metal disks in a machine known as a refiner. As the disks rotate relative to one another, the action of a series of grooves and bars on their surfaces separates and disrupts the cell fibres. Since the disc refiner is sensitive to dirt and dust, it might not be sensible to use it in Zambia.

The disc refiner is suitable in large-scale systems as the machine is widely used in a large range of capacities (paper industry) and has a high throughput. Thereby, the disc refiner has a relatively low energy usage and is easily operated.
Disadvantage is the cells will not be extensively disintegrated. The discs are sensitive to fooling, dirt and dust.

Heating

Upon heating, the cell walls will disintegrate. Heating can be done in many ways and the most efficient way for the process must be found. The heating process can be done in every country, but the solid/solid/liquid separation step is a delicate technique.

Advantage is the simplicity of the heating process.
Disadvantage is the denaturising of proteins. Due to this denaturisation a solid/solid/liquid separation step must be made to separate the fibres from the solid proteins.

Ultrasonic cell disruption [1,2,7,8]
This method uses ultrasonic sound waves to create little bubbles of air inside the cells. Once these bubbles are formed they grow in size and try to find their way out of the cell, thereby destroying the cell walls.

Advantage is that complete cell breaking is –in theory- possible
The first disadvantage is that the process is usable only in lab-scale. Secondly, high energy uses, due to high temperature increases in the liquid. Only investigations into less resistant cell walls

Radiation [9]
Several methods have been thought of which use a kind of radiation to destroy (parts of) the cell walls.

For this case no advantages are found. Disadvantage is microwaving will only heat the water and there are more efficient ways to heat water. Higher wavelengths have less energy, and will not destroy the cell walls. Because ultraviolet, visible and infrared light are sources a normal cell is used to, there will be no significant damage to the cell walls. Gamma and lower wavelength radiation contain too much energy, they will not only destroy the cell wall, but also all of its contents.

Freezing [1,2]
When the grass stream is frozen, the crystals of water will penetrate the cell walls, thus destroying it. Possible in the Netherlands, but removing heat on a mobile unit in tropical areas is energy intensive.

Advantages are that this is a relatively simple process and that it is easy to control.
The intensive use of energy is a disadvantage. At this moment this technique is only available on lab scale because of scale-up difficulties. Another disadvantage is the long residence time.

Osmosis [1,2,8]
When cells are suspended in pure water, the concentration of solutes inside the cells is higher than outside the cell, which results in the flow of water into the cells. The flow of water into the cells increases the intracellular pressure until the low chemical potential inside the cell (due to the presence of solutes) is balanced by an increase in the pressure due to the flow. If the pressure becomes too large to handle for the cell wall, it will burst. It is a very complex process with some different steps, so it is not a real good option for the Netherlands or Zambia.

The advantage of the process is the high efficiency. Cells that lack a cell wall can be easily lysed using this method.
The disadvantage is the process is not well suited for large-scale processes that handle large amounts of fluids. It isn't very efficient, and comparatively complicated for plant tissue because grass cell wall is more difficult to disrupt, requiring use of higher osmotic pressure.

French Press [1,2]
A liquid cell suspension is subjected to pressure as high as 20,000psi. A sudden drop on pressure then disrupts the cells. Because of the needed pressure drop it is a non-preferable process.

The main advantage is little or no collateral damage caused compared to other methods. Disadvantage is it only is reserved for laboratory scale. Another disadvantage can be that the energy imparted to the cell suspension is converted to heat. As a result, the system must provide cooling to avoid damaging the product. Normally, each pass results in a temperature rise of approximately 10 °C.

Stone Groundwood Process [4-6,10,11]
In this process, pulp is produced by pressing blocks of wood against an abrasing, rotating stone surface, while adding hot water. The rough stone surface breaks the wood down into intact fibres, fibre fragments and/or fine fibre particles. Then following screening, cleaning, thickening. Because the cells do not break, this is no process option for this part of the process.

There are no advantages because it's only applicable for larger biomass sources like wood; not for small parts such as grass

Even if it were applicable, some disadvantages remain: Groundwood pulp contains slivers of wood, which have to be removed by coarse screening. If, as is commonly the case, rejects from coarse screening are not shredded and recovered into a refiner system, this can cause severe operating problems downstream and excessive discharge of suspended solids.

Alternative options for protein and sugar separation

Microorganisms
Yeast can be used to produce ethanol from the sugars in the mixture. Upon heating the ethanol evaporates, and the proteins will denaturize and precipitate. The proteins can easily be removed, together with the microorganisms. This complete solid phase can be used as protein cake. The ethanol water mixture can be separated by distillation. It also requires very good sterilizing between the processes. Yeast consumes proteins in the liquid, which leads to some protein loss.

The advantage is that all useful components within the feed are used. The methods used are well known as they are applied in many systems. The alcohol produced can be used as a fuel.
In order to use the protein-micro organism solid cake as a protein cake, the microorganisms may not be harmful for the pigs, and may not produce toxic compounds. This problem can be overcome by sterilizing, but this results to other problems and higher costs. Protein recovery is limited.

Organic solvents [1,2,12,13]
Organic solvents have been employed extensively for the precipitation of proteins. Most enzymes precipitate in the range of 20 to 50 percent organic solvent. Above 50 percent solvent only proteins smaller than 15,000D will remain in solution. The larger the molecule, the less organic solvent is needed for precipitation to occur. This process would only be applicable in the Netherlands as it can be considered to be a high tech solution due to solvent recovery from feed streams.

As an advantage it is possible to use ethanol produced elsewhere in this process, but this cannot be needed as a fuel. If something else is used, a new chemical is added which is also not preferable.

Extraction [12,14]
The working principle in this option is separation by difference in densities. The time required to separate the two phases under unit gravity depends on the protein load. With high loads a stationary interface is reached after 15-20 hours; when no solids are presents, a stationary interface is reached in less than 2 hours. Centrifugal separation will naturally speed up the process. Because it is not easy to control this process, a lot of quality research should be done, which makes it very expensive for Zambia, but can be done in the Netherlands.

The extraction process has high recovery rates while low investments are needed. The operation of the process is relatively simple and the energy consumption is low. The process can be operated in large-scale systems and can be safely conducted at room temperature. Introduction of organic solvent is a disadvantage. The organic solvents are expensive and must be separated from the product in a later step. The recycle stream of organic solvent could be large. The costs for waste treatment are relatively high.

Crystallization [14]
Another well-known precipitation technique is crystallization.

Although bench-scale laboratory crystallization is a simple technique, the scale-up from this level to industrial crystallization processes can be complicated. Large-scale crystallization processes suffer from an ill-defined geometry, with simultaneous mass and heat transfer taking place in a multiphase, multicomponent, thermodynamically unstable system. The resulting crystals can be profoundly affected by trace impurities.

Electrostatic precipitation
The nature of this process is to precipitate proteins by using electrostatic force.

This method is only useable in a gas stream; since it is impossible to get the sugars and protein into the gas phase, this method cannot be used. A method that works like this, but in a liquid environment is called electrophoresis.

Electrophoresis [15]
The process is very similar to the electrostatic precipitation. This method is most known from DNA analysis. It can also be used to separate proteins.

Because this process is only done on lab scale, it currently has no use for a process plant.

Non-ionic polymers [12]
Proteins typically precipitate in the PEG concentration range 3 to 30 percent (weight per volume). PEG may be removed from protein solutions by several methods, including adsorption of the protein on ion exchange resins, salt induced phase separation, and ultrafiltration.

Advantage is PEG (nonionic polymer glycol) precipitates proteins in aqueous solution without denaturing the proteins or otherwise interacting with them. PEG solubility is fairly insensitive to temperature, obviating the need for strict temperature control.
Disadvantage is the introduction of new chemicals, which must be separated later.

Gellation methods
The idea was to add a certain substance that would solidify the proteins into a gel.

The advantage is an easy solid/liquid separation step after the gel is formed, but no such methods exist, and even if it did, the main disadvantage would be that the substance must be separated again from the gel. The separation problem could be overcome by placing the substance on a surface. In that case first the liquid with everything in it can be flown over the surface, and later washed with clean water to get the proteins off again. This is almost the definition of chromatography, and that is treated elsewhere.

Gel filtration [16,17]
This method uses a gel to separate different molecules in size.

This method can separate very accurately. The disadvantage is that this process must be operated batch wise with a sample size in the order of magnitude of several millilitres, so an enormous amount of these expensive units would be needed. Furthermore it is needed to buffer the flow trough the gel, so large amounts of acids and bases are also needed.

PH
Changing the pH rate will result in precipitation of the proteins.

It is a simple process, but the introduction of new chemicals is a disadvantage, especially when the products are used in food processing.

Radiation [17]
Separation based radiation has been proposed.

The same problems as with cell breaking occur. High wavelengths have not enough energy to do anything, microwaves will only heat the water, and much less energy-consuming ways of heating water exist. Ultra violet, visible and infrared light are sources of radiation all sugars and proteins are exposed to everyday. And shorter wavelength radiation has too much energy, destroying everything inside the mixture.

Freezing [1,2,18]
If a method using heat could be used to separate the proteins from the sugars, cooling could also be a method. In literature [4] the only method described which uses freezing, is freeze-drying. This method can only be used to get the water out of a particle. It cannot be used to separate the sugars and proteins. The reason it is not described in literature is that it is not a feasible method. Upon freezing the proteins will denaturate, and become solid. Since frozen water is also solid, a solid-solid separation is needed, which is complicated. Or the water can be heated, but in that case there is energy needed to cool, and energy needed to heat. If the mixture is only heated less energy is needed.

Thus, a disadvantage is the Solid/solid separations, which is hard to execute.

Micro Membrane Filtration [12,14,19]
Microfiltration is commonly used to remove suspended particles (insoluble material) from a process fluid and comprises operations such as the recovery of cells from fermentation broth and the clarification of lysed-cell slurries.

Energy savings is one of the most important advantages as well as the fact that is environmental friendly. The quality of the products is very high and the technique is applicable in a great range of capacities.

The major disadvantage of membrane separation techniques is the fact that these techniques are usually very expensive. It also cannot take the product to dryness, as ultrafiltration systems are limited in the extent of the solids that they can handle. Fouling of the membranes is another disadvantage.

Chromatography [14]
Separation occurs because the difference in distribution coefficients of the components of the mixture between the stationary and mobile phase results in differing velocities of travel. Viscosity cannot be too high, so the feed must be diluted. In addition, the flow cannot be too high or too low.

Alternative options for fibre usage

Pyrolysis [20,21]
Pyrolysis consists of heating hydrocarbons in presence of water, oxygen and/or other reacting or inert gases. Occuring reactions and their resulting products are strongly dependent on temperature, heating rate, heating time and the composition of the feed stream. Because this process mainly produces char and other solid compounds, it is not very useful in either of the counties. It might become applicable in the Netherlands if great effort is put in research on the process and its control.

The advantages are the simplicity of the process, and the production of high energy density pyrolytic oils
The disadvantages are that pyrolysis mainly produces coal and char, has a low yield on liquid hydrocarbons and produces a lot of CO_2.

Hydro-gasification / liquefaction [20,22]
Liquefaction is mostly carried out in presence of CO/H_2, H_2 or H_2O, and yields oxygen rich oils as well as small acids, ketones and aldehydes. The produced liquid (commonly referred to as biocrude) can easily be processed using conventional refining techniques to produce a diesel type fuel. Relatively small amounts of gas (CO_2) and some solids can also be formed. Because China has a pretty big oil industry, the post-processing is well known. The same can be said about the Netherlands. The process is at this time still too little researched to be applicable in Zambia.

The advantages are that the main product is liquid and the process can give a lot of different products by slight changes in pressure, temperature and other process variables.
Here also a disadvantage is further processing is necessary. High pressures (up to 280 bar) can also cause some problems.

Chemical biomass conversion [20,23,24]
Biomass processing is also possible by acid treatment. HCl gas, concentrated or diluted HCl, H_2SO_4 or HF can be used. Biomass is reduced to form different sugars, both pentoses and hexoses, which can be converted into for example ethanol, using conventional biochemical means. Pre-hydrolysis (dilute mineral acid, acetic acid or even water) is often used to convert the hemicellulose to sugars (423-433K in water). The cellulose can then be treated using more concentrated acids to yield glucose. Lignin is not converted, but can be used in aromatics production through for example hydrocracking. Because of the strong acids in combination with the low education, this is not a preferable option for Zambia. In the Netherlands it could be used, but there are only few advantages to weigh up against concentrated acid at high temperature.

One of the advantages is that this produces different sugars, which can be used in many ways. The second one is pre-hydrolysis can also be applied as cellulose softener in other conversion strategies.
The main disadvantage is the use of very strong acids. These acids can cause glucose degradation, which in turn can cause yeast poisoning in further use. Strong acids also give trouble through equipment corrosion.

Methane and CO [25]
With anaerobic bacteria a mixture of fibres and fertilizer can be converted to methane and CO, which are useful energy sources. The fertilizer doesn't lose its use, but is turned into a slightly less environmentally harmful form. A lot of research should be done before this process can be used, but in the future it can be an option for all three countries.

Advantages are that the process is biological and is currently making profits.
Disadvantages of this process are that desulphurisation is necessary, CO should be converted into CO_2 and methane is not an easy fuel to work with. Also, in literature the process is done with silage grass, not just with fibres

Photo biological [26,27]
There are also MO's who can convert the fibres into methanol. Because methanol is more toxic, this process will not be an option for Zambia. The same reason also makes the process unfavourable for fuel production in the Netherlands.

The advantage of this process is the hydrogen production, which could reach efficiency of 24%. The ability of micro algae and cyanobacteria to grow photoautotrophically can be directly coupled with carbon dioxide elimination from power plant flue gas.
Disadvantage is that the technology must overcome the limitation of oxygen sensitivity of the hydrogen-evolving enzyme systems. Lipids are insufficiently converted, which means that lipids need to be removed from the cells.

Biochemical Fuel Cell [26,27]
For this process option a lot of research is needed before it could become an actual option.

Bio plastics [28-30]
Some species can convert fibres into plastic (PHBV). Because the use of very specific microorganisms it is difficult to apply this process in Zambia. In the Netherlands it also is not an option until a lot of research on bio plastics has been done.

Because the process is done in a biological way, without any chemicals, it is an environmentally friendly way of converting the fibres into something useful. In addition this process is considered to be potentially profitable. Because this plastic is made in a biological way, the plastic is easily degradable.
However, the plastics decompose to quickly too make anything useful from it (saving something in a plastic bag that decomposes itself is not very helpful).

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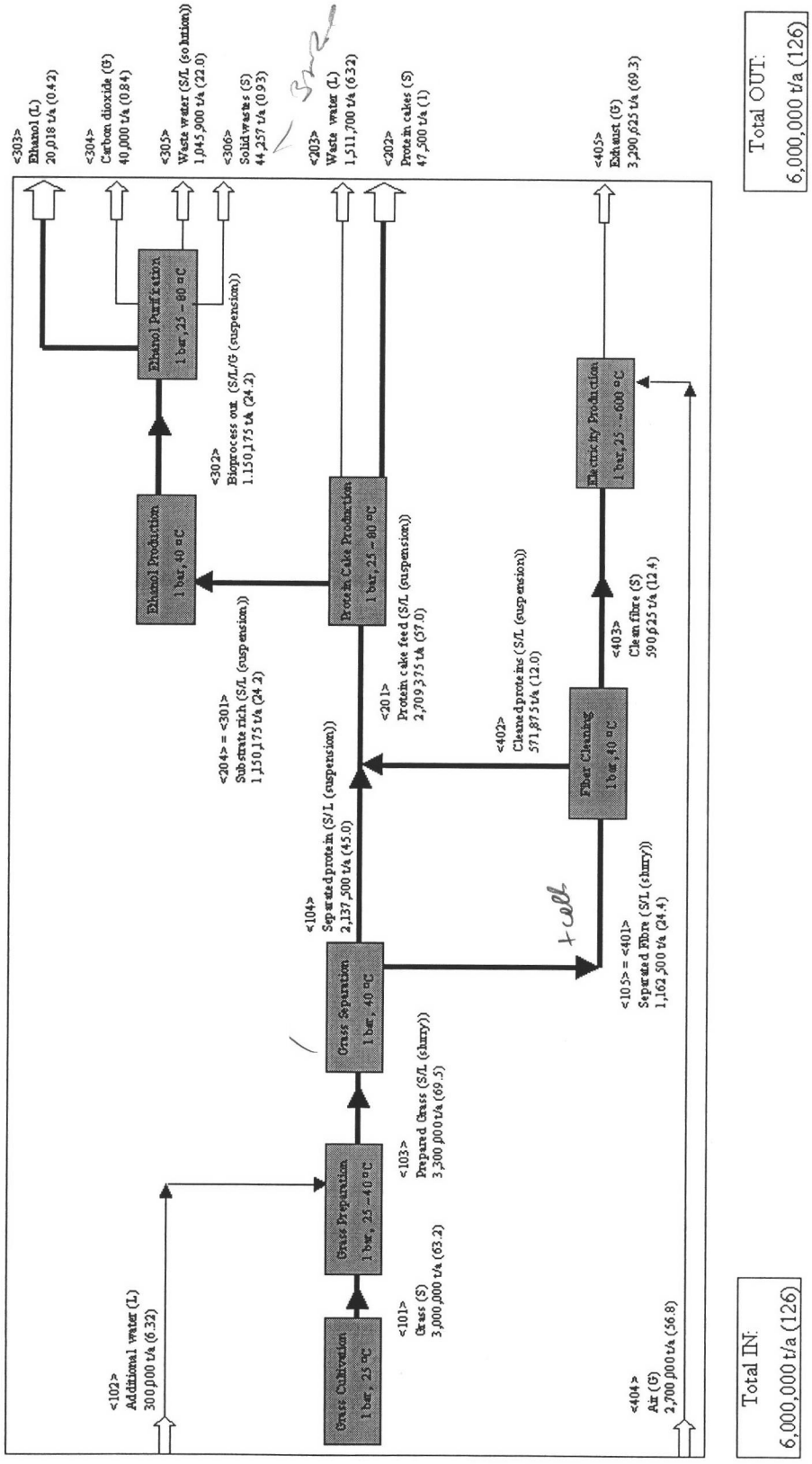
Appendix 2-1 Thermodynamic Properties

Systematic	Formula	Mol. Weight	Phase	BP	MP	FP	SD	LD [2]	VD	viscosity	solubility in water
		(g/mol)	(room T)	[1] (oC)	[1] (oC)	[1] (oC)	kg/m3	kg/m3	[3] kg/m3	0°C and 1.013bar) (uPa.s	(0°C,1 atm) (vol/volH2O)
Nitrogen	N2	28.013	G	-195.86	-209.95				0.967		Slightly soluble
Oxygen	O2	31.9988	G	183	-219.0			1141.0	1.354(at 15 deg)		0.05
Carbon	C	14	S	4827	-3550		1800	n.a	?		
Carbon Monoxide	CO	28.01	G	-191.6	n.a	605		788.6	1.184	16.62	0.0354
Carbon Dioxide	CO2	44.01	G	-78.5	n.a		1562	1032	1.87	13.73	1.7163
Methane	CH4	16.043	G	-161.6	-182.5	-187.78		422.62	0.68	10.28	0.054
ethene	C2H4	28.054	G	-103.7	-169.14	n.a			0.97		26 g/100 mL. Slightly soluble
Ethanol	CH3CH2OH	46.07	L	78.5	-117.3	12.78		789	1.6		
Hydrogen	H2	2.016	G	-252.8	-259			70.973	0.085	3.42	0.0214
Water(room T)	H2O	18	L	100	n.a			999.839at0		0	100
Steam	H2O	18	G		n.a			958.365at100		0	100
Glucose	C6H12O6	180.16		118.87	146-150						154cc at 15deg, 82cc at 17.5 deg [8]
Cellulose	(C6H10O5)x	(162.14)x					1.3-1.4				0

Systematic	Formula	H	S	G	Cp	Tc	Pc	Dc	Ttr	Ptr
		[9] (kJ/mol)	[9](J/mol*K)	[9](at 1 atm)	kJ/(mol.K)	(oC)	(bar)	(kg/m3)	(°C)	(bar)
Nitrogen	N2	0	191.6	0.0	29.124	-147.0	34.0		63.1	0.1
Oxygen	O2	0	205.1	0.0	29.4	-118.6	50.4	436.1	-218.8	0.0
Carbon	C	0	5.74	0	8.536					
Carbon Monoxide	CO	-110.53	197.658	-137.168	29.141	-140.23	0.349			
Carbon Dioxide	CO2	-393.51	213.783	-394.373	37.135	31	73.825	464	-56.6	5.185
Methane	CH4	-74.6	186.3	-50.5	35.7	-82.7	45.96			
ethene	C2H4	52.47	219.3	68.4	42.9	9.35	50.6		-169.15	0.0012
Ethanol	CH3CH2OH	-277.6	169.7	-174.8	112.3	240.85	63	6mol/l	-123.15	
Hydrogen	H2	0	130.68	0	28.836	-240	12.98	30.09	-259.3	0.072
Water(room T)	H2O(l)	-285.83	69.95	-237.141	75.3	373.98	0.2194			
Steam	H2O(g)	-241.826	188.832	-228.582	33.598					

Systematic	Formula	AIT	IT	Flammable Limits	LEL	UEL	LC 50 [7]	MAC Value	LD50 {7}	Chemical Reactivity
		(°C)	(°C)	% by vol in air	%	%	In air/	mg/m3	Oral	
Nitrogen	N2	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	reactions may cause fire or explosion.Gas/air mixtures are explosive.
Oxygen	O2								n.a	Risk of fire and explosion on contact with combustible materials such as oils or fats.
Carbon	C	n.a	537	n.a	n.a	n.a	n.a	6	n.a	
Carbon Monoxide	CO	608.89	805	12.5-74	12.5	74	n.a	33	n.a	Extremely flammable(4),reacts violently with oxgygen difluoride and barium peroxide
Carbon Dioxide	CO2	n.a	n.a	n.a	n.a	n.a	n.a	9000	n.a	no flammable (0)
Methane	CH4	600	537	5.0-15.0	5	15	n.a	n.a	n.a	Extremely flammable.Gas/air mixtures are explosive.
ethene	C2H4	723.16	450	2.7-36.0	2.7	36	n.a	n.a	n.a	Extremely flammable. Gas/air mixtures are explosive
Ethanol	CH3CH2OH	422.78	363	3.3-19	4.3	19	n.a	1900	n.a	Highly flammable.Vapour/air mixtures are explosive. □
Hydrogen	H2	400	500-571	4.0-74	4	75	n.a	n.a	n.a	Extremely flammable. Many reactions may cause fire or explosion.Gas/air mixtures are explosive.
Water(room T)	H2O	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	
Steam	H2O	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	

Appendix 3-1 Block Scheme for the process in Zambia



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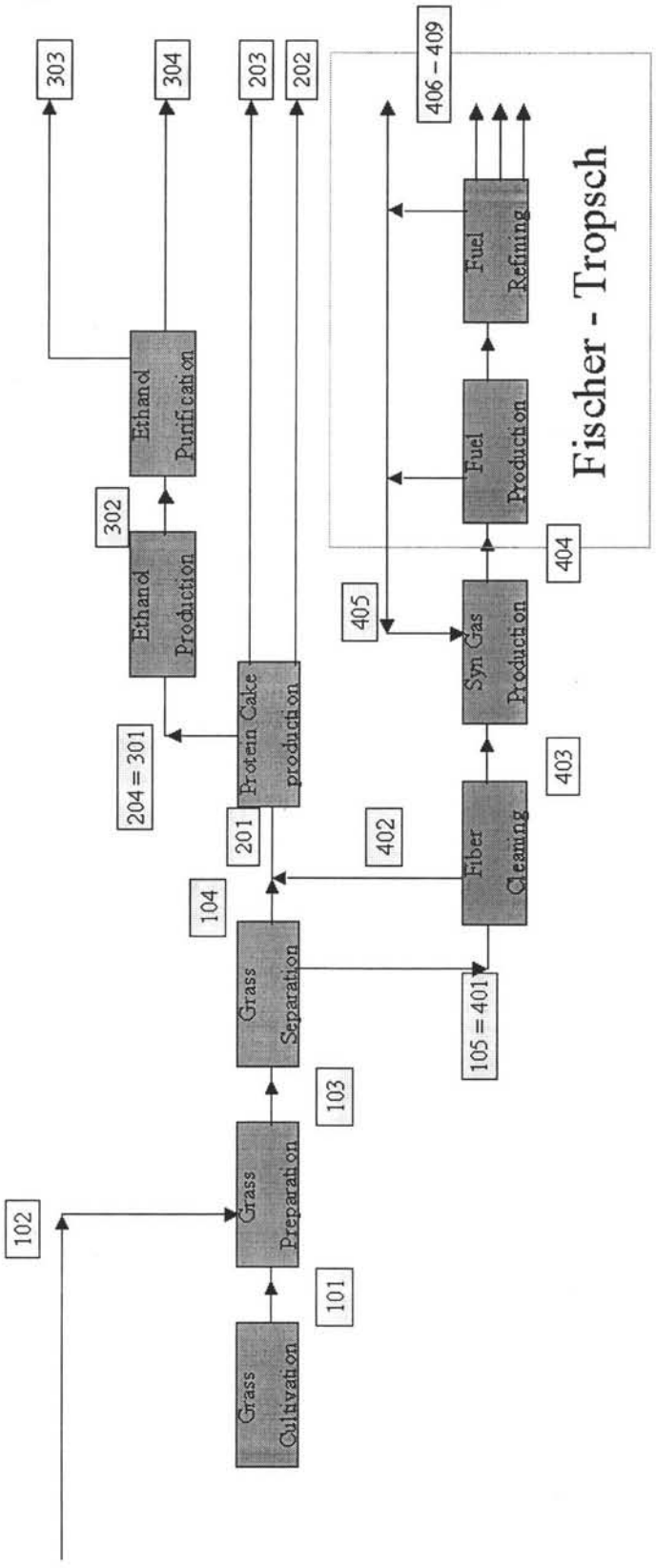
Appendix 3-2 Block Scheme for the process in The Netherlands



Appendix 4-1 Process stream summary cell breaking

STREAM Nr. :	101 IN		102 IN		103		104		105	
Name :	Grass in		additional water		prepared grass		Separated protein		Separated fibre	
COMP MW	t/a	kmol/s	t/a	kmol/s	t/a	kmol/s	t/a	kmol/s	t/a	kmol/s
Grass cells	3000000.00				3000000.00				600000.00	
Protein							28500.00		1500.00	
Fibre									450000.00	
Substrates							85500.00		4500.00	
Ashes							28500.00		1500.00	
Water			300000.00		300000.00		1995000.00		105000.00	
Biomass										
Ethanol										
CO2										
O2										
N2										
Total	3000000.00		300000.00		3300000.00		2137500.00		1162500.00	
Enthalpy kW										
Phase L/V/S	S		L		S/L		S/L		S/L	
Press. Bara	1.0		1.0		1.0		1.0		1.0	
Temp oC	25.0		25.00		25.0		40.0		40.0	

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Appendix 4-2 Process stream summary of protein cake production

STREAM Nr. :	201		202 OUT		203 OUT		204	
Name :	protein cake feed		protein cakes		waste water		sugar rich	
COMP MW	t/a	kmol/s	t/a	kmol/s	t/a	kmol/s	t/a	kmol/s
Grass cells								
Protein	37500.00		35625.00				1875.00	
Fibre								
Substrates	112500.00		7125.00				105375.00	
Ashes	37500.00		2375.00				35125.00	
Water	2521875.00		2375.00		1511700.00		1007800.00	
Biomass								
Ethanol								
CO2								
O2								
N2								
Total	2709375.00		47500.00		1511700.00		1150175.00	
Enthalpy kW								
Phase L/V/S	S/L		S		L		S/L	
Press. Bara	1.0		1.0		1.0		1.0	
Temp oC	40.0		25.0		80.0		80.0	

Appendix 4-3 Process stream summary of ethanol production

STREAM Nr. :	301		302		303 OUT		304 OUT		305 OUT		306 OUT	
Name :	sugar rich (=204)		bioprocess out		ethanol		CO2		waste water		solid wastes	
COMP MW	t/a	kmol/s	t/a	kmol/s	t/a	kmol/s	t/a	kmol/s	t/a	kmol/s	t/a	kmol/s
Grass cells												
Protein	1875.00											
Fibre												
Substrates	105375.00		5269.00								5269.00	
Ashes	35125.00		34693.00						34693.00			
Water	1007800.00		1015629.00		198.00				1011006.00		4425.00	
Biomass			34563.00								34563.00	
Ethanol			20021.00		19820.00				201.00			
CO2			40000.00				40000					
O2												
N2												
Total	1150175.00		1150175.00		20018.00		40000.00		1045900.00		44257.00	
Enthalpy kW												
Phase L/V/S	L/S		L/S		L		G		L/S		S	
Press. Bara	1.0		1.0		1.0		1.0		1.0		1.0	
Temp oC	80.0		40.0		25.0		25.0		25.0		25.0	

Appendix 4-4 Process stream summary of electricity production

STREAM Nr. :	401		402		403		404 IN		405 OUT	
Name :	separated fibre (=105)		cleaned proteins		clean fiber		air		exhaust	
COMP MW	t/a	kmol/s	t/a	kmol/s	t/a	kmol/s	t/a	kmol/s	t/a	kmol/s
Grass cells	600000.00									
Protein	1500.00		9000.00							
Fibre	450000.00				562500.00					
Substrates	4500.00		27000.00							
Ashes	1500.00		9000.00							
Water	105000.00		526875.00		28125.00				365625.00	
Biomass										
Ethanol										
CO2									825000.00	
O2							600000.00			
N2							2100000.00		2100000.00	
Total	1162500.00		571875.00		590625.00		2700000.00		3290625.00	
Enthalpy kW										
Phase L/V/S	S/L		S/L		S		G		G	
Press. Bara	1.0		1.0		1.0		1.0		1.0	
Temp oC	40.0		40.0		40.0		25.0		50.0	

Appendix 4-5 Process summary of the total plant

STREAM Nr. :	101 + 102 + 404		202 + 203 + 303 + 304 + 305 + 306 + 405	
Name :	Total Plant	IN	Total Plant	OUT
COMP MW	t/a	kmol/s	t/a	kmol/s
Grass cells	3000000.00			
Protein			35625.00	
Fibre				
Substrates			12394.00	
Ashes	300000.00		37068.00	
Water			2895329.00	
Biomass			34563.00	
Ethanol			20021.00	
CO2			865000.00	
O2	600000.00			
N2	2100000.00		2100000.00	
Total	6000000.00		6000000.00	
Enthalpy kW				
Phase L/V/S	S/L		S/L	
Press. Bara	1.0		1.0	
Temp oC	40.0		40.0	

Appendix 5-1 Margin Calculations

The price of ethanol was given as a ratio number for Zambia and the Netherlands. With the ratios for both countries and the liter price of gasoline in the Netherlands on this moment, the price of gasoline in Zambia is calculated.

$$Gasoline_{Zambia} = \frac{Ratio_{Zambia}}{Ratio_{Netherlands}} * gasoline_{Netherlands} = \frac{1.64}{1.69} * EUR1.15 = EUR1.12 \text{ [1, 2]}$$

This is the price per liter gasoline. Because the amount is given in tons, this price is calculated for 1 ton of gasoline with the density of gasoline.

$$\frac{1.12 \text{ EUR/liter}}{0.805 \text{ g/ml} * 1{,}000 \text{ ml/l}} * 1{,}000{,}000 \text{g/ton} = 1391.304 \text{ EUR/ton}$$

Calculation of the maximum investment costs is done with the Discount Cash Flow Rate of Return.

Assumptions that are made are:
- Plant is build in 1 year (negative cash flow which is equal to the investment costs)
- The maximum interest percentage is 25%
- The pay Back time of the plant is 10 years
- The Net Cash Flow is constant during this 10 years

$$\text{DCFRR} = \sum \frac{NCF(n)}{(1+r)^n} = 0$$

$$\frac{NCF(1)}{(1+0.25)^1} + \frac{NCF(2)}{(1+0.25)^2} + \frac{NCF(3)}{(1+0.25)^3} + \frac{NCF(4)}{(1+0.25)^4} + \frac{NCF(5)}{(1+0.25)^5} + \frac{NCF(6)}{(1+0.25)^6} +$$
$$\frac{NCF(7)}{(1+0.25)^7} + \frac{NCF(8)}{(1+0.25)^8} + \frac{NCF(9)}{(1+0.25)^9} + \frac{NCF(10)}{(1+0.25)^{10}} + \frac{NCF(11)}{(1+0.25)^{11}} = 0$$

NCF (n) = Net Cash Flow year n
r = 0.25 = (Estimated) interest percentage in Zambia

The NCF in year 1 is equal to the investment costs. The NCF in the other years is equal to the product revenues - raw material costs.

$$\frac{NCF(1)}{(1+0.25)^1} + \frac{40{,}311{,}462(2)}{(1+0.25)^2} + \frac{40{,}311{,}462(3)}{(1+0.25)^3} + \frac{40{,}311{,}462(4)}{(1+0.25)^4} + \frac{40{,}311{,}462(5)}{(1+0.25)^5} + \frac{40{,}311{,}462(6)}{(1+0.25)^6} +$$
$$\frac{40{,}311{,}462(7)}{(1+0.25)^7} + \frac{40{,}311{,}462(8)}{(1+0.25)^8} + \frac{40{,}311{,}462(9)}{(1+0.25)^9} + \frac{40{,}311{,}462(10)}{(1+0.25)^{10}} + \frac{40{,}311{,}462(11)}{(1+0.25)^{11}} = 0$$

Which gives NCF(1) = EUR 115,145,766

References

1. http://www.nationmaster.com/country/za/Energy&b_define=1
2. http://www2.shell.com/home/nl-nl/html/iwgen/app_profile/nl-nl_hoeveelkost.html

Appendix 6-1 Planning CPD