

Project no.: 44336 – FP6-2005-SSP-5A

Project acronym: BIOPOL

Project title:  
**Assessment of BIOrefinery concepts and the implications for agricultural and forestry POLicy**

Instrument: **Specific Support Action**

Thematic Priority: Scientific Support to Policies (SSP)



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## Deliverable 1.3

**Technical, economic and ecological system assessments and market perspectives of biorefinery systems and platform chemicals**

Due date of deliverable: June 2008  
 Actual submission date: April 2009

Start date of project: 01.03.2007

Duration: 24 months

Organisation name of lead contractor for this deliverable: **Research Institute Biopos e.V., Germany**

Version: 1.4

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination level		
<b>PU</b>	Public	<b>X</b>
<b>PP</b>	Restricted to other programme participants (including the Commission Services)	
<b>RE</b>	Restricted to a group specified by the consortium (including the Commission Services)	
<b>CO</b>	Confidential, only for members of the consortium (including the Commission Services)	

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# 1. Introduction

A description of the general biorefinery concepts, consisting of a chain of linked composing sub-processes for production of platform chemicals is represented in D.1.1.1. A data-base with key-data (efficiency, mass balance, energy input) for biorefinery processes (example Green biorefinery) was given in D.1.1.2.

The book „Biorefineries–Industrial Processes and Products. Status quo and Future Directions“ gives details about the biorefinery-systems in single articles (Kamm, 2005a, Kamm, 2007a).

## 2. Green Biorefinery – Technical and energetic assessment

Today green crops are primarily used as forage and a source of leafy vegetables. A process called wet-fractionation of green biomass, green crop fractionation, can be used for simultaneous manufacturing of both food and non-food items (Carlsson, 1994).

The power and heat energy requirements of a forage fractionation of a protein concentrate production system are within practical limits for large farms and dehydrating plants (Bruhn et al., 1978). Mechanical squeezing of the fresh crop results in an energy savings of 1.577 MJ per ton of crop input, equal to 52 % of the total energy input (Ricci et al., 1989). Three simplified systems of wet green crop fractionation, which are characterized by the direct use of green juice or deproteinized juice as feeding supplements for pigs or liquid fertilizer are described (Favati et al., 1989). Wet green crop fractionation involves an energy saving of 538 MJ per ton of fresh crop, equal to 17.7 % of the total energy input of crop drying (Ricci et al. 1989). Membrane filtration in comparison with conventional fractionation technology results in an energy saving of 370 MJ per ton of crop input, which corresponds to 14.8 % of the total energy input (Favati et al., 1989).

Via fractionation of green plants green biorefineries are able to process amounts in the range of a few tons of green crops per hour (farm scale process) to more than 100 tons per hour (industrial scale commercial process). The careful wet fractionation technology is used as first step (primary refinery) to isolate the ingredients in their natural form. Thus, the green crops (or humid organic wastes) are separated into a fiber-rich press cake and a nutrient-rich green juice. Beside cellulose and starch, the press cake contains valuable dyes and pigments, crude drugs and other organics. The green juice contains proteins, free amino acids, organic acids, dyes, enzymes, hormones, further organic substances, and minerals. In particular the application of biotechnological methods is predestined for conversion processes since the plant water can simultaneously be used for further treatments. In addition the pulping of lignin-cellulose composites are easier compared to lignocellulose-feedstock materials.

Starting from green juice the main focus is directed to products such as lactic acid and corresponding derivatives, amino acids, ethanol, and proteins.

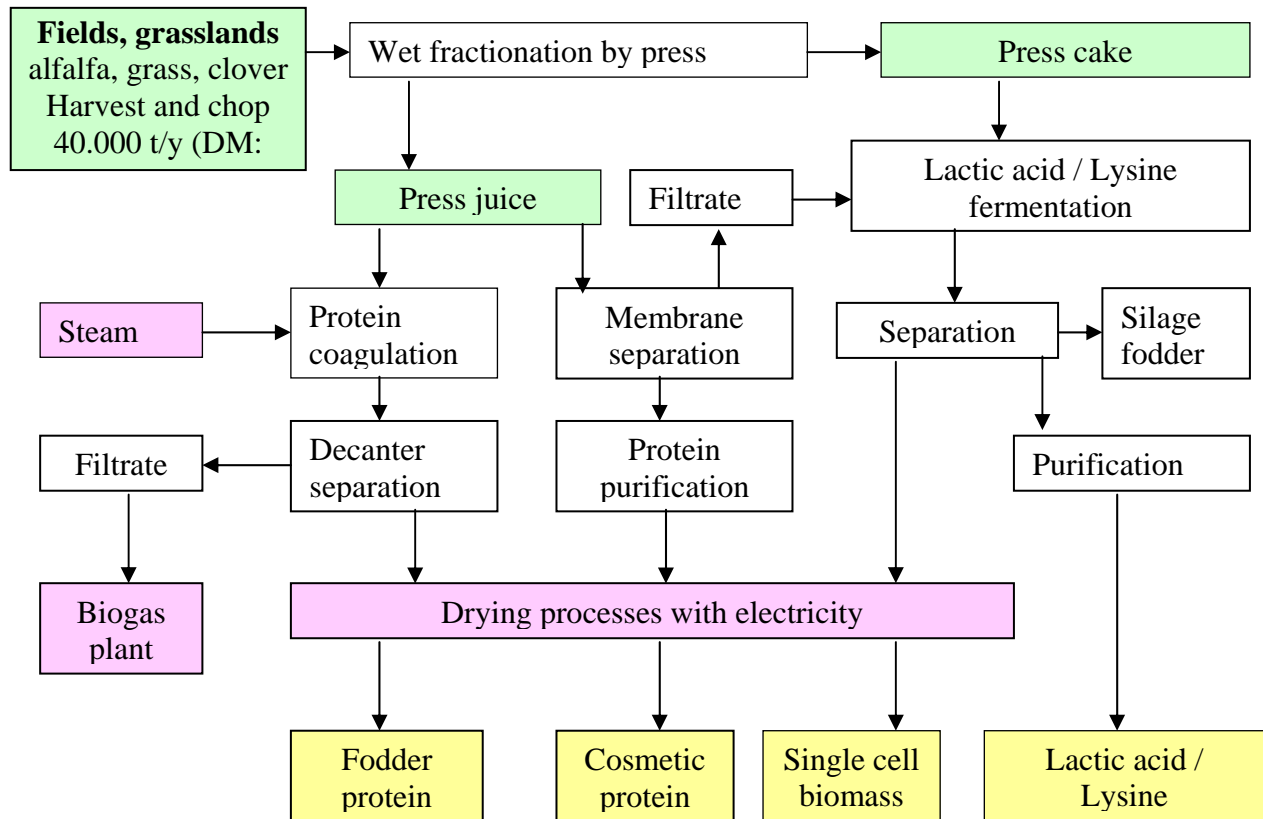
The press cake can be used for production of green feed pellets, as raw material for production of chemicals, such as levulinic acid, and for the conversion to syngas and hydrocarbons (synthetic biofuels).

The residues of substantial conversion are applicable for the production of biogas combined with generation of heat and electricity. Special attention is given in this communication to the mass and energy flows of the biorefining of green biomass.

### 2.1. Mass and Energy flows for combined production of platform chemicals lactic acide, lysine, cosmetic protein, single cell biomass, feed, and biogas

Green biorefining are described as an example of a typed agricultural factory in the green land rich area. Key figures are determined for mass and energy flow, feedstock and product quantities. Product quantities are variable with view on the market and demand of quality of products. Mass flows (Scenario 1, Scenario 2) result from own experimental results combined with market demand in the feed-, cosmetic-, and biotechnological- industry.

The technical and energetical considerations of the fractionation processes of a green biorefinery and the production of platform chemicals lactic acid and lysine show figure 1.



**Figure 1.** Selected and simplified processes of a Green Biorefinery.(Kamm et al, 2009).

Using a mechanical press about 20.000 t press juice (DM: 5%) can be manufactured from 40.000 t biomass. First the juice is the raw material for further products; and second the green cutting biomass contains much less moisture.

Through the fractionation of the green juice proteins in different separation and drying processes high quality fodder proteins and proteins for the cosmetic industry can be produced (Bruhn et al., 1978); (Bohlmann, 2002); (Reismann, 1988). The fodder proteins would be a complete substitute for soy proteins. They even have a nutritionally physiologic advantage due to its special amino acids pattern (Schwenke, 1998).

The utilization of the easily fermentable sugar in the biomass and the available water offers an excellent biotechnologically-chemical potential and makes the utilization of basic technologies possible (such as the production of lactic acid or lysine).

In the next step (fermentation) the carbohydrates of the juice and one part of the press cake can be used (after hydrolysis) for the production of lactic acid (scenario 1, (Kamm et al., 2006)) or lysine (scenario 2, (Thomson et al., 2004)). Thus single cell biomass is produced, which can be applied after appropriate drying as a fodder-protein. A fermentation auxiliary in lactic acid fermentation is sodium hydroxide. By means of ultrafiltration (Patel et al., 2006), reverse osmosis (Patel et al., 2006), bipolar electrodialysis (Kim & Moon, 2001); (Datta & Tsai, 1997) and distillation (Lavis, 1996) lactic acid (90 %) is recovered from sodium lactate fermentation broth. Lysine hydrochloride is the product of the lysine fermentation (Reismann, 1988). After

separation of the single cell biomass by ultrafiltration (Patel et al., 2006) and a membrane separation of water following by a drying process lysine hydrochloride (50%) is received (Thomsen et al., 2004).

The broth that is left after separation from lactic acid respectively lysine and single cell-biomass can be supplied to a biogas plant.

**Table 1.** Combined production of lactic acid, lysine, cosmetic-protein, single cell biomass, fodder, and biogas with energetic input (Kamm et al., 2009).

**Green Biorefinery**

input:

Green biomass (Lucerne, Clover, Grass)

Steam

Electricity

**scenario 1:**

**Lactic acid**

	quantity	unit
DM: 20 %	40.000	t
	2.268	GJ
	1,3 Mio	kWh

output:

Silage fodder

Fodder-Protein 80 %

Cosmetic-Protein 90 %

Lactic acid 90 %

Residue to Biogas plant TS: 2 %

Single cell-Biomass

(as Fodder-Protein 60 %)

DM: 40 %

DM: 90 %

DM: 90 %

DM: 90 %

DM: 90 %

	13.000	t
	400	t
	29,6	t
	660	t
	17.690	t
	33	t

**Green Biorefinery**

input:

cut Green Biomass (Lucerne, Clover, Grass)

Steam

Electricity

**scenario 2:**

**Lysine**

	quantity	unit
DM: 20 %	40.000	t
	2268	GJ
	0,492 Mio	kWh

output:

Silage fodder

Fodder-Protein 80 %

Cosmetic-Protein 90 %

Lysine-HCl, 50%

Residue to Biogas plant DM: 2%

Single cell-Biomass

(as Fodder-Protein 60 %)

DM: 40 %

DM: 90 %

DM: 90 %

DM: 90 %

DM: 90 %

	13.000	t
	400	t
	29,6	t
	620	t
	17.770	t
	31	t

Input and output data including required energy were estimated for the production of lysine-hydrochloride, lactic acid, proteins for fodder and cosmetics and the utilization of the residue (press cake) as silage fodder from 40.000 t green cutting biomass (Table 1).

By drying, the press cake could be manufactured to fodder-pellets. However, this drying is energetically very expensive. From an energetical point of view it is far better to suggest the press cake as a silage-feed. From an ecological and economical consideration at this point it has to be concluded that a coupling of green biorefineries and green crop drying industry is necessary.

## 2.2 Assessment of green crop fractionation processes

In a Green Biorefinery different kinds of energy (steam and electricity) are used for the treatment of press cake and press juice (intermediate products) to produce valuable end products. It is also possible to use the press cake together with the press juice as a carbohydrate source for the fermentation. For the separate processes mass balances were set up and thus the consumption of energy can be calculated by means of power consumption of the facilities (plants and machinery).

A linear programming model used to optimize the profitability and determine an optimized planning process for biorefineries is described (Annetts & Audsley, 2003). The raw materials are wheat (straw and grain) and rape and therefore this would be a model for a "Whole Crop Biorefinery" and hardly applicable for a "Green Biorefinery".

At a capacity of 40.000 t/a fresh biomass (lucerne, wild-mixed-grass) and a campaign-operation at 200 working days per year, averaged 200 t are converted per day.

Under these conditions the used screw extrusion press has an energy consumption of 135.000 kWh/a. It generates 100 t/d press cake with DM ~ 35% and 100 t/d press juice with DM~5%.

10 t of the 100 t press juice are fed into a membrane-separation for a cosmetic-protein-extraction. For separation of feed protein, 90 t press juice are put into a steam-coagulation. The required heat quantity as steam is 2268 GJ/a. The freshly pressed juice is preheated up to 45°C in a heat exchanger within a counter current process. Via steaming, a temperature rise up to 30 K is reached for the freshly pressed juice. The steam coagulation occurs at a temperature of 75°C. These calculations are carried out acc. (Bruhn et al., 1978). For the separation of feeding proteins the following energy input is required: 1.500 kWh/a for skimming, 15.000 kWh/a for dehydration to approx. 50% DM and 32.000 kWh/a for drying up to DM = 90%. The separation of the cosmetic-proteins via ultra filtration needs an energy input of 9.700 kWh/a. For the following solvent extraction, a further energy input of about 507 kWh/a is generated via stirring, acc. (Petrides et al., 1989).

For the separation via centrifugation 101 kWh/a (Bohlmann, 2002) are required and 2.360 kWh/a for the subsequent spray-drying to DM = 90%, acc. (Bartholomew & Reismann, 1979). If the press-juice contains 2% proteins, 400 t feed proteins as protein concentrate and 29,6 t cosmetic proteins can be produced per year. Proportionately increasing quantities can be produced if the press juice contains a higher share in proteins

After protein-separation 100 t fermentation-broth (respectively 96,6 m<sup>3</sup> at a density of~ 1,035 kg/l) are available per working day. The energy input during fermentation via stirring, amounts 150.000 kWh/a, acc. (Thomsen et al., 2004).

For the lactic-acid fermentation NaOH is added as a base resulting in sodium lactate. The purification of lactic acid occurs within the following steps and corresponding energy yields, ultra filtration: 97.000 kWh/a, and reverse osmosis: 171.000 kWh/a, acc. (Patel et al., 2006) as well as bipolar electro dialysis: 660.000 kWh/a acc. (Kim & Moon, 2001).

The bipolar electro dialysis is extra energy-intensive. Subsequently the lactic acid solution (45 %) is concentrated up to a 90 % lactic acid via vacuum distillation. The energy consumption for this single-stage distillation will amount 26.400 kWh/a, acc. (Lavis, 1996). The energy consumption for 660 t of 90% lactic-acid amounts 1.104 MWh/a using this procedural method.

If the lysine fermentation is chosen instead of lactic acid, ultra filtration and reverse osmosis are required for purification with the following corresponding energy-yields, ultra filtration 97.000 kWh/a, and reverse osmosis: 171.000 kWh/a, acc. (Patel et al., 2006). Afterwards the lysine-hydrochloride is dried to a DM = 90 % with an energy amount of 49.000 kWh/a (Annets & Audley, 2003). The energy consumption of 620 t lysine-hydrochloride using that method results in 296.000 kWh/a .

In a biorefining plant processing 40.000 t green biomass for the combined production of 660 t lactic acid, 29,6 t cosmetic-protein, 33 t single cell biomass, 400 t fodder-protein, 13.000 t silage fodder and 17.690 t liquid residues for biogas production the following energy input is required: 2.268 GJ heat, and 1,3 Mio kWh electricity. The combined production of 620 t lysine, 29,6 t cosmetic-protein, 31 t single cell biomass, 400 t fodder-protein, 13.000 t silage fodder and 17.700 t liquid residues to produce biogas requires the following energy input: 2.268 GJ heat, and 0,492 Mio kWh electricity.

These results clearly demonstrate the quantity of products a Green Biorefinery can provide by the help of biotechnology and the corresponding required energy input.

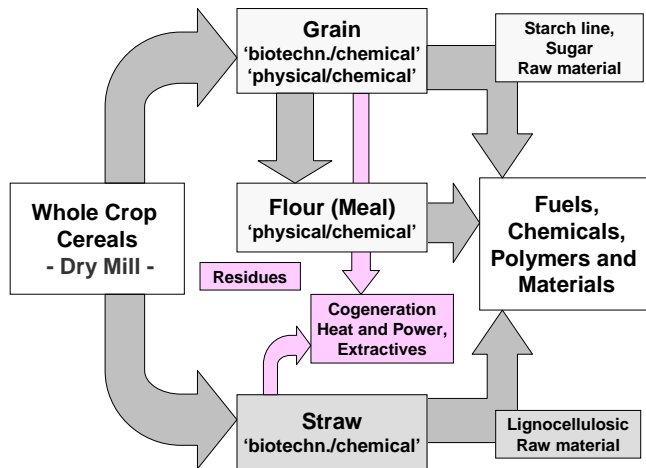
The economic benefit of biorefining Green Biomass are the high yields of biomass per hectare and year and synergetic effects via combination with established production processes in agriculture and feed industry.

Therefore in intermediate-term it is certainly reasonable to combine the economic potential of green agriculture and green-property-drying-plants.

These data of quantity, quality and required process energy are a foundation for further economic considerations in connection with calculation of the break-even point to plan and establish a Green Biorefinery. In future the energy input will be further reduced due to optimization of the corresponding Biorefinery technology. The combination of biotechnological and chemical conversion processes will be a very important aspect for decreasing of process energy input. Thus could be the biotechnological production of aminium lactates as start material for high purity lactic acid and poly(lactic acid) a new approach (Kamm et al., 2006).

### 3. Whole crop Biorefinery – Technical and energetic assessment

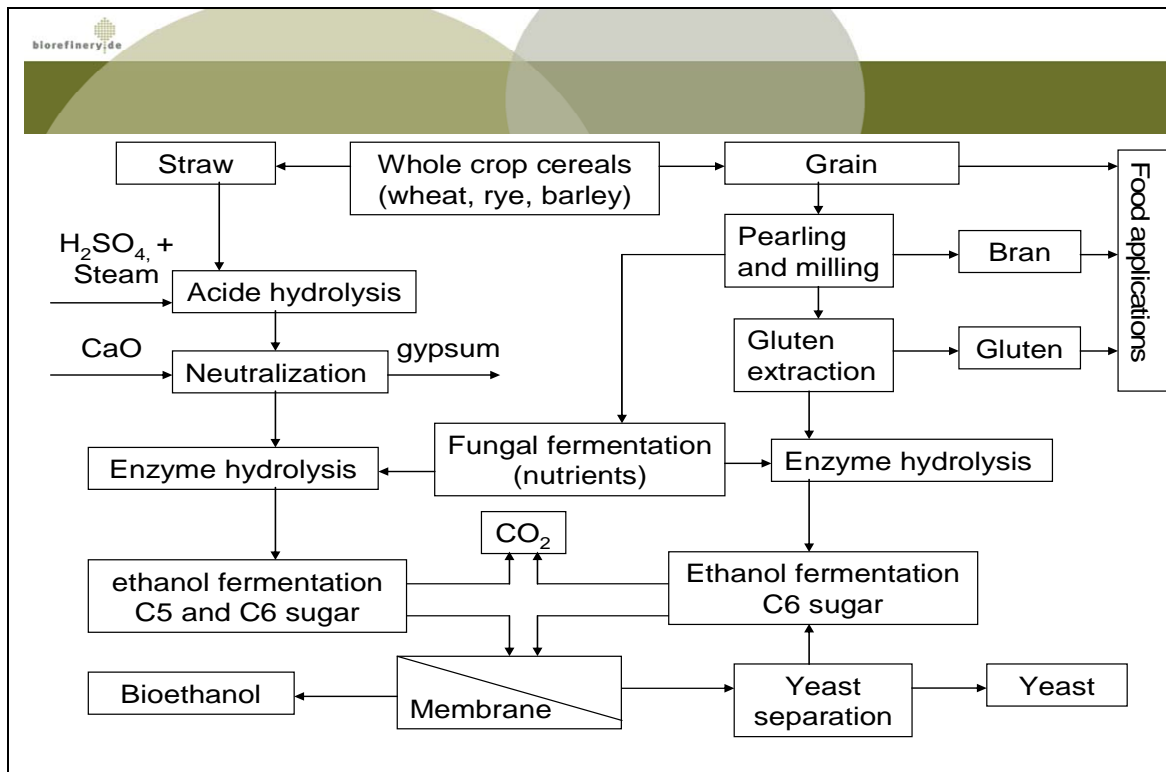
Raw materials for the 'Whole Crop Biorefinery' are cereals, such as rye, wheat, triticale and maize (Figure 2). The first step is their mechanical separation into grain and straw, where the portion of grain is approximately 1 and the portion of straw is 1,1-1,3. Straw is a mixture of chaff, nodes, ears and leaves. The straw represents an LC-Feedstock and may be further processed in an LCF biorefinery system.



**Figure 2.** Whole Crop biorefinery – based on dry milling, (Kamm et al., 2006)

The corn may either be converted into starch or directly used after grinding into meal. Further processing may be carried out in the directions of Fungal fermentations which conducted by pearled wheat flour suspension. Whole wheat grains were pearled remove to 3% of the kernel mass. Pearled wheat was then milled to produce pearled wheat flour using a hammer mill. Flour for the production of bran-free (endosperm-rich) wheat hydrolysate were produced by milling pearled wheat (Figure 3).

Pearled wheat flour suspensions were used as a media in fungal fermentations. Afterwards the solids from fungal fermentation are given to fungal cell autolysis and produce an autolysate (Arifeen et al. 2007).



**Figure 3.** Combined using of corn and straw for production of food and ethanol Arifeen et al. (2007).

**Table 2.** Analysis of Biorefining of grain.

**Biorefining of grain**

**Ethanol input:**

Electrical power  
steam  
Grain  
Water

	unit	Flour quantity
11.16 Mio	kWh	n.b.
339 715	t	n.b.
121 400	t	121 400
73 652	t	73 652

**output:**

pure ethanol  
Ethanol (96%)  
CO<sub>2</sub>  
Bran rich pearlins  
glutene  
Yeast  
Nutrients for „straw-ethanol“

	unit	Flour
37 877	t	96 710
39 455	t	
36 183	t	-
3 642	t	3 642
14 753	t	14 753
16 417	t	-
6 295	t	6 295

In our calculation these nutrients are used for fermentation of sugars produced from straw.

Initial separation from straw is possible into cellulose, hemicellulose and lignin. The process used in this analysis is co-current dilute acid prehydrolysis of the lignocellulosic biomass with simultaneous enzymatic saccharification of the remaining cellulose and co-fermentation of the resulting glucose and xylose to ethanol. In addition to these operations, the process involves feedstock handling and storage, product purification, wastewater treatment, enzyme production, lignin combustion, product storage, and other utilities. The feedstock, in this case corn stover, is delivered to the feed handling (A100) area for storage and size reduction. From there, the biomass is conveyed to pre-treatment and conditioning (A200). In this area, the biomass is treated with dilute sulphuric acid at a high temperature for a very short time, liberating the hemicellulose sugars and other compounds. Ion exchange and overliming is required to remove compounds liberating in the pre-treatment that will be toxic to the fermentation organism. Only the liquid portion of the hydrolysis stream is conditioned.

Simultaneous saccharification and co-fermentation, or SSCF, of the hydrolyzate slurry is carried out. Glucose and xylose will have been converted to ethanol. Product recovery consists of a rectification column to distill the ethanol from the majority of the water and residual solids.,

Biogas is produced by anaerobic digestion of organic compounds in wastewater treatment. The treated water is considered suitable for recycling and is returned to the process, so there is no water discharge from the process.

The solids from distillation and biogas from anaerobic digestion are combusted in a fluidized bed combustor, to produce steam for process heat. Soluble components are combusted. The majority of the steam demand is for the pre-treatment and distillation areas. Generally, the process produces excess steam that is converted to electricity for use in the plant; any excess electricity is sold to the local power grid (basic reference: McAloon A. et al.), Table 3.

**Table 3.** Analysis of biorefining of straw by using of nutrients from corn.

<b>Input</b>	<b>quantity</b>	<b>unit</b>
<b>Straw feedstock (95% DM)</b>	320 000.00	t
Sulfuric acid (concentr.)	11 170.28	t
Lime	2 934.86	t
Ammonia	4 724.57	t
Grain-nutrients from Fungal fermentation	6 294.86	t
<b>Auxiliary supplies</b>		
Ammonium sulfate	1 083.43	t
Antifoam	726.86	t
Process water	689 334.85	t
<b>Energy</b>		
Diesel	1 467.43	t
Electrical power	63 284.57	MWh

<b>Output</b>		
Ethanol 96%ig	63 992.85	t
CO <sub>2</sub>	58 686.94	t
Minerals	9 497.14	t
Lignin	96 168.00	t
Gypsum	17 239.00	t

Futhermore is considered the production of ethylene from both 'straw'- ethanol and 'corn-ethanol' (Table 4).

**Table 4.** Analysis of ethylene production from ethanol.

<b>Ethylene production</b>	<b>Input</b>	
	„straw-Ethanol“ 96%ig	63 993 t
	„grain-Ethanol“ 96%ig	39 455 t
	energy	55 418 MWh (34282+21136)
	<b>Output</b>	
	Ethylene	62 970 t (38953t+24017t)
	Water	40 477 t (25040t + 15437t)

## 4. Parameters to evaluate today's and future potential for different types of biorefineries

With our 10 years experience in developing Biorefinery concepts we have tried to estimate the potential of development for these three key data from current status (today) to nearly mature status (future). The figures say nothing about break-even point and economic feasibility.

(integrated biorefineries, phase 3 biorefineries):

There are three types of biorefineries:

1. Green Biorefinery
2. LCF Biorefinery
3. Whole crop Biorefinery

1. Green Biorefinery	1	2	3	4	5
Technical maturity (today)		x			
Technological improvement potential			x		
Cost reduction potential			x		
Research effort (demand)				x	
Efficiency increase	10 %				
Product yield	5 %				
Investment cost reduction	20 %				

2. LCF Biorefinery	1	2	3	4	5
Technical maturity (today)	x				
Technological improvement potential				x	
Cost reduction potential			x		
Research effort (demand)					x
Efficiency increase	20 %				
Product yield	20 %				
Investment cost reduction	10-30 %				

3. Whole crop Biorefinery	1	2	3	4	5
Technical maturity (today)		x			
Technological improvement potential			x		
Cost reduction potential			x		
Research effort (demand)				x	
Efficiency increase	10%				
Product yield	10%				
Investment cost reduction	5%				

## 5. Current status of industrial implementation of biorefinery plants and biobased products

### 5.1. The concept of platform chemicals and product family trees

Whereas functional products from renewable resources (fibre composite materials, starch-following products, protein-following products) today already at the market (Peters, 2005, Clark & Deswarte, 2008), current chemical research is focused on the production of platform chemicals and synthesis gas in order to design consistently structured compounds in the system of chemical building blocks (Kamm, 2007a, Clark & Deswarte 2008).

The US Department of Energy submitted a list of 12 potential biobased platform chemicals obtained by screening of around 300 substances. Selection criteria were biomass precursors (carbohydrates, lignin, fats and proteins), process platforms, building blocks, secondary chemicals, intermediates, products and final application (US Department of Energy, 2004).

All of the products from the petrochemical industry are derived from 8-9 foundation chemicals. An iterative review process was established which used chemical and market production data, estimates of the material and performance properties of the potential candidates and over 75 years of cumulative industry experience of the research team as the basis for the down selection. From the initial list of over 300, the team systematically down selected to a smaller list using factors that are important components of the strategic criteria shown in table 1. The screening criteria for this first round included the raw material and estimated processing costs, estimated selling price, the technical complexity associated with the best available processing pathway and the market potential for each of the candidate building blocks.

Almost 50 potential building block candidates resulted from this initial screening.

Continuing to use the strategic fit criteria (direct replacement, novel properties, and potential utility as a building block intermediate) shown in Table 5, the team organized the 50 candidates using a carbon number classification framework of one six carbon compounds (C1 to C6).

Next the team reviewed the candidate group for chemical functionality and potential use. Chemical functionality can be based on the number of potential derivatives that can be synthesized in chemical and biological transformations. Simply, a candidate with one functional group will have a limited potential for derivatives where candidate molecules with multiple functional groups will have a much larger potential for derivatives and new families of useful molecules.

Each candidate molecule was then classified for its current utility to serve as a simple intermediate in traditional chemical processing, as a reagent molecule for adding functionality to hydrocarbons, or as byproducts from petrochemical syntheses. Examples of candidates that fell into this category included acetic acid, acetic anhydride, or acetone.

**Table 5.** Biorefinery Strategic Fit Criteria (US Department of Energy, 2004).

	Direct Product Replacement	Novel Products	Building Block Intermediates
Characteristics	Competes directly against existing products and chemicals derived from petroleum	Possesses new and improved properties for replacement of existing functionality or new applications	Provide basis of a diverse portfolio of products from a single intermediate
Examples	Acrylic acid obtained from either propylene or lactic acid	Polylactic acid (glucose via lactic acid is sole viable source)	Succinic, levulinic, glutamic acids, glycerol, syngas
Upside	<ul style="list-style-type: none"> <li>• Markets already exist</li> <li>• Understanding cost structures and growth potential</li> <li>• Substantial reduction in market risk</li> </ul>	<ul style="list-style-type: none"> <li>• Novel products with unique properties hence cost issues less important</li> <li>• No competitive petrochemical routes</li> <li>• Differentiation usually based on desired performance</li> <li>• New market opportunities</li> <li>• Most efficient use of properties inherent in biomass</li> </ul>	<ul style="list-style-type: none"> <li>• Product swing strategies can be employed to reduce market risks</li> <li>• Market potential is expanded</li> <li>• Capital investments can be spread across wider number of unit operations</li> <li>• Incorporates advantages of both replacement and novel products</li> </ul>
Downside	<ul style="list-style-type: none"> <li>• Strictly competing on cost</li> <li>• Competing against depreciated capital</li> <li>• Limited (green label) “market differentiation” for Biobased vs. petrochemical based sources</li> </ul>	<ul style="list-style-type: none"> <li>• Market nor clearly defined</li> <li>• Capital risk is high</li> <li>• Time to commercialization may be long</li> </ul>	

The team then reviewed the candidate group for potential status as a super commodity chemical. Super commodity chemicals are derived from building block chemicals or are coproducts in petrochemical refining. Although the ability of biomass to serve as a source of these compounds is real, the economic hurdles of large capital investments and low market price competitors would be difficult to overcome. Table 6 shows the results of this first screen classified by the carbon number taxonomy C1-C6.

**Table 6.** Top Candidates from the First Screen (US Department of Energy, 2004).

C #	Name	Projected or Known Use (Building block, reagent, intermediate)	Selected for top 30	Rationale
1	Formic Acid	Reagent	N	Very limited BB, use mostly for adding C1
1	Methanol	BB-limited	N	Super commodity from syngas
1	Carbon Monoxide (+ H <sub>2</sub> gives syngas)	BB	Y	
1	Carbon dioxide	Reagent	N	Thermodynamics barrier
2	Acetaldehyde	Intermediate	N	V. limited BB
2	Acetic acid & anhydride	Reagents and Intermediates	N	Limited BB, large commodity scale today from syngas. Adds C2
2	Ethanol	Fuel	N	Major use envisioned as fuel. Limited BB. Will become supercommodity.
2	Glycine	Reagent	N	V. limited BB. Few uses envisioned
2	Oxalic acid	Reagent	N	Used primarily as chelator and reagent
2	Ethylene glycol	BB & Product	N	Super commodity
2	Ethylene oxide	BB & Reagent	N	Super commodity
3	Alanine	Intermediate	N	V. limited BB. Few uses envisioned
3	Glycerol	BB	Y	
3	3-Hydroxypropionic acid	BB	Y	
3	Lactic acid	BB	Y	
3	Malonic acid	BB & Reagent	Y	
3	Serine	BB	Y	
3	Propionic acid	BB & Reagent	Y	
3	Acetone	Intermediate	N	Super commodity, byproduct from cumene to phenol synthesis
4	Acetoin	BB	Y	
4	Asparic acid	BB	Y	

(continued):

C #	Name	Projected or Known Use (Building block, reagent, intermediate)	Selected for top 30	Rationale
4	Butanol	Intermediate	N	Large commodity chemical, Not a good BB, but large intermediates market. No competitive advantages from biomass
4	Fumaric acid	BB	Y	
4	3-Hydroxybutyrolactone	BB	Y	
4	Malic acid	BB	Y	
4	Succinic acid	BB	Y	
4	Threonine	BB	Y	
5	Arabinitol	BB	Y	
5	Furfural	BB	Y	
5	Glutamic acid	BB	Y	
5	Glutaric acid	BB	N	V. limited market. Intermediates set of derivatives
5	Itacon acid	BB	Y	
5	Levulinic acid	BB	Y	
5	Proline	BB	N	Limited market. Intermediate set of derivatives
5	Xylitol	BB	Y	
5	Xylonic acid	BB	Y	
6	Aconitic acid	BB	Y	
6	Adipic acid	Intermediate	N	Super commodity.
6	Ascorbic acid	BB	N	Limited market. Intermediates set of derivatives.
6	Citric acid	BB	Y	
6	Fructose	BB	N	Other routes to the derivatives would be easier than from fructose
6	2,5 Furan dicarboxylic acid	BB	Y	
6	Glucaric acid	BB	Y	
6	Gluconic acid	BB	Y	
6	Kojic & Comeric acid	BB	N	V. limited market. Intermediate set of derivatives
6	Lysine	BB	Y	
6	Sorbitol	BB	Y	

BB = Building Block

By eliminating those that did not meet the criteria, a list of top 30 building block candidates was produced that

- 1) exhibited multiple functionalities suitable for further conversion as derivatives or molecular families,
- 2) could be produced from both lignocellulosics and starch,
- 3) were C1-C6 monomers,
- 4) were not aromatics derived from lignin, and
- 5) were not already supercommodity chemicals.

These are shown in Table 7.

**Table 7.** Down Selection – Top 30 Results (US Department of Energy, 2004).

Carbon Number	Potential Top 30 candidates
1	Carbon monoxide & hydrogen (syngas)
2	None
3	Glycerol, 3 hydroxypropionic acid, lactic acid, malonic acid, propionic acid, serine
4	Acetoin, aspartic acid, fumaric acid, 3-hydroxybutyrolactone, malic acid, succinic acid, threonine
5	Arabinitol, furfural, glutamic acid, itaconic acid, levulinic acid, praline, xylitol, xylonic acid
6	Aconitic acid, citric acid, 2,5 furan dicarboxylic acid, glucaric acid, lysine, levoglucosan, sorbitol

Of note, C2 compounds such as acetic acid and acetic anhydride, were considered to have lower potential and C3 compounds such as acetone which is already a petrochemical byproduct were not included.

Conversion of biomass feedstock into liquid or gas could be one way of using existing infrastructure (developed pipe network), but with the disadvantages of the need to remove hetero-atoms (O,N,S) and minerals present in the biomass and the highly endothermic nature of the syngas process. Currently, production of simple alcohols, aldehydes, mixed alcohols, and Fischer-Tropsch liquids from biomass is not economically viable and additional developments are required (Kamm et al. 2007a).

## 5.2 Recent industrial production and markets of platform chemicals, final products

Industrial activities in the USA have the focus on the realization of the already mentioned cellulose-ethanol-plants. So first pilot plants with dynamic research- and development were realized in Jennings, Louisiana and a 1, 4 m gallon demonstration plant is under construction at the same place. The main raw material in Louisiana is cellulosic bagasse (Howe, 2007). The industrial activities of the chemical industry are concentrated in Joint Ventures with the agro-industry on the raw material grain of maize, whereby the research- and development capacities are focussed on the conversion of Cellulose-raw materials. Thereby the fabrication of new products with new characteristics, like in case of biodegradable polyester polylactid, as well as the entry in the production of conventional polyester-building blocks (on basis of

propanediol) or conventional polyethylene (on basis of ethanol) are industrial ways (Kamm 2007 b).

**Table 8.** Examples of industrial production of platform-chemicals and final products (Kamm 2007 b).

Plant	Company	Place	Production capacity (tons/year)	Products	Final application	State of affairs
(1) platform chemical	DuPont/ Tate & Lyle	Loudon, Tennessee USA	45.000	1,3 Propanediol	clothes, cover fabrics, resins	initiation 2007
(2) platform chemical and biodegradable polymer	CARGILL-DOW Natureworks	Blair, Nebraska, USA	200.000 140.000	Lactic acid polylactid (PLA)	packages, films, bins	initiation 2003 2002
(3) platform chemical and polyolefin	Crystalsev Dow	Brazil	350.000	ethanol ethylene polyethylene	pipe systems, cables, pilotages, automobiles	initiation 2011

Furthermore there were established programmes in education and science, like new study paths, e.g. degree course Biorenewables (Master and PhD-programmes) at American universities since 2001 (Iowa State University, 2007). The courses (lectures, seminars, practical course and communication) contain,

- the plant physiology, plant production, processes, harvesting technologies and logistics of raw materials
- production of chemicals and materials
- conversion processes of biotechnology and chemistry
- production of biomass fuels
- production of biomass energy
- biorefinery-system research

In particular against the background of educational tasks of the US-American states, five years ago the Sun-Grant initiative was initiated. It is necessary to establish networks between the universities, further research- and educational institutions with companies of the region, like in the plant production and technology companies as well as of public authorities, to develop the a wide comprehension and the necessary knowledge for a Biobased economy (Nipp, 2006).

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