The Green Biorefinery Austria – Development of an Integrated System for Green Biomass Utilization

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A Green Biorefinery is a concept to utilize green (grassland) biomass as raw material for the production of biobased products like proteins, lactic acids, fibres and energy (via biogas). The exploitation of grassland might have intriguing side effects like the conservation of cultural landscapes and the improvement of the "stay option" of farmers. Since 1999 comprehensive research starting from the raw material up to product formulation and development is carried out in Austria. However, in contrast to the centralized Biorefinery concepts in Europe, the Austrian Green Biorefinery focuses on a decentralized system based on grass-silage. Silage is rich in lactic acid and storage is organized decentralized. During the last years different green biomass and silage were analyzed. As a next step fractionation was carried out and trials for product separation took place. This work led to an integrated system elaboration of the Biorefinery concept. For economic assessment mass and energy balances were taken as the basis and a biogas plant has been considered as benchmark.[5,9,12] However, due to permanent adoption of the economic models only current trends of economic assessment are summarized in this paper. With lactic acid and amino acids (proteins) as key products from silage the results support the assumption that Biorefineries can be viable and sustainable development efforts in rural regions are supported in Austria. This paper provides a condensed overview on research results of the last four years.

Keywords:
Green biorefinery, biomass, grassland, silage, proteins, lactic acids, grass fibres, sustainability

Introduction

Products based on Renewable Resources are supposed to become an important substitute for petrol based goods within the next two decades. Globally, there is still a large discrepancy between the estimated annually growing biomass and the actually utilizable biomass for the non-food sector.[1] Most of the exploited renewable resources – except timber – are dependent on *intense* agriculture as well as on relatively *limited* space for their cultivation, especially in Europe. Examples are corn and sugar beet for the production of ethanol or other biobased chemicals, rape to generate "biodiesel" or hemp for fibre utilization. Contrary, grassland pasture is extensively available by providing high yields in Europe. Additionally, grassland can be cultivated in a sustainable way.

A Green Biorefinery is therefore an integrated concept to utilize green biomass as an abundant and versatile raw material for the manufacture of industrial products. This concept is currently in an advanced stage of development in several European countries, especially Germany, Denmark, Switzerland, The Netherlands and Austria.[2–4, 5] The basic idea of this concept is to utilize the whole green biomass like grass, alfalfa and various other sources, and generate a variety of products that are either valuable products themselves or form the basis for further production lines. Besides biobased materials, energy (via biogas generation) may be supplied by this technology. The exploitation of grassland pasture might have intriguing side effects like the conservation and improvement of cultural land-

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scapes or the improvement of the so called "stay option" of farmers. Thus the Green Biorefinery offers not only a very high economic potential, but probably supports sustainable development efforts, especially in rural regions. Green Biorefineries could therefore significantly contribute to a sustainable development of the Bio-Industry sector.

The Green Biorefinery Austria

The impact on regional development that emanates from this technological concept is two fold. (1) On the one hand the Green Biorefinery helps to stabilise current green land, that besides its economical value serves many important purposes, like keeping the landscapes open and attractive and regulating the water balance. Many other economic factors of regional development, like tourism, depend on intact and attractive landscapes and will be detrimentally affected if green land is reduced due to economic pressures on agriculture. (2) On the other hand the Green Biorefinery has direct impact on the economic structure of rural regions. The decentralised nature of the raw material generation for the Green Biorefinery calls for decentralising at least certain steps of the utilisation of the resource green biomass. This will generate jobs in rural areas thus considerably reinforcing the economic structure of these regions as well as raising the skills of the workforce in these regions as operating this technology needs up-to-date technical knowledge especially in the field of chemical engineering.

Due to the restructuring of the European agriculture and the possible reduction of the milk quota huge amounts of forage-grassland could be spare within the next years. Estimations of Experts stress that the available grassland-biomass could amount to 500,000 to 1,000,000 tons dry matter a year only in Austria in future (about 2.5 to 5 mio. t/a fresh matter).[6] Thus the "grassland industry" could be second behind the timber industry in the non-food sector based on Renewable Resources. In case of not utilizing the grassland, pasture in the cultural landscape would diminish significantly.

To ensure a decentralized system, a key element in the Austrian concept is the utilization of fermented grass (Grass Silage) instead of fresh biomass. This ensures year round availability of the raw material and farmers could be more integrated by running the silos respectively provide the system with mobile equipment as it is already very common in classical agriculture or waste management.

However, the development of the Austrian Green Biorefinery follows 10 ambitious principles: (1) utilization of grassland (Silage), (2) integration of agricultural residues, (3) whole crop utilization and generation of biobased materials and energy, (4) establishment of a multi product system based on sustainable technologies, (5) integrated production of process energy via biogas or biomass combustion, (7) sustainable land cultivation, (8) protection of the cultural landscape, (9) fair income for farmers (social sustainability), and (10) economically viable system.

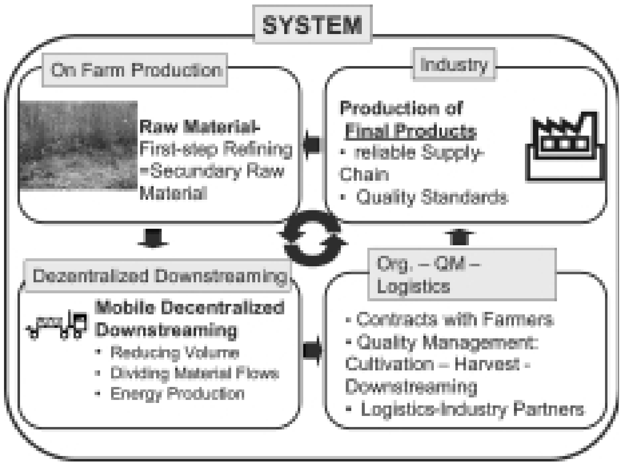


Fig. 1 – *Green Biorefinery System Austria with on Farm Production, Decentralized Down-streaming, Organization of the Supply Chain and industrial Production of final Products (BioRefSYS®-BioRefinery Systems)*

Basic technology and products from a Green Biorefinery

Since 1999 the technological aspects of the Austrian Green Biorefinery are developed within a broad interdisciplinary network of scientists, engineers, farmers and the industry.[7] The first step included the identification of interesting products which can be exploited from the grassland biomass in a feasible way. The second step which started in 2000 included the on field production of the Raw Material and the start of fractionation and Down streaming trials. The results should lead to the installation of a basic pilot plant in 2004. As Grassland biomass does not offer a specific major component, like sugar beet (sugar) or corn (starch), it is compelling to establish a multi product system.[5]

The most promising products which have been identified are:[5]

- Lactic Acid: for Neutralization/Buffering, as Solvent (ethyl lactate), Bio-Plastic (PLA = Polylactide)
- Proteins: as Feed or Food (low price), hydrolysed as Amino Acids for Cosmetics or Pharmaindustry
- Fibres: as Insulation Material, special Panels or Fleeces

– Speciality Products like Xanthophylls, Carotinoides, Chlorophyll, etc.
– Energy: Residues will be converted into biogas

For establishing such an integrated system the technology has been divided into six modules: (1) Raw-material supply chain (cultivation, harvest, ensiling, storage), (2) fractionation (into Juice and Presscake), (3) down-streaming of proteins resp. Amino Acids (AA), (4) down-streaming of Lactic Acid (LA), (5) preparation of grass-fibre products, and (6) biogas generation by fermentation of bio organic residues. However, current technology development elaborates integrated process units to combine module 3 and 4. Therefore, each grassland harvest is ensiled in clamp-silos after being inoculated with special starter bacteria which are supposed to enhance Lactic Acid fermentation in the Silo.[7] After at least two to three weeks of fermentation a mobile fractionation (pressing) system will call at the farm to divide the Secondary Raw Material into a liquid and a solid stream. Parts of the stream could undergo Downstream-processing or being utilized in the biogas plant for energy production directly on the farm. The silage juice (clarified or/and concentrated) could be transported to a centralized industrial site for further Down streaming respectively product upgrading.

Production of proteins, lactic acid and fibres

The best known product which can be obtained from grassland-biomass are Proteins. Protein fractions from fresh alfalfa could be isolated already in 1773.[8] The major disadvantage of the production of Proteins from fresh green biomass is the dependency on the vegetation period (May to October) each year (harvest campaign). In contrast, through the concept of ensiling the green biomass and utilizing the silage continuous production can be ensured over the whole year. The structure (Proteins, Peptides, free Amino Acids), the necessary Downstream-Technologies and the product upgrading have been elaborated in two important projects.[5,9] Fresh Green Biomass with medium to high protein content – up to 20 % crude protein in dry matter – (Clover/Grass, Ryegrass, Permanent Pasture, Alfalfa and Cocksfoot) had been harvested for the experiments in the years 2001 and 2002. Both, fresh green matter and silage, inoculated with Lactic Acid bacteria, underwent cutting and pressing. So far two different screw presses with a capacity of up to 500 kg FM/h were used to produce Green and Silage Juices rich in crude protein.[5,9]

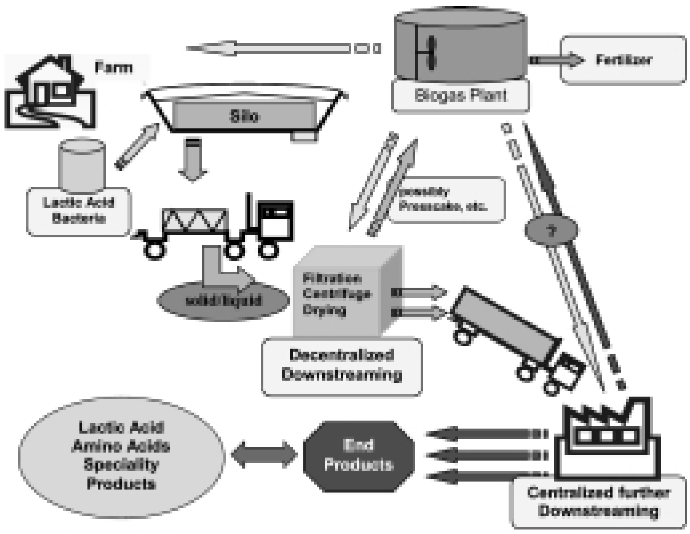


Fig. 2 – *Concept of a decentralized Green Biorefinery Austria based on Grass-Silage as Raw Material (BioRefSYS®-Bio-Refinery Systems)*

Analytical Methods for Green and Silage Juice

The crude protein content was determined using the Kjeldahl method. To convert the organic nitrogen, except ammonium, the factor 6.25 was used. The dry matter content was determined after drying at 105 °C for 12 h. After dry matter determination, the ash content was measured at 550 °C. The content of monosaccharides, disaccharides, organic acid and alcohols was determined by HPLC using a Polyspher OA KC column at 42 °C. The running isocratic eluent was 0.01 N H_2SO_4. The compounds were detected by an RI detector.

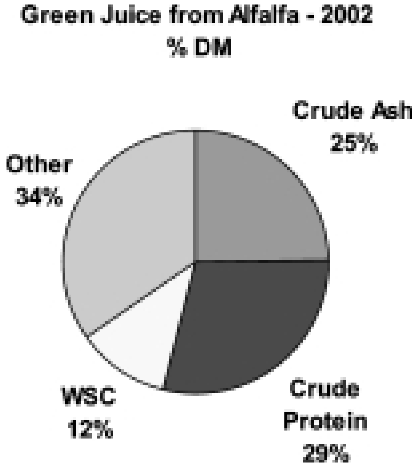
Green Juice and Silage Juice Composition

The typical composition of the dry matter of fresh Green Juices (GJ) from Bastardryegrass (*Lolium hybridum* Gumpenstein) and Alfalfa (M*edicago sativa*) is presented in Fig. 3 and Fig. 4.

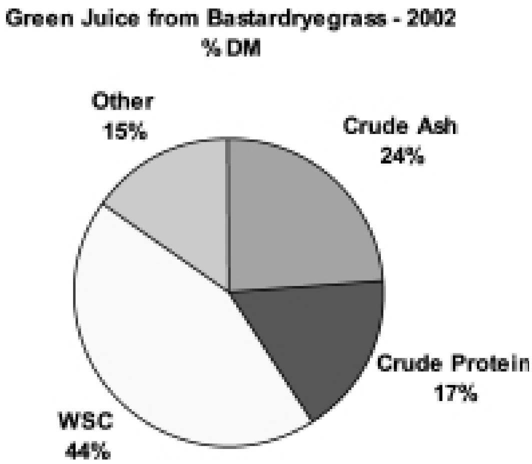
In comparison one Silage Juice of Bastardryegrass from the pressing period of 2002 is presented in Table 1.

Fractionation Balances of Green Grass-Biomass and Grass-Silage

In case of fresh matter the recovery rate of crude protein into the juice was about 20 % despite the variation of parameters, in both years. The recovery rate of silage proteins could be increased by 70 % to about 50 % in year 2002. However, the experiments showed that only part of the Crude Protein (CP) can be separated either by ultra-filtration or by standard coagulation/centrifugation. All green protein concentrates produced show similar characteristics. Regarding the classical process of coagulation/centrifugation comparisons with an operating



F i g . 3 – *Example of the composition in % of Dry Matter (DM) of the Green Juice from Alfalfa (pressed alfalfa / Medicago sativa) – Experiments 2002; (WSC = Water Soluble Carbohydrates)*



F i g . 4 – *Example of the composition in % of Dry Matter (DM) of the Green Juice from Bastardryegrass (pressed Ryegrass / Lolium hybridum Gumpenstein) – Experiments 2002; (WSC = Water Soluble Carbohydrates)*

T a b l e 1 – *Example of the composition of Silage Juice from Bastardryegrass Silage (pressed Ryegrass Silage / Lolium hybridum Gumpenstein) – Experiments 2002*

Dry Matter (DM) [%]	8,57
Ash [g l^{-1}]	23,84
Crude Protein [g l^{-1}]	28,78
Water Soluble Carbohydrates [g l^{-1}]	6,78
Lactic Acid [g l^{-1}]	30,52

plant in France[10] protein concentrates can only be produced by the utilization of the raw material Alfalfa efficiently.[9] Evidence was found that there exists a considerable gap between the so called "crude protein" and the protein accessible for separation by the mentioned technologies.[11] Especially in silage juices only 5 to 10 % of the proteins are peptides > 1.2 kD (~ 15 amino acids). Thus the yield of silage proteins were too low as to be separated by the suggested technologies economically. However, it was possible to yield high quality protein products out of green matter. Drying of such concentrates in a pilot-scale spray dryer could be managed without any major difficulties. Due to the retention time in the ultra filtration system concentrates produced by this technology showed increased contamination by pathogen microorganisms. All different liquid streams underwent comprehensive chemical analysis. The amino acid profile of the products shows a very high content of essential amino acids.[9] However, Silage Juices offer very high yields and an enormous potential of free amino acids available for separation by innovative technologies.[9]

The conformation of the silage proteins has major impacts on the isolation of Lactic Acid from the silage juice. Silages with about 10 % Lactic Acid in the dry matter were fractionated in 2001 and 2002. However, the generated Silage Juices contained about 25 to 36 % LA in the dry matter (2001 and 2002) with variation of sugar (WSC = Watersoluble Carbohydrates) and crude protein content. Therefore, the LA yields from the silage into the juice could be increased from a mean of 49 % in 2001 to about 80 % in 2002.[12] It is assumed that with an fractionation efficiency of 80 % the maximum has been reached. Thus, next steps will be to build up a pilot plant with continuous fractionation at this high level.

The high content of salts as well as sugars makes the separation steps of grass silage juice much more difficult than that of the fermentation broth of lactic acid, in which the sugar residue and salt content is quite low. Currently, comprehensive research is focusing on the down-streaming of Lactic Acid and Amino Acids in one integrated process chain offering attracting economic potential.[12,13] The process will apply nanofiltration, electrodialysis and chromatographic methods, which are not only crucial for the further development of the Green Biorefinery, but can be seen as sustainable key technologies in the whole renewable resources, bio-industry sector respectively.

In principle, grass fibres from a Green Biorefinery may be used as raw material for the following products: (1) Insulation material, (2) fibre boards, (3) products used in horticulture, erosion control etc., (4) biocomposites, (5) packaging material, (6) additives for building material, (7) gypsum boards, (8) pulp and paper, (9) bioenergy and (10) speciality feed for animals. However, technical grass fibres are not suited for textile applications.

Thus, the focus of further research should be on products utilizing the whole stem together with the leaves of grasses and/or legumes.

Economic assessment of different Green Biorefinery models

In case of Green Biorefineries the regional circumstances are of utmost importance by the appraisal of feasibility. Therefore, three most influencing parameters for economic evaluation besides classical investment calculation have been identified: (1) Raw material price including agricultural subsidies, (2) Logistics and Storage costs, (3) National policy regarding renewable energy (subsidies for electrical energy generation).[5] With this structure data of important benchmarks have been gathered.[5] Especially, the comparison with crude biogas plants with plant material as feedstock, were chosen for further evaluation. Based on data of the year 2002 different models for green biomass and silage biomass could be elaborated.[5] However, as technology is still in a medium stage of development final statements are not yet possible and the models are adopted to new research results permanently. Besides, in 2003 considerable changes of the subsidies for renewable energy have lead to a different picture of the absolute numbers.[9,12] However, the trends presented in this paper are still valid. Summarizing the models calculated,[5,9,12] which are based on the Austrian agricultural situation with its small scaled structure and almost no quota for forage grass pellets, it must be assumed that the production of a green protein concentrate based on fresh alfalfa or protein rich grasses is not feasible as well as the combination of green biomass, and silage biomass does not provide a positive outcome due to the different conformation of the juices especially of the proteins as described above. This holds not only for small decentralized units but also for size optimized plants by benefiting of "economy of scale". Contrary, due to the successful optimization of fractionation yields and considerable lower costs for logistics and storage the exclusive utilization of grass silage as raw material offers promising economical chances especially due to the application of integrated technology for the separation of amino acids and lactic acid.

Due to open technological questions the system is still subjected to economical risk. However, the cost structure shows sufficient capacity for the suggested downstream processing even by calculating a worst case scenario (Amino Acids at 1,5 Ykg product and 80 % conc. Lactic Acid 1,00 Ykg).[5,12] With upgrading the amino acid products average returns for amino acid products could amount up to 2,50 to 9,50 Ykg product or even higher and, therefore, offering huge economic potential. Due to relatively high costs for fibre drying it seems to be more feasible to utilize the wet press cake for biogas generation unless an ecological niche product made from grass fibres can be developed. A Biorefinery system based on silage juice combined with biogas generation from the residues (mainly press cake) suggests a modification of the decentralized system into an semi-decentralized system with a very large ("economy of scale") unit for silage juice conditioning with decentralized satellite like silage storage, fractionation and biogas units (up to 500 kW electrical capacity due to power subsidizing).[5,12] Such decentralized fractionation units could also provide process technologies for juice concentration (filtration/evaporation by heat of biogas combustion) to reduce transport volumes to the centralized plant. The complexity of these semi-decentralized structure demands for a new approach of Supply Chain and Quality Management as farmers will be integral part of this new bio-industry.

Conclusions

Complex Bio-Refinery Systems are therefore not only a challenge in regard to the technological questions (more than 15 partners work on different tasks) but also in regard to the organizational structure (combination of central and decentralized units) and the strong commitment to foster Sustainable development. Thus it is very important to integrate comprehensive environmental assessment into the development process.[14]

It seems to be clear that the Austrian Green Biorefinery project should further focus on grass silage and not fresh green biomass due to the outcome of the economic assessment.[5,9,12] Although there are still loose ends regarding down-stream processing of Amino Acids and Lactic Acid the fractionation unit should be erected as basis pilot plant to ensure high yields out of grass silage in a continuous system. After further technological development this pilot plant can be extended by process modules most likely membrane and chromatographic units for juice conditioning. Despite, the existent technological and economical risk optimism about the Austrian Green Biorefinery System is permitted for the following reasons: (1) the suggested technology can be seen as key-technology in the bio-industry field, (2) Amino Acids and Lactic Acid can be separated by integrated process units, and (3) the economical fancy for products developed from crude Amino Acids and Lactic Acid can be considered as very high.

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