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Utilisation of Grass for Production of Fibres, Protein and Energy

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UTILISATION OF GRASS FOR PRODUCTION OF FIBRES, PROTEIN AND ENERGY

Stefan Grass[1]

Abstract

Grassland has a number of well recognised, positive effects on the environment, *e.g.* groundwater protection, habitat for species, soil stabilisation and soil sanitation. It covers 70% of total Swiss agricultural land use. For utilisation of grass, a new process was developed, which converts grass to technical fibres, protein and energy. This process, using a *biorefinery* was developed and implemented by the Swiss Agency for Energy and the Swiss Agency for Environment, Forests and Landscape.

A first biorefinery started operation at the end of 2001 in Schaffhausen, Switzerland. The plant produced technical fibres and biogas, and had a throughput capacity of around 0.8 tonnes of dry matter per hour. Market introduction of the blow-in insulation product *2B Gratec*, made from grass fibres, was successful. Biogas was converted to power, which was marketed as the certified label product "Nature Made Star". However, the Schaffhausen installation was not economically viable and operation ceased in summer 2003. The technical concept is now being re-designed and directed to the production of insulation boards with a much higher market value compared to the "blow-in" insulation product. The production of boards can be realised in simple plants of small scale. Production of commercial boards for insulation purposes has been proved economically viable.

This paper addresses questions related to raw materials, processing, products and the economics of a biorefinery. The author has been appointed contact person by the Swiss Agency for Environment, Forests and Landscape.

Introduction to grassland and grass

Environmental benefits of grassland

Most people have very positive associations with grassland: leisure time, picnics, the gentle movement of the wind, mountain hikes, grazing cows, but, besides that, it is well known and documented that grassland offers a number of environmental benefits. The most important are:

- ***Groundwater protection****:* grass is a perennial crop and forms a dense root system throughout the year. This root system prevents leaching of nitrates and pesticides into the groundwater. (Nitrates and pesticides in groundwater are a concern for several drinking water wells in Switzerland.)

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- ***Habitat for species****:* grassland is inhabited by many different species, some of them belonging to the red list of endangered species. Survival and multiplication of some species depend on the availability of extensive grassland with a late first cut (semi-natural habitat).

- ***Stabilisation of soil, hills, and slopes****:* the perennial nature and the root system of grass act to stabilise soil systems. Soil erosion on cultivated crop land can cause soil losses. Soil stabilisation is also an important factor in preventing mud slides in mountain areas.

- ***Soil sanitation in crop rotation systems****:* grass and clover/grass-mixtures prevent build-up and proliferation of root diseases. In integrated production systems, grassland can reduce utilisation of pesticides.

Swiss policy decisions for the preservation of grassland

Grassland covers around 70% of the total Swiss agricultural production area. From this point of view, it is the most important agricultural crop. However, grass utilisation is decreasing in many European Union countries and regions, due to decreasing milk and beef production. Even small decreases in milk and beef production have a major effect on the economic value of grassland. In some areas, the rent for grassland has come very close to zero.

The Swiss government has taken a number of measures to preserve grassland and utilisation of grass. These measures include:

- Direct payments for maintenance of grassland. These payments depend on the level of production intensity: low-input systems receive compensation for reduced productivity.

- Specific support of mountain eco-systems and semi-natural habitats.

- Support of technology development for new uses of grass.

Properties of grass as an industrial raw material

Grass is composed of raw fibre (cellulose, 20-30% of dry matter), hemi-cellulose (15-25%), lignin (3-10%), protein (6-25%), fat and starch (1-2.5% each), ash (5-20%) and water-soluble extracts (20-55%). This composition defines the potential for creation of value added. The following fractions of grass are of particular interest:

- *Cell wall components* (cellulose, hemi-cellulose, and lignin): the basis of fibre products. Due to the low lignin content, wet grass fibres can be fibrillised without the addition of chemicals. Hydrolysis of cellulose and hemi-cellulose to monomeric sugars can be achieved with moderate levels of energy input and acid/enzyme addition.

- *Proteins:* grassland can yield more then 2 tonnes of dry matter of protein per hectare. This is about 50% higher compared to peas, beans or soya. The amino acid composition varies between clover and grass and is suitable for animal feed.

- *Water-soluble extracts:* these contain a considerable amount of sugars (*e.g*. glucose, fructose, galactose) and can be used as a full fermentation medium for the production of single-cell protein, lactic acid, ethanol, or biogas.

Grass is also subject to considerable raw material variation, which must be handled in an industrial process. Raw material variation is due to:

- The origin of the material: permanent pasture, grass sown in crop rotation systems, growing in a semi-natural habitat, or by the roadside.
- Growth stage of grass at harvest (*e.g.* full shooting, blossoming).
- The relative ratios of grass, clover and herbs in the harvested material.
- The species involved, level of fertilisation, type of soil, exposition to the sun, and many other factors.

The most relevant quality parameters are the content of raw fibre, protein and digestible energy. Depending on the origin, grass often contains considerable amounts of small branches, stones, sand and loam. It is very important to design a process which takes into account the probable quality of the raw material. Raw material quality standards must be established and strictly enforced.

Another critical parameter is grass storage. Favourable conditions for fibrillation are given at a moisture content <40% of dry matter. This is given with fresh or wilted grass as well as silaged grass. During buffer storage, carbohydrates contained in fresh grass degrade rapidly. This reduces significantly the energy production potential. Practical knowledge of grass silaging is widespread in the agricultural community.

The market price for grass

Since there is not much trade with fresh grass or silaged grass, there is no established market with a transparent price for this raw material. Agricultural research stations in many countries have conducted numerous calculations on the production cost of grass. But sometimes the production cost fails to reflect the market value of grass.

An established market does, however, exist for hay. In Germany, the hay price has decreased over the past few years and is today around EUR 70/tonne, including drying, baling and storage. Delivery of fresh grass requires less labour and should therefore be cheaper (based on dry matter content) than hay. The cost of grass silaging should not be higher than for hay because it allows more flexibility with respect to weather conditions.

Naturally, the cost of grass varies, due to agricultural policy, climatic conditions, the regional agricultural structure, the general cost of agricultural land and labour, and other reasons.

Price schemes for grass delivered to a technical processing plant (biorefinery) should be established with respect to the raw material characteristics required to achieve the expected end-product yield and quality parameters. This requires a thorough understanding of the relation between the raw material and the quality of the end product.

New products made from grass

Grass fibres

Grass fibres can be recovered at a length of 2-30 mm. Variation is due to raw material variation and process conditions. Grass fibres are suitable and competitive for short fibre applications. The following products can be made from grass fibres:

- Insulation products.

  - Insulation boards can be produced in a density range between 60 and 160 kg/m^3. The heat conductivity is 0.04-0.045 W/mK, depending on the density of the board. Resistance against fire and fungi can be achieved using additives. Advantages compared with mineral wool include the high specific heat capacity, which results in a 10-12 hours delayed release of outside heat to the inside and improved summer heat protection. Boards can be used for thermal insulation in ventilated facades and cavity masonry, steep-pitched roofs, over rafters and for sound insulation. Possible applications of grass-based insulation boards cover around 80% of all insulation applications.

  - Blow-in insulation is successful at a blow-in density of 55-60 kg/m^3. The heat conductivity is 0.04 W/mK. Resistance against fire and fungi can be achieved by using additives. Quality control must include settling properties. Blow-in insulation is an industrial standard in many countries and makes about 1.4% of the total insulation volume in Germany.

- Natural fibre re-enforced plastic: specifications include filling grade and mechanical properties.

- Paper: specifications include colour and mechanical properties.

- Combustion pellets: specifications include mechanical stability, levels of ash, nitrogen, and sulphur content and ash melting point. To reduce the ash content, low or medium-quality grass requires washing.

Grass protein

The value of grass as a ruminant feed is based on its raw protein content. Separation of the protein fraction from the cell wall components opens marketing opportunities for non-ruminants, *e.g.* pigs and hens.

Juice pressed from silaged grass has been fed successfully to pigs and piglets. A dried protein product from fresh grass contains around 40% raw protein, 10% raw fat and 15% raw ash, depending on raw material quality and processing conditions. The high methionine content of grass protein makes it particularly suited to laying hens. However, protein extraction and drying are significant cost factors.

Energy

For the production of energy from grass using biological conversion, two processes were developed:

- Conversion to ethanol using yeast. Common yeast only converts C6-sugars to ethanol – C5-sugars remain unused. Since raw material storage as silage results in conversion of C6-sugars into lactic acid, grass must be processed when it is fresh. Hydrolysis of the cellulose content, using heat and dilute acid or enzymes, can extend the C6-sugar basis to around 400 kg per tonne of dry matter. Using good-quality grass and an enzymatic hydrolysis process, an ethanol yield of 150-200 litres per tonne of dry matter (raw material) was achieved during a pilot scheme. This translates to an energy yield of 900-1 100 kWh (kilo watt-hours) per tonne of dry matter of grass. This yield could be increased by around 40% using a genetically modified yeast for conversion of C5-sugars. Ethanol can be used as an industrial raw material or as a liquid transportation fuel. However, the costs involved in an enzymatic hydrolysis process are considerable, and the price of ethanol is lower than the price of the fibre products discussed above.

- Conversion to biogas offers the advantage that all substrate components are consumed and no heat losses occur. The water-soluble fraction of good-quality grass yields 200-250 m^3 of biogas (or 1 200-1 500 kWh per tonne of dry grass matter). Utilisation of biogas includes combustion in a combined heat and power machine, as well as feeding into the natural gas distribution network or gas fuelling stations (after purification and compression).

The biorefinery – a new technology concept for whole crop utilisation

General concept of a biorefinery

A biorefinery is a technical concept for whole crop utilisation. It applies fractionation to separate different fractions from the raw material, thereby optimising the value added. It is suited to processing large quantities of raw materials and to supplying volume markets, so it can be a land-use option. No chemicals are used for the fractionation and no waste is generated. Nutrients are recycled, and wastewater streams are minimised (recycled as processed water).

Key process steps and process innovations

The innovation of raw material fractionation

Fractionation is a defining process step of a biorefinery. It can be engineered according to the specific aims of a process. This can be the fibre recovery at a specific length distribution profile or the extraction of proteins or lactic acid, or the optimised recovery of soluble chemical oxygen demand (COD) for biogas production.

The fractionation step is normally defined by process conditions such as pH, temperature, water content, mechanical energy input, residence time, type of equipment, enzyme addition, and other factors. The efficiency of this step in processing can be assessed by the fractionation efficiency, or the specific energy input.

The innovation in the design of the biogas reactor

Another new process is the adoption of the up-flow anaerobic sludge bed (UASB) reactor design for biogas production from the water-soluble extracts of grass. This reactor design is widely applied in breweries, the sugar industry and various other industries. High-rate anaerobic reactors, such as UASB reactors offer advantages for soluble substrates and larger-scale applications. They also offer scale-up advantages for biorefinery systems applying solid/liquid separation. Scale-up can significantly reduce the cost of power production from renewable raw materials.

The grass washer innovation

Grass deliveries from permanent pasture often contain considerable amounts of soil (sand and stones). This is particularly true for late cuts in autumn, when mice move soil into and onto grass. In order to protect machinery and secure product quality, such material must be washed. The washer should perform the continuous, automated removal of sand and stones.

Such a washer has to be designed and built specifically for the biorefinery. It is a cost factor which must be considered.

The innovation in board production

For the production of boards, a new process has been designed and developed. This process includes the ad-mixing additives (protection against fire and funghi); does not require binders for board stabilisation; allows the production of several product types (*e.g.* density of 60 or 100 kg/m^3) on the same machine; and is cost efficient at small scale. This innovation largely improves the economics of a biorefinery, and makes the technical utilisation of grass economically feasible at relatively small scale. Initial production and marketing of commercial boards is due to begin in 2004.

Economic considerations

Generation of value added

The total value that can be generated from grass is listed in Table 1. The following price assumptions were made:

- The raw material cost is EUR 65 per tonne of dry matter;
- The feed-in tariff for power is EUR 0.1/kWh;
- For the blow-in product, the net sales price *ex* factory is EUR 0.40/kg;
- For insulation boards with a density of between 60-100 kg/m^3, the net sales price *ex* factory is EUR 0.80/kg. The net sales price of stone wool products, in the same density range and recommended for the same applications, is between EUR 0.80 and 1.00/kg;
- For combustion pellets, the net sales price *ex* factory is EUR 0.13/kg.

The use of net sales prices, *ex* factory, considers the margins necessary for product marketing and distribution.

Table 1. Creation of value added

Raw material	Cost of raw material	Sales (energy)	Sales (non-energy)	Total sales	Value added	Value factor
	EUR/ha	EUR/ha	EUR/ha	EUR/ha	EUR/ha	
Grass – power + blow-in insulation[1]	650	500	2 200	2 700	2 050	4.1
Grass – power + insulation boards[1]	650	500	4 400	4 900	4 250	7.5
Grass – power + combustion pellets[2]	390	657	0	657	267	1.7
Rapeseed – liquid fuel + animal feed	641	660	450	1 110	469	1.7

Notes:

1. Mid-intensive production, harvest 10 t/ha dry matter.
2. Extensive production, harvest 6 t/ha dry matter.

Source: Author.

The value added is defined as total sales minus raw material cost. The value factor is defined as total sales divided by raw material cost.

Table 1 shows that attractive fibre products such as insulation boards help to generate an attractive value added. The value factor 1.7, as determined for the production of power and combustion pellets from grass, as well as for the production of liquid fuel and animal feed from rapeseed, is too low to support an expensive process (such as processing grass), but possibly sufficient for a low-cost process such as oil extraction. Utilisation of low-quality grass from semi-natural habitats for the production of insulation boards has not yet been proven.

Plant concept and size

Determining the value added of a potential product from a biorefinery helps to develop and design a viable plant concept. Other essential plant design criteria are the investment and operating costs for a specific production line, the related yield per tonne of raw material, and the marketability of the product on a large scale.

Table 2 lists these criteria for the evaluated products and defines the overall attractiveness of a product for integration into a biorefinery concept. Production of biogas and power requires high investment, but generates low value added and is therefore not an attractive option for a biorefinery. Grass juice for animal feed purposes can be an interesting by-product outlet. Insulation boards appear to be the most attractive of the products reviewed.

Products requiring high investment, but offering low or medium value added, can only generate profit at a large scale of production. However, small-scale operations have advantages to offer:

- Raw material transport over long distances can be avoided;
- The number of raw material suppliers for one processing plant is small, therefore organisation of raw material delivery and raw material quality control is easier;

- Silaging of very large quantities of raw material for winter production requires a significant surface area; and

- Levels of investment are lower, which makes financing feasible for agricultural organisations.

First implementation of a biorefinery

The first production-scale biorefinery was built and commissioned in Schaffhausen, Switzerland, at the end of 2001. Technological development and implementation were conducted by the Swiss company 2B AG. Technological development was supported by the Swiss Agency for Environment, Forests and Landscape. For the implementation in Schaffhausen, the Swiss Agency for Energy provided an investment subsidy of around 18% of the total plant cost.

The Schaffhausen installation was not economically viable and operation was stopped in summer 2003. Production-related reasons for the failure include low revenues from product sales (blow-in insulation) and the unsatisfactory performance of some plant components (*e.g*. fibre drying and packaging).

The plant produced technical fibres and biogas from grass. The innovations regarding raw material fractionation, production of biogas in the UASB reactor, and grass washing were demonstrated successfully. The technical fibres were further processed on-site for production of a blow-in insulation product marketed under the brand name *2B Gratec*. Certification and market introduction of *2B Gratec* were successful. Biogas was utilised in a combined heat and power plant. Heat was used internally for drying the fibres. The power was certified and marketed under the label "Nature Made Star". The plant had a raw material throughput capacity around 0.8 tonnes of dry matter per hour. The yield of *2B Gratec* was 500-600 kg per tonne of dry matter and the biogas yield was 150-250 m^3 at around 6 kWh/m^3, depending on raw material quality.

Table 2. Product attractiveness

	Investment cost	Yield	Value added	Large-scale product marketing	Overall attractiveness
Fibre insulation boards	high	high	high	possible	high
Fibre blow-in insulation	high	high	medium	difficult	medium
Grass juice for animal feed	low	high	low	possible*	medium
Dried protein for animal feed	high	medium	medium	easy	low
Biogas/energy	high	medium	low	easy	low

* In small-scale production units.

Source: Author.

Conclusions

Grass offers good prospects as an industrial raw material. However, production design and engineering, product development and marketing – as well as plant operation and management – require know-how and experience. During extensive production-scale testing, it was found that:

- Wet fractionation of grass is a powerful tool for the generation of value added from several products;
- Insulation boards combine high yield with high value added and appear as the most attractive of the products examined;
- Production of ethanol, biogas and power is cost-intensive and contributes little to the overall economics of a biorefinery;
- Linking two or more expensive new production lines results in the spreading of risks and should be avoided.

Despite the commercial failure of the first biorefinery at Schaffhausen, the Swiss agency for Environment, Forests and Landscape has decided to give further support to the development of the technical utilisation of grass. This decision is based on the high potential of this raw material for industrial utilisation and related environmental benefits. The agency has appointed the author of this paper as the contact person for related questions.

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