Biorefineries: From Concepts to Reality?

K. Wagemann
DECHEMA e.V., Frankfurt, Germany

Abstract

The concept of biorefineries addresses the conversion of plant biomass to fuels, materials and chemicals, waste streams being minimized and used for the production of electricity and heat. Four different types are presently discussed:

- Sugar-based biorefineries
- Whole-crop biorefineries
- Green biorefineries
- Lignocellulose biorefineries

Besides the lack of existing technical solutions and limited land resources, competition with food production and, as a consequence, rising raw material prices considered.

Introduction

The US Department of Energy gives the following definition of a biorefinery: “A biorefinery is an overall concept of a processing plant where biomass feed stocks are converted and extracted into a spectrum of valuable products”.[1)]

This definition would imply rather a large number of existing specific production plants based on renewable raw materials. High volume examples would be, among many others, the production of cellulose from wood, the fermentation of sugar to aminoacids, the production of starch derivatives and the production of bioethanol from sugar beet or cereals as well. In order to distinguish biorefineries from such mono-product facilities one should introduce additional criteria, bearing traditional petroleum-based refineries in mind: They produce different kinds of fuels and feedstock chemicals in large quantities. In addition they convert the crude oil to a very large extent into products and create only minor waste streams. These additional criteria immediately melt down the number of biorefinery examples realised.

Using the same arguments the recently published Cologne Paper “En Route to the Knowledge-Based Bio-Economy” edited by DECHEMA in the framework of the German Presidency of the Council of the European Union, contains the following[2)] definition: Biorefineries of the future will be able to extract novel, value-added compounds, like fine chemicals, and convert the remaining biomass into energy or building blocks for chemical synthesis, leaving only small amounts of waste whose inorganic compounds could be recycled for use as fertiliser.

Natural resources for renewables

For reasons of plant productivity and land availability, the amount of renewables for the production of biofuels and chemical products is limited. The domestic situation is as follows: presently around 12 million hectares are under the plough. If, for political as well as for ethical reasons, one does not wish to reduce the land available for the production of food and feed, then it is anticipated that there will be a maximum of around 3 million hectares for non-food use in the future[3)]. The situation in Europe and in the world differs, but not so as to

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reverse the general limitation.

The following table summarises the productivities of important plants in the context of biofuels production. The numbers given are best values assuming highly fertile soils and sufficient water supply, the latter evolving as the prime limitation in the future.[4)]

	Biodiesel (RME)	BTL	Bioethanol	Biogas
Yield (drymass) (t/ha • a)	3,5 (Rape seed)	15 (Energy plants)	6 (Crop)	15 (Silage corn, 1 harvest/a)
Fuel yield (t/ha • a)	1.34	1.54 – 2.46	1.98	3.38
Equivalent fuel yield related to diesel and/or gasoline (t/ha • a)	1.22	1.43 – 2.28	1.29	4.74

Table: Biofuel yield per hectare and year (FNR, 2005)

Classical smart breeding technologies and genetic engineering will allow this productivity to increase by a factor of more than two.

In addition there are presently four large streams of biomass which are only partially used for biofuels and bio products: straw from crop production (16-22 million tonnes in Germany), wood of inferior quality not used for materials and cellulose production (around 16 million tonnes), waste streams from food production (maximum 52 million tonnes) and biomass from waste water treatment (around 2 million tonnes)[2, 5)].

General considerations for biorefineries

There are different approaches to establishing a biorefinery concept:

1. Take a given production line based on renewables and make use of waste streams. Examples are bioethanol and biodiesel production. In the first case presently the distillers' grains, consisting to a large extent of proteins (converted into DDGS – distillers' dried grains - and sold as low-value feed) could be processed into specific proteins as food additives by extraction or into higher value aminoacids by conversion. The alternative would be biogas production. In the case of biodiesel production the by-product, glycerol, could be converted into higher value chemicals like 1,3-, 1,2-propanediol, lactic acid or epichlorhydrine.
   In the context of the biorefinery discussion, often the two prime products bioethanol and fatty acid methyl esters, are considered as feedstock for chemical products (i.e. butadiene or oleochemicals). Taking into consideration the concept of the classical petroleum-based refinery and the priority of fuel production, this additional concept might not be meaningful.

2. Take a given production line to high volume products, make use of waste streams and achieve forward integration in addition.
   This argumentation leads to the concept of the crop-based biorefinery, where starch- and cellulose-based derivatives and cellulose-based glucose production are integrated, contributing to the overall economy by higher value products.

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3. Combination of several biofuel and bio-based chemical production lines. In such combined production, the waste streams of one line would be the input for other lines. One example discussed is the combination of bio-diesel and bio-ethanol production. Here both waste streams are the input for a pyrolysis/gasification plant for the production of methanol, the methanol being used as feedstock for the biodiesel production.

4. De novo design of biorefineries. Examples are the green biorefinery making use of immature green plant materials and the lignocellulose biorefinery making use of straw and wood taking all constituents into consideration for the production of valuables.

Whereas the sugar-based and the whole-crop biorefinery concept can only take advantage of part of the biomass production, the green as well as the lignocellulose-based biorefinery have – at least theoretically – a larger material base.

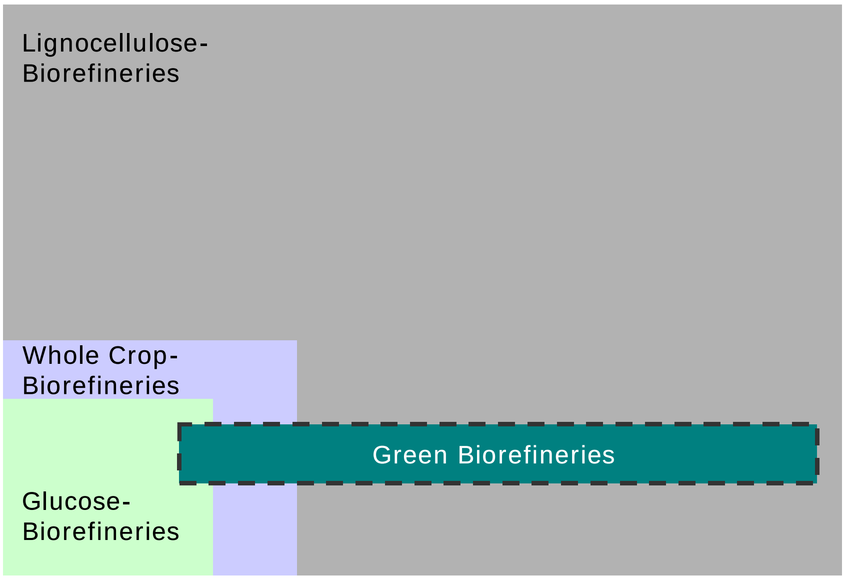

Figure 1: Whole Pool of Plant Biomass and its Use in Biorefineries

Taking into consideration that, analogous to the classical refinery, biorefineries should convert more or less the whole feedstock into valuables and produce energy self-sufficiently, the following general concept can be established

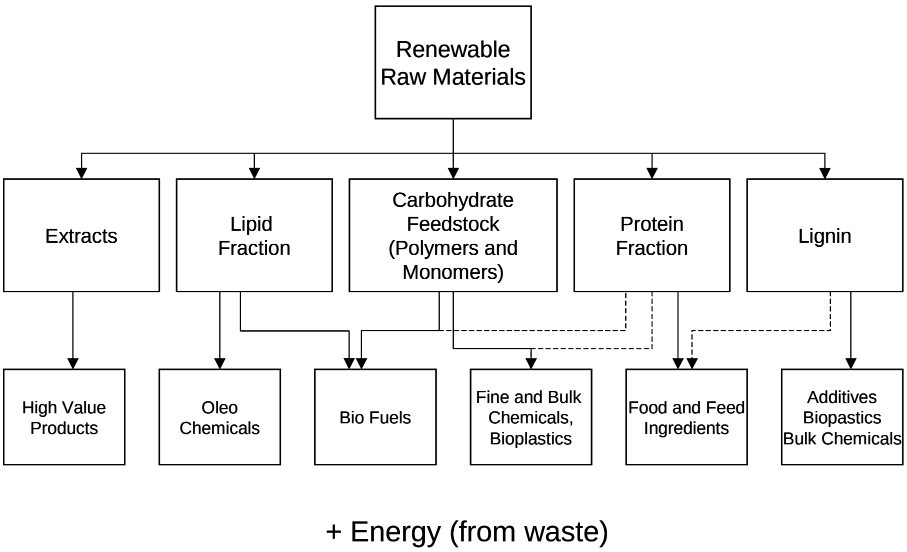

Figure 2: General Concept of Biorefineries

The different biorefinery concepts usually emphasize only some of the streams described. This explains why their product portfolios also differ.

Biorefinery concepts

The sugar-based biorefinery focuses on the press juice of either sugar cane or sugar beet. It can make use of all the experience of production based on glucose. This can be either chemical modifications like hydrogenation, producing for example sorbitol, or the whole wealth of fermentation products starting from ethanol and also aminoacids and higher value chemicals and pharmaceuticals. In this concept the remaining biomass (bagasse) and other waste streams are not considered as a basis for products but mainly for energy production.

The whole-crop biorefinery focuses on starch and its derivatives. For decades starch has been used for the production of dextrins and glucose as well as for starch derivatives like esters and ethers, products used in the food, textile and paper industries. In a cereal based biorefinery in addition the bran is converted into valuable products like xylose derivatives or ferulic acid.

Green biorefineries consist of two production lines. Their basis is the pressing of the green plants producing press juice and leaving behind the press cake. The latter can be either used as feed or, after drying, be thermally converted directly into energy or syngas. The press juice can be fractionated, yielding products like proteins, aminoacids and lactic acid, or be used as a fermentation medium taking advantage of the presence of monomeric and oligomeric carbohydrates and nitrogen-containing proteins. As a product of the fermentation, high value chemicals as well as biogas can be produced.

Lignocellulose biorefineries make use of straw as well as of different kinds of wood. These materials consist of cellulose (linear polymer of glucose units), hemicelluloses (linear and branched polymers of C_5- and C_6-sugars) and lignin (a three-dimensional molecule consisting of methoxyphenylpropane units) and low molecular extracts. The prime problem is the separation of these components. Several processes have been developed. One should always bear in mind that one of the largest productions, the production of cellulose with more than 100 million tonnes per year worldwide, is based on such a separation technology. While this technology relies on the use of alkaline sodium sulfide resp. sulfite solutions, others based on organic acids, organic solvents and combinations have been developed. The most recent research activities are related to the use of ionic liquids which might have several advantages as they are able to dissolve all constituents. The decision on the process and chemicals used very much depends on the biomass used and the products desired.

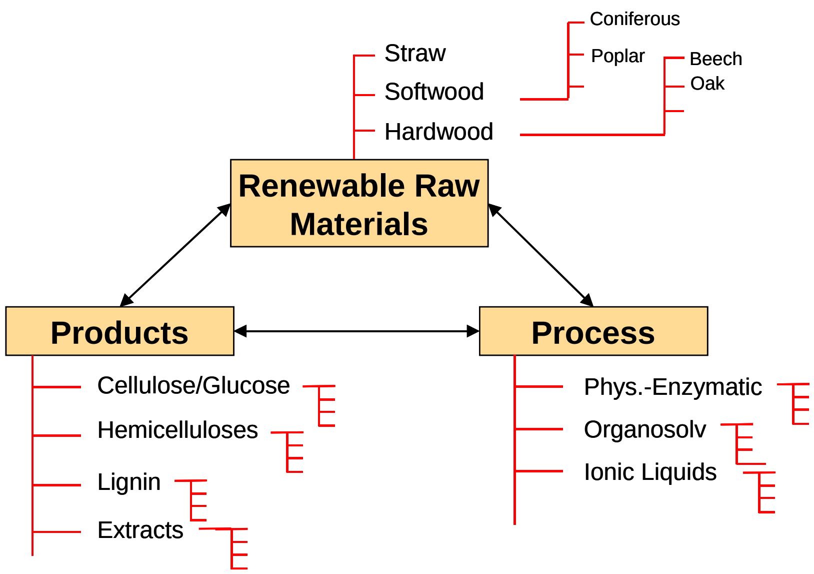

Figure 3: Triangle of Decision for the Design of a Lignocellulose Biorefinery

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Very few of these concepts have already become reality or are on the way in Europe; examples are:

- The Lenzing Zellulose-Werk produces high quality cellulose-fibres and in addition purified acetic acid, xylose and furfural.
- The Ghent Bio-Energy Valley will combine biodiesel, bioethanol and biogas production and in addition fermentation to higher value chemicals.
- The Icelandic Biorefinery will make use of lignocellulose primarily from lupins using acidic pulping
- In Selbelang a green biorefinery is going to be established combining press juice and starch for fermentative lactic acid production.

(Concluding) remarks

Every biorefinery concept and its realisation has to address the following aspects:

- The technological base has to follow the principles of process intensification making use of different technologies, chemical as well as biotechnological routes.
- Engineering aspects related to the separation and extraction of the major constituents are presently underestimated.
- Products from biorefineries must fit present production schemes in the chemical industry; platform chemicals are the prime need.
- The concept must allow for the complete utilization of the raw materials.
- There are good arguments that the cost of biorenewables will follow the price of crude oil as they are linked via biofuel production.
- There is competition between the production of food on the one hand and that of raw materials for fuels and chemicals on the other hand. This limits the resources and raises ethical questions.

1) http://www.doe.gov/
2) DECHEMA F+E Studie Integrierte Nutzung nachwachsender Rohstoffe, p. 11, 2006
3) D. Peters, DECHEMA-Workshop Weiße Biotechnologie, 2004
4) En Route to the Knowledge-Based Bio-Economy, 2007, http://www.bioperspectives.org/Cologne_Paper.html
5) Data from AwareNet