

Integrated Plant Conversion and BIOCASCADE optimising use of biomass as renewable resource in sustainable development

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This paper is a concise version of a presentation on the CHISA2000 congress in Prague, August 2000. The aim was to introduce aspects of sustainable development in chemical engineering as is done in the Netherlands, for the chemical engineering community in Eastern Europe.

It is thought worthwhile to bring this information here too because it forms the starting point for further projects on small scale application of the various hemp-crop-based materials [6]. Besides several other biomass based chemical production routes are investigated in the Netherlands and elsewhere using BIOCASCADE principles. Examples are the DSM ecothene proposal (ethylene from bio-ethanol) and polyhydroxyalkanolate from corn by Dow and Cargill.

1 INTRODUCTION

Sustainable development requires a thorough rethinking and re-engineering of our technology and our way we use technology. Already for the present the total impact of human activities on the environment is still much too large. Resources are being depleted, ecologies threatened and pollution is often above the bearing capacity of the environment. This directly endangers human health, economic development and thus prosperity.

In the last two decades technological development has led to much improvement in environmental performance. However the improvement attained is often off-set by growth which takes place or will be in the future. One has to question therefore if the present approaches suffice. We need to do better and substantially so. Totally innovative process routes, products and ways to organise our economic activities are asked for [1,2]. Chemistry and chemical engineering play an essential role in this.[3]

2 SUSTAINABLE CHEMICAL TECHNOLOGY DEVELOPMENT

A truly sustainable society will use only renewable and recyclable resources, in activities which use resources extremely efficient, causing minimal pollution and disturbance. Required is the development of extremely efficient processes, products with minimal environmental impact and risk, easy to recycle, the necessary (extremely efficient) recycling processes and the production-routes for sustainable energy sources, raw materials, food, etc.

The Dutch research program for Development of Sustainable Chemistry has defined the key areas on which sustainable development in chemistry should focus [4]. Using the methodologies as developed within the National Interdisciplinary Program Sustainable Technological Development [1, five areas for development of a sustainable chemistry have been chosen for further discussion and research. One of them is **Integrated plant conversion (IPC)** which aims for optimal and economically feasible use of biomass based resources. The essence to that is total utilisation of harvested crops by differentiated valorisation of plant parts for raw materials and energy.

3 BIOMASS BASED RESOURCES

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Biomass, seen with a chemical engineers eye, is a quite diverse group of materials, originating from agriculture and forestry, also including organic waste from food production. Not plant-originating biomass from animal and fishery waste can be used but plant materials form the main sources. It offers a challenging variety in form, composition, availability and possible derivatives and uses.

Biomass is presently used already extensively as source for chemical products, based on the specific structure and/or characteristics of the natural made molecules. Examples are cellulose and starch derivatives. Besides specific substances of plants, formed as secondary metabolites, are used such as resins, rubber, pharmaceuticals, flavours etc.. Such components are used often as first 'building block' to synthesize fine chemicals and pharmaceuticals.

Biomass is used as base material for ethanol and other compounds through fermentation, furfurals, biodegradable polymers. A route as yet under development is the use of biomass in bulk by converting it to simple building blocks as H₂ and CO in synthesis gas, or through CH₄ or methanol. Those can form the base of a whole line of chemical products: C1 Chemistry, eg using new developments in the field of catalysis.

Biomass resources are sufficiently available as the following 'order of magnitude' figures [5] indicate (global figures, based on dry matter and note: the spread in figures in literature is large):

- plant biomass available on land	1000 - 2000	Gtonnes in total
- NPP (net primary production) on land	100 - 150	Gtonnes/annum
- total agriculture	10 - 15	Gtonnes/a
* for direct human consumption	~ 1	Gtonnes/a
* feeding of livestock	6 - 8	Gtonnes/a
* by-products / usable residues	~ 2	Gtonnes/a
- wood production	1 - 1.5	Gtonnes/a
- organic chemical production	~ 0.4	Gtonnes/a
- oil production	~ 3	Gtonnes/a

Natural systems use only a few percent of the incoming solar energy. There appears to be ample room for biomass based chemical production. A substantial part of the agricultural production is residues and sometimes not used, spoiled, burned or just left on the fields. Yields are likely to be improved in the future.

There should be nevertheless attention for possible consequences. An important issue is the availability of land area, water and fertiliser. It is evident that an increase in cultivation of biomass for chemicals will put a strain on the resources needed for food, that with a growing world-population. Take into account a parallel shift towards biomass energy too. Productivity of land and plants will have to be improved. An option might be selection of plants which are able to grow on what is now unproductive and marginal, due to salting up for instance, or which need few water and fertiliser. Besides changes will occur in the total production systems using biomass, due to logistic requirements and seasonality of biomass production. Production will be more decentralised, with resulting changes in socio-economic structure of areas. And biomass waste could have a local use (fuel for the poor!) already.

4 INTEGRATED PLANT CONVERSION

4.1 The principle of IPC

The principle of IPC is to use the integral yield of plant material from a crop as efficient as possible. That implies that for all parts of a plant most efficient and profitable use must be selected. Furthermore all wastes must be processed and used in a profitable application again. Only thus the economics can become favourable and competition for resources, e.g. with food production is kept low.

Plant materials to be considered, are:

- seeds: for oils, starch, proteins, sometimes fibres and special substances
- stem: for fibres and cellulose, special substances

- leaves: for proteins, fibres
- tubers and bulbs: for starch, proteins, special substances
- fruits: for starch and sugars, special substances

All can be used for chemicals, or a part for food or fodder and the remainder processed for chemicals. Wastes can be used as fodder when still having a high protein content. A last resort use is as fuel through direct combustion or fermentation to biogas.

4.2 The BIOCASCADE method

The key issue is selection of plants, which offer an interesting ‘product package’ through multiple use of all crop components. In such way that (scarce) resources as land-area, fertiliser etc. are optimally used. That offers economical and ecological advantages and lead to commercial feasibility for replacing non-renewable resources. The BIOCASCADE is a method that does just that. Figure 1 give a schematic outline of it..

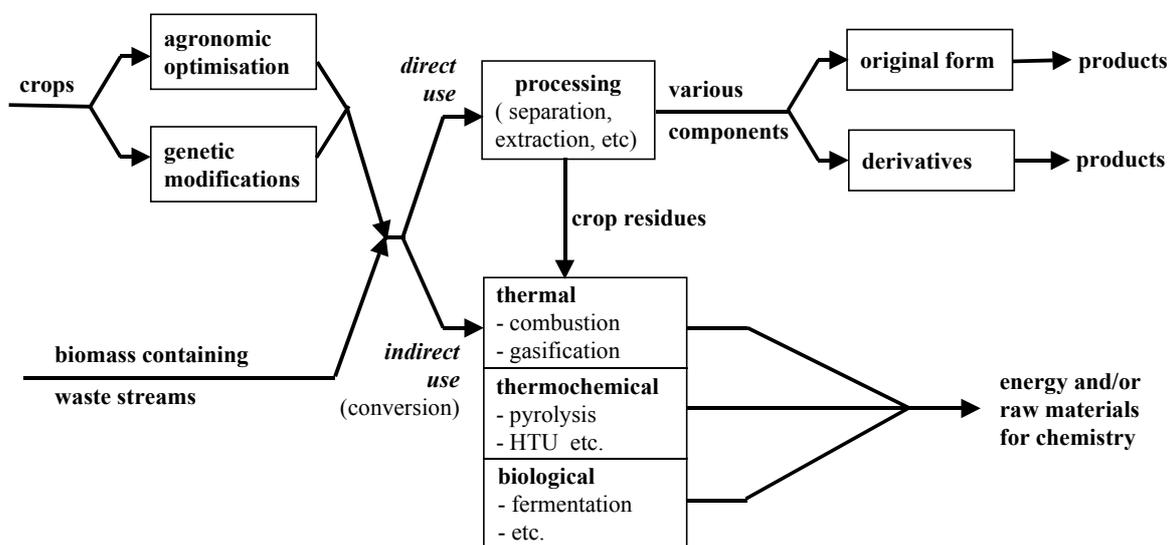


figure 1 The BIOCASCADE concept, schematically

The essential elements of the BIOCASCADE-concept are:

- input is a crop of one or more plants offering several usable components of strong commercial interest. Other biomass-flows, eg residues from other crops which contain the same usable components can be included.
- Yield of the crop as a whole or of specific components can be maximised by:
 - ◇ optimisation of the cultivation methods (aiming for yields that can be reached theoretically)
 - ◇ selective breeding or genetic transformation for enhancing yields of the crop and/or specific substances
- The concept offers two main processing-routes:
 - ◇ extraction of useful components, and if needed purification and/or modification
 - ◇ complete conversion (thermal, chemical or biological).
 - ◇ This route in particular used for:
 - ⇒ energy-generation through direct combustion or after gasification (thermal conversion)
 - ⇒ production of liquid energy-carriers/“biofuels” (thermochemical conversion)
 - ⇒ production of ethanol and other (chemical/biological conversion)
 - ⇒ production of ‘bio-syngas’ (H₂ and CO)
 the latter two can form the bases for a whole range of chemical products
- All remaining residues can be used in a last total conversion route.

5 THE BIOCASCADE METHOD, THE HEMP PILOT STUDY

In the framework of the Dutch DCO program a practical example has been worked out.[6] Options and attractiveness of this BIOCASCADE method approach were to be demonstrated under conditions as prevail n the Netherlands. At the same time practical insight in what is needed, not only in technical sense but also economically was needed. Visions and perspectives of the partners involved (agriculture, chemical industry, authorities) should be reviewed.

A pilot had to be realistic with respect to usefulness of materials, profitability and feasibility in view of present agricultural and chemical technology. A plant crop had to be found which can easily grow under Dutch climate conditions and offers a range of materials and substances. And it should fit into the necessary crop rotation practice and offers an economically interesting addition for farmers to the present main crops wheat, potatoes and sugar beet roots.

Hemp proved to be the best choice. Much is known of the crop and the specific components and a variety of materials that can be derived from it. Table 1 gives an overview of the areas in which specific hemp components can be used and their potential for replacing existing sources of raw materials.

Table 1 Selected hemp components for BIOCASCADE, obtained through direct extraction and their area of application

Component	Area of application	Yield for 100.000 ha (Dutch situation) 1)
barkfibre (long)	High performance buildingmaterials (eg laminates and MDF)	400 (700 paper-pulp)
	Fibre-reinforced products	
	Bulk quality building materials	
	Textiles	
	(although presently fibres are still too coarse and stiff, and lowering lignin content is needed)	
stemfibre (short)	High quality paper	
	Bulk quality building materials	1.000
	Low quality paper	(700 paper-pulp)
cellulose (barkfiber)	Chemical base material for phenolic substances	
	Chemical base material for rayon and cellulose-derivatives	700 (75)
lignin (stemfiber)	Chemical base material for resins (filler in woodfibre-products) and for lignin derivatives	100
	oil	
seedmeal (after extract. of oil)	Food-additives and supplements	70
	Non-food components (paints, personal care products)	(1.500)
edestine/protein (seedmeal) residue	Fodder	130 (3.000)
	Non-food applications (glues, paper chemicals)	
(+ bark-/stem-fiber, when crop is used for oil from the seed)	Energy generation:	400 (1.800)
	• (co-)combustion	(8.000 for energy generation available biomass)
	• thermal gasification and pyrolysis	
	• HTU (biofuel, additive for diesel oil)	

1) (.) indicates present consumption in the Netherlands based on conventional resources

Assessing the various options and approaches several BIOCASCADE processing routes have been identified for hemp.

The most promising BIOCASCADE-route for the moment is considered to be:

- a. Barkfibre: high quality building-materials (laminates) or textile and/or high quality paper;
- b. Stemfibre: low quality building-products and/or paper;
and possibly combined with:
- c. Seed (unripe): cattle fodder or extraction of oil for human feed supplements and additives

- (seed and fibres have a non-compatible ripening-time);
- d. Residue (tops and residues of fibre-extraction process): use for energy through co-firing in e.g coal-fired furnaces, gasification, HTU or pyrolysis.

BIOCASCADE-routes which are considered to be less promising are:

- ◇ Extraction of the oil (from ripe seeds) as primary product;
- ◇ Extraction of the various specific substances (secondary metabolites) as side products;
- ◇ Conversion of residues through Solid State Fermentation (SSF);
- ◇ Extraction of products on base of the oil obtained from pyrolysis of hemp.

Fibres of hemp have been used before, mainly for rough cloth for packaging purposed but also strong clothing. They are quite strong and durable offering potential for instance for use as reinforcement of cement (alternative for asbestos) but also in polymers and resins. A process which converts the lignin, called PLATO, is developed elsewhere to improve the durability of wood. This is now tested for hemp fibres making them even more attractive for use in construction materials.

The fibres and other stem material can be used as source for paper, as an alternative for cellulose from wood. The same cellulose could be the source for chemical derivatives of cellulose (such as CMC) used for whole range of purposes and products.

Plant-derived fatty oils are used already in various chemical products. There is a wide range of known processing routes to interesting derivatives of triglycerides and fatty acids based on hempseed oil.

- ◇ Various factors offer good prospects for the profitability of the BIOCASCADE-route proposed: Better yields using improved agricultural technology. Proven is that under Dutch conditions high yields are possible (up to 16 tonnes/ha), using hemp varieties which give under the specific conditions and production scenarios, high yields for the main component.
- ◇ Using hemp for Integrated Plant Conversion, using all fractions and residues optimally (multi-output), farmers can improve the financial result of such a crop substantially. It will make them less dependent on EU-subsidies.
- ◇ The possibility, in principle, of selective breeding or genetic modification aimed at:
 - higher cellulose-content / lower lignin-content for use in paper and textiles;
 - synchronous ripening of seeds and fibers;
 - improved and easier separation of bark- and stemfibres from their plant matrix;
 - adaptation of the ratio between saturated and unsaturated fatty acids.
- ◇ Further development of the use of biomass for energy (Dutch policy targets are 75 PJ biomass based energy in 2020). Hemp BIOCASCADE fits with that.
- ◇ Developments in crop-rotation practice in the Dutch agriculture policy. This can support the targeted reduction in the use of pesticides and the like. Hempcultivation can play a role here.

6 CONCLUSIONS AND FURTHER RESEARCH

Sustainability is not really attainable without transition from fossile to renewable resources based on biomass. Integrated Plant Conversion (IPC) is essential to that aim. Finding the right crop, the right 'mix' of products from the components of the plant-material involved is an important step. The BIOCASCADE approach shows to be quite useful in that respect.

The seasonal character of agriculture however is a disadvantage. A further important factor is the keeping qualities of the plant material, so storage and processing over an extended period of time is possible. Seeds and fibres are preferred in that respect.

To make it profitable both in economic and in ecological sense, and therefore offering real sustainable options, the cultivation and use of plant-crops have to be optimised. Besides chemical engineering must develop fitting processes and production methods. Production methods, processing and production of the actual products have to be harmonised. The hemp pilot has shown that such is possible in principle.

Agronomics and chemical technology face a combined challenge in this. Exchange, co-operation and 'tuning and linking' of agriculture and chemical industry is needed with respect to knowledge, processes and production practices:

- ✓ finding the more promising plant species for profitable BIOCASCADE 'product packages' and when necessary develop new varieties, through selective breeding and/or genetic modification;
- ✓ developing cultivation methods and supporting technologies adapted to industrial requirements, and adapting industrial practice to specific agricultural characteristics such as seasonality;
- ✓ investigating the way the various materials and components are to be recovered from the harvested plant biomass in the most useful form;
- ✓ first phase of processing of the obtained materials and components, to separate them, to treat them for instance through drying and to prepare it for further processing, transport etc..

Chemical process engineering and industry face their own challenges, involving a transition from 'classic chemistry and classic resources to new and sustainable chemistry and renewable resources:

- ✓ managing the change from homogeneous base materials (oil and gas) to the rather differentiated and complex biomass resources (difficult to process but offering new options for fine chemicals);
- ✓ developing specific technology to use biomass components for a broad range of chemical products;
- ✓ improving products, employing the characteristics of specific plant components to their largest advantage also for new products;
- ✓ further sustainability aimed process development: low energy – high efficiency, process intensification and process integration specifically aimed for these type of raw materials.

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