IENICA

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0 Introduction

Germany has a total area of 35.7 million ha. 19.5 million ha of this area is agricultural area. In 1996, 17.3 million ha were used by agriculture, 11.8 million ha of this area were arable land.

In 1997, Germany had a good 525.000 farms with more than 1 ha agriculturally used area, a good 31,000 of these farms were located in the new states.

Production of biorenewable raw materials has a long tradition in agriculture. Beside food, raw materials were always provided for craft and later also for industry and energetic use. In the 20th century, biorenewable raw materials lost much of their importance because of the use of fossil energy carriers and the production of petrochemical products. Only in the last years, the interest increased again. The reasons for this are:

- Biorenewable raw materials are CO2 neutral to a great extent and therefore without negative impact on the world‘s climate.
- The use of these raw materials helps to extend the limited fossil resources.
- The production of biorenewable raw materials eases surplus food markets and opens up production and income alternatives to the agriculture. This safeguards jobs and creates new jobs in agriculture and at industry locations.
- Biorenewable raw materials offer the chance for innovative developments and products, which can be placed on the worldwide market. The high environmental compatibility from production via use to disposal of natural raw materials is a main sales argument.

With 500,182 ha (1998), the biorenewable raw materials are only cultivated on a relatively small part of the arable area. While the cultivation on base areas is steadily increasing, the cultivation on set aside areas mainly depends on the set aside rate determined by the European Common Agricultural Policy. Oilseeds, especially rape, is cultivated on set aside areas. Starch, sugar, vegetable oils (especially linseed oil) as well as flax and hemp are produced on base areas.

1 Oil Crops

1.1 Opportunities

1.1.1 Science and Technology

The biorenewable raw material oil crops normally produces fatty acid ester of glycerin as seed oils.

In theory, a great number of species can be used for the production of chemical products made of native vegetable oils. Today, rape, linseed, sunflower and mustard are available for use in the German climate. Other interesting species are, among others, gold of pleasure, crambe, safflower or coriander. The plant protection mainly sees problems for "new cultivations” and cultivations which were only cultivated to a small extent in the past.

The production method for rape is known to the greatest possible extent. Outstanding progress in plant-breeding was achieved in the field of oil and coarse meal qualities. 0-varieties (free of erucic acid) were introduced in 1973 and a conversion to 00-varieties (in addition with a low glucosinolat content) was established in 1987/88. Beside questions regarding yield increase and breeding for resistance, research scientists mainly work on modifications of the fatty acid spectrum of oils. Two varieties are available for breeding rape as industry and energy plant. On the one hand there are the "old” rape varieties which were selected on a stable yield output and winter hardiness and which have a high erucic acid content. On the other hand there are the "new” rape varieties with a seed oil which is free of erucic acid because of breeding modifications.

Erucic acid is an interesting parent material for the chemical industry which never completely lost its importance as a biorenewable raw material. Therefore people started to increase the content of erucic acid in rape oil both on the classic way and with the help of biotechnics and genetic engineering. The present results indicate that it will be possible to produce rape varieties with an erucic acid content of more than 70% by combining different breeding methods.

In the last years the "new" rape varieties with the characteristics "free of erucic acid" and "high oleic acid content" which were bred at the end of the 70s and beginning of the 80s for nutrition have been further developed in different ways as energy and industry plants.

The oleic acid content of the seed oils was increased further. As a result, on the one hand rape oil can be used energetically as parent material to produce rape oil methyl ester (RME, "biodiesel") and on the other hand it is possible to produce high quality lubricating and hydraulic oils based on rape oil and use the rape oil as parent material to produce surfactants and plastics.

Like for rape, the cultivation method for sunflowers is known to the greatest possible extent. The experience and knowledge from southern areas under cultivation must be adapted to the climatic conditions in Germany. Breeding of sunflowers suitable for cool regions is not very advanced compared to the cultivation method. At the moment, the sunflower with a high concentration of oleic acid which was cultivated on several hundred hectares in Germany in 1996 and 1997 is of special interest. Breeding of the sunflower as a biorenewable raw material plant became possible due to the discovery of a spontaneous sunflower mutant with an oleic acid content of more than 80% in its seed oil. The seed oil of "highly oleic acid sunflowers" became a much sought-after raw material in the oleochemical industry because of its high oleic acid content. The climatic adoption of these varieties to the relatively short vegetation period in the German climatic zone is an important aspect for further breeding of "highly oleic acid sunflowers".

Linseed oil is mainly used by the paints and coatings industry. Its high content of polyunsaturated fatty acids causes curing of colours and paints. As a biorenewable raw material, linseed oil is only bred further to a limited extent because of the low amount of areas under cultivation. However, there are several attempts to increase the polyunsaturated fatty acids content further.

Some species of the wild flora containing seed oil are very interesting for technical use because of their fatty acid composition. Although these species cannot be cultivated in the short term, they will be cultivated in the medium to long term. As a matter of fact, these species need more research and development than oil plants cultivated in the past.

Prerequisite for the use of vegetable oils is on the one hand the availability of a sufficient amount of vegetable oil to the industry and on the other hand a constant quality. If these prerequisites are not given, the use of these raw materials is of no interest to the chemical industry. Furthermore, an economically successful production of the oil crops must be possible to offer the industry the vegetable oils at an acceptable price. The development of productive plants as well as some experiments for the cultivation of not yet established oil crops are a contribution. Cultivation plans for crambe, high oleic acid sunflower, euphorbia and the Iberian dragon head (*Lallemantia iberica* Fisch et. May) are supported by public funds. Answers to harvest and processing engineering as well as technical questions regarding the production as well as utilisation ways for the oils are to be found within the scope of these projects.

It is a great disadvantage that most seed oils consist of different fatty acids. This is a disadvantage for the use as industry raw material because separation processes must be carried out for many applications before using them as intended. To avoid or reduce such processes, many breeding projects in the "oil crops" field aim at an increase of at least 80% of the corresponding main fatty acid.

With the help of genetic engineering it is possible to adapt the fatty acid pattern of oil crops to the requirements of the chemical industry. The greatest progress was made with rape because this plant can be genetically processed very easily.

Several old and nearly forgotten cultivated plants and wild plants from German and foreign climate zones were examined on their suitability as biorenewable raw material plants to use the immense natural potential of different fatty acid forms and with it the possibilities of subsequent chemical processing.

Two old cultivated plants, gold of pleasure (*Camelina sativa*) and crambe (*Crambe abyssinica*), were processed by breeding to a certain extent. Gold of pleasure oil is similar in its composition to linseed oil. Crambe oil has an erucic acid content of more than 50 %.

The wild plants which were selected for use as industry plants are, among others, coriander (*Coriandrum sativum*), cruciferous spurge (*Euphorbia lathyris*) and pot marigold (*Calendula officinalis*). The seed oils of each plant consist of unusual fatty acids which are of great interest from the chemical-technical point of view.

With the help of genetic engineering the production of unusual fatty acids can also be realised with established oil crops, like e.g. rape. Rape plants which store e.g. lauric or myristic acid (short-chain fatty acids) or ricinoleic acid (fatty acid with one hydroxyl group) in their seed oil were successfully developed by transferring genes from oil crops which produce these unusual fatty acids.

In Germany, protein plants like e.g. lupines are not cultivated with the main aim of using them as biorenewable raw material. However, coarse meal with a high protein concentration is produced during processing of all oilseeds. The coarse meal is mainly used as animal food. As the Blairhouse Agreement restricts the use of coarse meal from oilseeds cultivated on set aside areas and the use of certain oil coarse meals, e.g. gold of pleasure coarse meal, in the animal food sector, alternatives to the food sector are searched for.

1.1.2 Industry

Long-chain fatty acid molecules offer a great number of possibilities for chemical-technical transformations because of the natural variability of the chain length as well as the number and position of functional groups so that vegetable oils became the raw material for a varied base and plastic chemistry at an early stage.

1.1.2.1 Lubricants

1.1.2.1.i Technology

In Germany, a good 1.2 million t of different lubricants are consumed per year. Approx. 60% are industry lubricants and 40% are car lubricants (gear and engine oil).

Rape oil plays an important role as base oil for the formulation of quickly biodegradable lubricants. The reason for that is not only the good availability of the vegetable oil obtained from German plants but especially the technical properties of today‘s 00 rape oil. Because of these technical properties, rape oil is preferred to other vegetable oils, like palm and soy-bean oil, which are more important regarding their quantity. The fatty acid pattern is mainly responsible for the technical properties. If the vegetable oils contains a too high portion of saturated fatty acids, like e.g. palm oil, the low-temperature flow property of the oil will be very bad. But if the oil contains a great portion of polyunsaturated fatty acids, like e.g. in sunflower oil, the oil has an unfavourable oxidation behaviour and tends to resinification when being heated. Therefore, rape oil with its high concentration of monounsaturated fatty acids (oleic acid) is a good compromise between oxidation resistance and low-temperature behaviour.

Vegetable oils have outstanding tribological properties which can, among others, be seen from the very good viscosity-temperature behaviour. Apart from this, vegetable oils are better lubricants than mineral oils which receive these properties only with additives.

The evaporation loss of the rape oil which is five times lower than the evaporation loss of mineral oils is another advantage. Beside the technical importance, this is especially relevant to the environment.

Compared to vegetable oils, mineral oils have a better thermal oxidative resistance. Therefore, especially the oxidation resistance and the low-temperature properties of the vegetable oils must be improved with suitable additives.

The market for lubricants, including hydraulic oils, offers a great technical sales potential to rape oil and other German vegetable oils.

In the medium term, the market potential for lubricants based on rape oil is estimated at 10 to 15% of the total consumption of lubricants in Germany. This corresponds to approx. 120,000 to 180,000 t of quickly biodegradable lubricants per year.

The research support took up the different problems of the lubricants field in different research projects. Research projects were and are supported in the following fields: hydraulic fluids, additives, forestry machines, sealing, metal processing, gear oils, engine oils and concrete parting agents.

The reasons for carrying out these projects can be focused on two points. The environmental aspect plays one important role. Therefore, the development of environmental compatible lubricants is the reason for several development plans. On the other hand, vegetable oils must be formulated to lubricants which fulfil the technical requirements of the different machines and which have the same or a better performance than lubricants based on mineral oil.

The progress of the technical development of quickly biodegradable lubricants is in different states because the technical requirements differ according to the intended use.

First, the loss lubrication sector was developed when developing quickly biodegradable lubricants. The substitution of products on mineral oil basis was relatively unproblematic in the field of chain saw oils. The currently offered chain saw oils based on vegetable oil have reached a market share of more than 90 %.

The hydraulic fluids sector is more difficult. To test the suitability of quickly biodegradable hydraulic fluids, projects have been supported which examine the use of quickly biodegradable hydraulic fluids in field tests in detail, e.g. in combine harvesters, self-propelled forage harvesters, street cleansing vehicles and fork-lift trucks. It turned out that the so-called biological oils can be used without problems if there is a light and medium load on the hydraulic fluid. There is still a research and development demand for higher loads. In a joint project, saturated synthetic esters based on biorenewable raw materials are examined on their suitability as hydraulic liquid in fork-lift trucks with heavy loads. The aim is to achieve the same number of operating hours with these native hydraulic liquids as with mineral oil products.

In addition to the field tests, projects were carried out to clarify the most important stability criteria of pressure transferring media and an examination regarding the avoidance of water penetration in hydraulic liquids.

One problem of quickly biodegradable liquids is the incompatibility of conventional sealings and vegetable oil. This may lead to damages or failures of the sealings. The reason for this must mainly be searched for in the solution properties of the biofluids. Therefore sealing materials suitable for mineral oils must not also be suitable for biofluids. Until now, people tried to develop piston rod packings, the type of sealing which is used most, to use quickly biodegradable pressure media. These sealings are only used for linear movements. First acceptable solutions were presented in the past. But especially in mobile hydraulics there are rotor sealings which must facilitate the sealing of rotating parts. Diggers with sealings between the upper and the lower part of the digger are a typical range of application. In practice, problems occur if biofluids are used with rotor sealings. Therefore, biofluids can currently not be recommended for use with rotor sealings. Problems are the lack of media compatibility as well as the insufficient lubrication and cooling of these sealings depending on the pressure medium and the packing material. Therefore new packing materials for rotor sealings shall be developed within the scope of a project supported by the BML (German Federal Ministry of Food, Agriculture and Forestry).

In the past, people tried to increase the efficiency of biofluids by a more efficient additivity. In the meantime, new ways are followed. In a joint project, improved property profiles are to be produced by chemical modification of the parent oils.

The publication of the environmental symbol for hydraulic liquids has shown that there is a lot to catch up on the way of developing environmentally compatible additives. Therefore, this subject was picked up by the BML. Environmentally compatible additives for the prevention of nonferrous corrosion and the improvement of the ageing performance as well as for improving the hydrolytic stability and the wear resistance are developed in two projects.

If we focus on the division of lubricants onto the different ranges of application, engine oils have the largest share with approx. 37 %. Normally 90% of the engine oils are parent oils and less than 10% are chemical additives. Today, mineral oils or petrochemical synthetics are used as parent oils. These parent oils as well as the additives are not or hardly degradable in the environment to a great extent. An engine oil with a parent oil component consisting of vegetable oil derivatives (synthetic ester) and a new type of engine lubrication concept where the low ageing resistance of native vegetable oils is compensated by permanent refreshing were developed in a project to use the biodegradability and the good lubricating properties of vegetable oils also in the engine oil sector. This new lubricating concept offers the possibility of using rape and sunflower oil for the lubrication of engines for the first time. In this process, the used oil is dosed to the fuel and burned without negative impact on the emissions. The new concept for the lubrication of engines proved to be a suitable alternative to the conventional circular lubrication. Projects that are still in progress work on the optimisation of formulations, carry out engine tests and test continuous usability.
The results showed that crop oils can be applied in fields which have been said to be hardly accessible. Not long ago, the first motor oil on a vegetable basis was introduced on the market.
Apart from developing engine oils, the BML also promotes the use of vegetable oils for the production of gear lubricants. Thus, the objective of another project is the development of an ecologically sound gear oil based on native vegetable oils.

Every year, the German building industry uses approx. 25 million litres of concrete parting agent consisting of mineral oils at more than 90%. Apart from the mineral-oil-based concrete parting agents, there are now also a few formulations available which are free from mineral oils but contain vegetable oils instead – mostly rape seed oil. However, they amount to only a small percentage of the market.
The main reason why these vegetable-oil-based concrete parting agents are not as well accepted as their conventional mineral counterparts, is the fact that properties of use are still unsatisfactory. Thus, nearly all concrete parting agents used today consist of mineral oils with a high potential of environmental impact. Due to the nature of its application, only a small part of the concrete parting agent remains on the surface of the concrete. The main part of the agent is released directly into the environment and thus contaminates the soil, the water and/or the air surrounding the indirect working area. The objective of one of the projects is to concentrate the research on the development of a concrete parting agent based on biorenewable raw materials which offers the same level of performance as a mineral oil product.

From 1988 to 1991, the first experiences were made with rape-oil-based hydraulic fluids in the forest economy. Hydraulic systems in logging equipment are subject to extreme stress, since they are operated at full power over a longer period of time. These machines – above all, the harvesters used for bringing in timber – have a high potential of environmental impact due to leakages and torn hoses. According to experimental values, up to 4 harvester oil fillings get lost in the woods each year due to accidents – this corresponds to up to 600 litres of hydraulic fluid. Up to now, it has not been possible to force the use of biological oils in the forest economy, even though they have been improved a lot during the last years. When analysing the reasons, it became clear that the main problem is the fact that it is not sufficiently known to what extent hydraulic oil in logging equipment is actually subject to stress. Therefore, there are no officially researched values relating to the environmental impacts available which the oil producers could use as a guideline for the minimum requirements, and the machine owners are not prepared to use biological oils.

However, intensifying the use of vegetable oils in this field is only possible if these impacts are known. Within the scope of a combined project, exactly this important next step will be taken in order to promote the employment of so-called bio-oils in the forest economy. The objective of this project is to determine the stress bio-oil is actually subject to in logging equipment. The results which may also reveal possible weak points of the system will be used to work out general constructive directives. If possible, the construction of the hydraulic overall system will be optimised by reselecting and recombining components.

Another field of major relevance with regard to environmental aspects is the metal-working industry which currently uses approx. 1 million machine tools of various sizes. Apart from the cooling lubricants necessary for working metal, they also use considerable quantities of other fluids such as hydraulic oils, gear oils, and bed oils. Due to certain constructional and operational characteristics, occasional leakages and regular introduction of lubricants into the working fluids have to be reckoned with. The disposal of these fluids causes a lot of problems since they consist of many different components and the individual elements can hardly be recovered. In just one year the total amount of fluids (hydraulic oil, gear oils, and bed oils) is introduced into the cooling lubricant. Currently, approx. 45.000 m³ water immiscible cooling lubricants are consumed in Germany. The mixing, the short service life, the evaporation of the various fluids used by the machine tool, and their problematic recycling have a major impact on water, air, and soil. Moreover, they are also responsible for one of the most frequently discussed work place problems.

A combined project will deal with these problems. The objective of this project is to develop a multipurpose diester oil for metal-cutting applications which is based on biorenewable raw materials and can as well be used as cooling lubricant and machine tool fluid for hydraulic systems, gears and beds, is biodegradable and therefore economically friendly and has no impact on the working environment.

The use of vegetable oils as a mineral oil substitute in lubricants and hydraulic fluids plays an important role in the development of biorenewable raw materials and in environmental protection. To promote the employment of vegetable oils in this field, it will be necessary to improve the capabilities of theses native fluids in the near future.

1.1.2.1.ii Environmental Aspects

Lubricants are released into the environment due to leakages, improper use and certain operation conditions and thus, are potentially very harmful to the environment. Approx. 47% of the lubricants used are released into the environment this way. It should therefore be a major goal to substitute the petrochemicals generally used today by less hazardous lubricants.

Vegetable oils are already used today for special ecologically friendly and biologically degradable lubricants and working fluids and thus partly relieve the environment of the threatening hazards. Mineral-oil-based lubricants should be substituted by ecologically more sound formulations especially in cases where more or less the whole amount of lubricant is released into the environment after use, for example, in operating cycles with high lubricant losses.

Regulations and laws (including water resources law, chemicals law, dangerous substances decree, waste disposal act) and the liability for environmental damages promote the use of ecologically friendly hydraulic fluids, especially in mobile hydraulic applications. Ecologically friendly fluids that have been tried in long-time tests have already met the approval of machine and aggregate producers.

The environmental compatibility of the new generation of lubricants is proven by means of objective measuring methods based on researches that have been implemented into the regulations for the "Blauer Engel" award, the German mark of environmental soundness. Apart from the protection of aquatic areas, also the protection of soils and plants is defined in various tests, and criteria of the dangerous substances decree are considered with regard to hazardous chemicals and the health protection are considered as well.

1.1.2.1.iii Economy

The efficiency of the employment of rapidly biodegradable lubricants and hydraulic fluids depends on the procurement, storage, and machine adaptation costs. Also, the maintenance costs for the machines and appliances in the course of the conversion play an important role as well as the costs for possibly shorter oil change intervals and the disposal of waste oil.

The procurement costs for rapidly biodegradable lubricants and hydraulic fluids depend on the quality of the products and are in some cases higher than those for comparable mineral oil products. The prices of vegetable-oil-based chain saw lubricants which take up a market share of more than 90% are comparatively low since the price difference between these lubricants and their mineral-oil-based counterparts is approx. 30%. The price difference of products of superior quality such as rape-oil-based hydraulic fluids is about 50-200% while rapidly biodegradable synthetic diesters and glycols cost even 400-800% more than mineral oil products, depending on the quality requirements.

Changing from mineral working fluids to rapidly biodegradable fluids involves additional costs due to the increased oil consumption during the conversion period and the higher amount of waste oils. Additionally, it might be necessary to carry out maintenance work. This also increases the overall costs.

The storage costs for biodegradable lubricants are comparatively lower than those for mineral-oil-based products since they have been classified as poor water pollutants. Furthermore, the insurance premium that needs to be paid in order to provide for the event of damages within the bounds of the environmental liability act is lower if only rapidly biodegradable substances are stored. Legislation in this field is currently under transition, with a view to European harmonisation.

If you look at the lubricants market you will realise that rapidly biodegradable lubricants take up quite a big share of the market, even though their use involves higher costs. The reason for this is above all their ecological soundness which is expressed by the "Blauer Engel" award. There is already a number of lubricants available to which the "Blauer Engel" has been awarded.

According to the German federal association of medium-sized mineral oil companies, the annual consumption of biodegradable lubricants – mostly loss lubricants – is approx. 25,000 t. Since the total consumption of loss lubricants is approx. 70,000-80,000 t per year, this corresponds to a market share of 30%.

Rape-oil-based hydraulic fluids are also available on the market. The consumption of these products amounts to approx. 10,000-15,000 t per year, i.e. 7-10% of the total hydraulic fluid consumption of 150,000 t. The medium-term prognosis for vegetable-oil-based products forecasts a consumption of 20,000 t (which corresponds to a market share of 13%). Synthetic esters which can be produced from mineral oils or vegetable oils (e.g. dicarboxylic acid esters, aromatic esters, polyol esters, complex esters) are likely to take up a market share of 13% as well. In other fields of application, several ten thousands tons of rape seed oil being used in lubricants can be expected on the market within the next years.

1.1.2.2 Native Vegetable-Oil-Based Chemical Products

1.1.2.2.i. Chemistry

In the European industry, many applications are based on vegetable oils and fats which cannot be produced in Germany at this stage. Rape seed oil, linseed oil, and sunflower oil are the most important vegetable oils being produced in Germany.

About 900.000 t of vegetable oils and fats are currently used in chemical engineering applications in the EU. The oil and fat consumption is expected to continue to increase. In the oil and fat industry, the development of new application possibilities for native vegetable oils and new market opportunities are of major importance.

Up to now, more than 90% of the oleochemical reactions performed were carried out to test the carboxyl group of fatty acids, and less than 10% of these reactions involved transformations within the chain of fatty acids. However, this area offers great possibilities to extend the range of fatty chemical compounds.

Scientists intensify their efforts to try out new reactional options within the chain of carbon atoms of fatty acids, whereas they intend to take above all the carbon-carbon double bonds of unsaturated fatty acids as an example. Also a joint research project supported by the BML entrusted a total of five working teams with this task. Among other things, they are to prove that monomeric components can be accessed through catalytic conversion which is important for the plastics sector. Two projects involve addition reactions within the double bound to gain new fatty substances.

Oleochemical applications can be subdivided into the following fields: polyurethanes, surface-active compounds, biotechnology, lacquers, and by-products.

In the chemical industry, not only petrochemical substances are used for varnishes and paints but also biorenewable raw materials. The range of possible applications, however, has by far not been exhausted yet. One project involves a feasibility study on the employment of biorenewable raw materials in the varnish industry in order to collect up-to-date information and results of activities involved in the utilisation of biorenewable raw materials in varnish and paint applications. Furthermore, the purpose of this study will be to find new fields of application for biorenewable raw materials (carbohydrates, vegetable oils and fats etc.). Economical, ecological, and technical aspects will be considered for the evaluation of the results of this study.

One of the characteristics of native vegetable oils is the high percentage of unsaturated fatty acids. Thus, they offer a good starting-point for the further functionalization which is necessary to achieve efficient applicability in the plastics sector. A completed joint project the objective of which was the development of polyurethanes can be given as an example. The individual subprojects involved the development of new vegetable oil derivatives, the synthesis of polyurethanes from these derivatives and last but not least the production of polyurethane materials for automotive applications. The polyurethane materials produced used natural fibres and consisted of approx. 80% biorenewable raw materials. To increase this percentage to more than 90%, another combined project has been started with the objective to develop the two components that are necessary for the production of polyurethanes from biorenewable raw materials.

Surfactants are also a field of application for vegetable oils. According to estimations, half the amount of the 2.18 million t of surfactants produced in Western Europe in 1996 are based on natural oils and fats. Since they are widely used, man comes into contact with them in many ways. The use of surfactants in detergents is certainly the best known field of application. However, surfactants do not only play an important role in household detergents and agents but also in cosmetics and industrial applications involving the production of plastics, varnishes and paints.

The introduction of the alcyl polyglycosides (APGs) was the first step in the production of 100% biorenewable raw-material-based surfactants. However, the APGs use mainly coconut oil and/or animal fats rather than native vegetable oils. In Western Europe, the potential for surfactants is approx. 350,000 t per year. The BML supports various projects involving the application in surfactants. Two university projects of the above mentioned association for fatty chemicals deal with the transfer of vegetable oils into biosurfactants using biotechnological, enzymatical or chemical methods. Two company projects place special emphasis on the production of anionic fatty acid amide surfactants and new types of nonionic surfactants on the one hand and the substitution of the polymeric base of petrochemical products by vegetable-oil-based dispersions on the other hand.

1.1.2.2.ii Environmental Aspects

The motivation for the employment of vegetable oils is above all the fact that they have a lot of ecological advantages. This does not only include their good biodegradability but also their CO_2-neutrality in energetic applications.

An interesting field of research is the employment of vegetable oils in plastics. Up to now, not as many native vegetable oils are used in the polymeric sector as imported ones, however, it can already be seen that, with regard to the plastics and coatings sector, they have a great potential. Therefore, it is to be expected that native vegetable oils will be used in a wider application range in future. The CO_2 neutrality of the products and the chance that these plastics might be decomposable in particular give impetus to further research.

With regard to the surfactants, the good biodegradability of surfactants produced from vegetable oils (in some cases, they are combined with sugars) plays the most important role. When determining the environmental aspects, the toxicity for fish, bacteria and daphnia in aquatic areas is analysed as well as the human toxicity.

1.1.2.2.iii Economy

It is of fundamental importance to ensure a supply of biorenewable raw materials in sufficient quantities and of constant quality in order to promote their use.

Up to now, it had to be accepted that in the chemical industry the applicability of oils and fats is restricted due to the properties of the raw materials they are made of. The fact that fatty acids consist of mixtures is particularly restrictive since they are technically not separable or can be separated only at very high costs.

In general, vegetable-oil-based raw material is presently more expensive than their petrochemical-based counterparts. Thus, in many sectors, this price difference is crucial for the profitability of native vegetable-oil-based products. However, a number of projects proved that, despite the fact that the raw material is more expensive, it is possible to produce competitive vegetable-oil-based products. This has been demonstrated, for example, in the above mentioned polyurethane material production project. In fact, the higher price is often given as main reason why vegetable-oil-based products are not commonly used but their performance capabilities in practical applications is a decisive factor, too. Generally, producing a comparable vegetable-oil-based product is not enough. A higher market price will be accepted only if the product offers special features mineral-oil-based products do not have. Better ecological compatibility is only one aspect among others.

In the German chemical industry, more than 1 million t of natural oils and fats are used every year. 310,000 t of these are animal fats, 515,000 t are vegetable oils of tropical origin, and 175,000 t are made from oil plants grown in Europe. Thus, Germany is the most important manufacturer of oleochemical basic substances in Europe.

In the course of the increased utilisation of biorenewable raw materials, the by-product glycerine is produced in the processing. To make production processes more efficient, it is of main interest to utilise the by-products in the most profitable way. Among other possibilities, glycerine could be transformed into propane-1,3-diol. Propane-1,3-diol is an intermediate product which is mainly used in the plastics industry. Technically, the transformation of glycerine into propane-1,3-diol is not feasible. There are some microorganisms though which, under anaerobic conditions, have the ability to ferment glycerine to propane-1,3-diol with very good results. However, one of the disadvantages of conventional biotechnological procedures is that, from cultivating the cells in the laboratory to the production on the scale of a technical school, the whole process needs to be performed under sterile conditions. This involves considerable energy, water, and labour costs and requires a big number of appliances. Additionally, the costs for the product conversion are very high due to the complex process involved for separating the biomass. Therefore, the objective of a project at the Federal Rsearch Centre for Agriculture (FAL) in Braunschweig is to immobilize the microorganisms at an earlier stage. Thus, the selected phylum of microorganisms will be cultivated under sterile conditions at sufficient quantities only once and then enclosed in a polymeric gel. Any further processing can then also be performed under unsterile conditions, reducing the costs considerably. Another advantage is that the biomass can be separated a lot easier and is also recyclable.

If we take a look at the profitability of growing oil plants you can see that, apart from the profits gained from selling the oil, also the utilisation of the residues left by the oil extraction process are of major importance. As for other oil plants, also crambe residues can be used to feed economically useful animals. Currently, it is not possible to use the by-products of crambe crops as feedingstuff, because there are no appropriate directives in the existing animal feed regulations. However, since growing crambe can only be profitable if also the by-products can be used in a profitable way, the suitability of crambe cakes and extraction grain as feedstuff needs to be investigated. This is the starting-point of a project the objective of which is to determine the feed value of crambe cake and extraction grain as well as their suitability for feeding cattle and pigs. Analogously, another study has already been performed to determine the suitability of camelina cake for feeding pigs and ruminants.

1.1.2.3 Protein-Based Chemical Products

1.1.2.3.i Chemistry

Among all protein supplying plants, the native oil plants rape, flax and sunflower are of particular interest, however, also the various cereals contain proteins. Beside carbohydrates and fats, plant proteins are the third big group of vegetable nourishments and reserve materials. Proteins are produced as by-products during the production of vegetable oils and starches and are mainly used for the feedingstuff industry. In the chemical industry, the applicability of plant proteins is restricted. Currently, proteins of animal origin such as casein and gelatine are mainly used.

The utilisation of plant proteins for producing technical polymers could be of particular interest. Plant proteins can also be useful as basic substances for biodegradable surfactants.

Plant proteins from native biorenewable raw materials could be used in the following fields of application:

- adhesives, glues, agglutinants, and paints,
- foils and packing materials,
- aggregates for rubber mixtures,
- detergents and
- cosmetics.

The results gained from previous research work being performed to describe and characterise the functional features of plant protein fractions from isolates and concentrates show that the proteins offer very interesting surface-active potentials. However, these potentials still need to be explained and put in concrete terms. Great strides have been made in the development of methods and procedures for producing protein concentrates and isolates. Also, the analytical methods for determining the amino acids and the functional features could be improved.

The objective of research and development work will continue to be the conversion of proteins into proteinhydrolysates with the help of enzymes. It is intended to achieve an application-specific distribution of molecular weight, using suitable proteases. The distribution of molecular weight and the composition of the amino acids of the "customised" proteinhydrolysates, for example, are of utmost importance for the surfactant effect of the compounds to be synthesised. The enzymatic hydrolysis has been proven to be a promising method.

Further research on plant proteins needs to be done to cover the following aspects:

- investigation of new applications for plant proteins,
- development of technically and economically optimised extraction processes,
- development of suitable modification methods for plant proteins.

To develop further applications for proteins in chemical engineering, it is necessary to realise a pilot scale production of protein isolates using industrial processes and to prove the efficiency and quality of protein production.

1.1.2.3.ii Environmental Aspects

Plant proteins offer a lot of possibilities regarding the environmental protection. For example, they enable the manufacture of products and the realisation of applications which are technically recyclable (e.g. packing materials) or biodegradable (e.g. surfactants). In applications such as adhesives and paints, proteins offer health protection by relieving the environment of products which are detrimental to health and harmful to the environment.

In addition, raw material reserves can be saved, for example, by substituting packing materials made of synthetic raw materials of fossil origin.

Furthermore, plant protein products manufactured at a high degree of CO_2 neutrality, contribute to climatic protection.

1.1.2.3.iii Economy

In higher value applications, plant proteins might contribute to securing and improving the profitability of growing oil plants. Above all, it seems to be possible to produce raw materials that can be used in superior applications in the non-food sector.

The economical success of products made of and/or with plant proteins is due to the fact that they meet certain technical quality requirements and can be produced and treated at competitive costs.

The suitability of plant proteins for various technical and chemical applications has already been proven in previous research projects. Methods for extracting and isolating plant proteins have been developed and improved on a small scale in laboratories and technical schools. An industrial scale pilot production is still to be realised. Thus, the efficiency of protein production cannot yet be sufficiently evaluated.

1.2 Constraints and measures to be taken for the development of non-food uses in Germany: Oilseeds

Constraints	Focus	Proposals
Scientific/technical	• Raw materials • minor oilseeds (crambe etc.) • Industrial processes	• Improve oil quality (e.g. fatty acid profile) • Optimise agronomy (yield stability, crop protection etc.) of minor oilseeds • Improve by-product utilisation • New/more efficient chemical and biotechnological industrial processes
Environmental	• GMOs • Biodegradability and ecotoxicity • Environmental impact of activity	• Environmentally sustainable cultivation practices • Measure and standardise biodegradability and ecotoxicity • Life Cycle Analysis (LCA) of important processing chains • Develop methods to recycle biolubricants
Legislative	• German legislation • European legislation	• Investigate legislation regarding introduction of new chemicals (EINECS) • Legal frame for utilisation of products fulfilling certain environmental criteria • Durable agricultural policy framework
Economic	• Crops • Industry	• Find more economic production and logistic systems • Find markets for by-products • Optimise industrial process yields • Find new, high added value markets • Quantification of external costs
Information	• Communication	• Advertise ‘natural’ products • Improve European co-operation

1.3 Prioritisation

Germany has a considerable production potential for oilseeds. Oilseed (rapeseed, sunflowerseed, linseed) acreage was around 1 million ha in recent years, leading to an oilseed production of 2 - 3 million tons per year. The 17 major German oilmills crush 7 - 7,7 million tons of oilseeds per year, i.e. a considerable part of oilseeds is imported from third countries. For all application areas described before, Germany possesses qualified research institutes and industries. To give just some examples, Henkel KG aA, Düsseldorf, is the major oleochemical producer in Europe, Fuchs Petrolub AG, Mannheim is market leader in biodegradable lubricants. So it is difficult to find one single bottleneck limiting further development. All the tasks described under 1.2 have to be tackled simultaneously.

2 Fibre Crops

2.1 Opportunities

2.1.1 Science and Technology

In Germany, the climatic conditions limit the production fibre crops to flax and hemp. The cultivation of fibre nettle is insignificant. In 1998, the total area of flax and hemp cultivation amounted to approx. 400 respectively 3600 hectares.

Until 1996, German drug law prohibited cultivation of hemp. Thus, it was the economic potential of this plant that was evaluated, first. Up to now, cultivation has only started recently.

Flax is an old cultivated plant, thus experience in cultivation and growing is extensive. Particularly in the Benelux countries, cultivation of flax did never fully stop; therefore, plant types with a very high level of performance are available there.

In order to increase the profitability of flax cultivation, it has been examined whether there is any possibility of developing plant types which would make it possible to use both fibre and oil. So far, the results that have been obtained suggest that profitability is not increased by double-usage. The reason for this is that double-usage either improves the fibre quality and reduces the oil output or vice versa.

Over the last years, research in the field of technological use of plant fibres has shown that there are a number of different application fields for short fibres. In order to meet these new requirements, cultivation of flax types for production of short fibres has been intensified. The first new flax types were registered in 1998.

Short Rotation Coppice

The cultivation of short rotation coppice is mainly used for the production of energy by burning of the harvested timber. This timber may, however, also be used to produce building materials, timber products, and fibre products.

In order to achieve a profitable cultivation, it is important to run short rotation plantations as extensively as possible. Therefore, cultivation aims at developing low input coppice. The results of field tests show that – depending on the supply of water and nutrients and the properties of the soil – there were large differences in growth between the different types of coppice. It is expected that – in the medium term and in the long run – specific cultivation will result in improved adaptation of specific types of coppice to short periods of cultivation, a higher growth rate and a better usability.

2.1.2 Industry

2.1.2.1 Insulation Material

Production and utilisation of insulation material made of biorenewable raw material has a very long tradition. Over the last decades, insulation material made of agricultural and forest raw material has partly fallen into oblivion. Currently, modern production and construction methods and an increased ecological awareness are leading to an increased demand for insulation material made of biorenewable raw material s, such as wood, sheep's wool, flax, hemp, and straw. Their use in modern construction methods is still very new and there may be a number of building owners who may feel unsafe about it, since long-time experience is still missing. Every building owner may, however, rely on expert knowledge gathered by suppliers of building material and scientists over the last few years. This knowledge is constantly being broadened by research. From a commercial point of view, thermal insulation mats made of artificial mineral and glass fibres and boards made of polystyrene and polyurethane are the most successful insulation materials.

In Germany, both building and construction industry and marketing of building products is governed by national regulations and the German "Bauproduktegesetz" (law on building products). The use of building and insulation material is regulated by DIN standards and first and follow-up registrations at the Deutsche Institut für Bautechnik (DIBt) (German institute for construction engineering) in Berlin. The DIBt is responsible for nation-wide licensing of building products and construction methods. Before a new product can be registered and approved, it has to pass an acceptance test, i.e. – and among others – a test on fire safety and thermal insulation properties. According to the test results and the assessment of the information on ingredients and intended fields of application given by the manufacturer, the insulation material is then divided into groups specifying both fire rating and thermal conductivity and approved for certain field of application.

Insulation material for thermal and acoustical insulation is used both in residential and industrial building. Insulation material made of natural fibre and assigned both the thermal conductivity class 040 and the fire safety class B2 (or B1) may, e.g., be used for insulation of exterior walls, interior walls, intermediate floors, and roofs. Moreover, these materials can also be used for thermal and acoustical insulation of technical devices, machines, and production systems.

For certain applications, the insulation material in the form of mats, flakes (for injection into or stuffing of walls), granules, and boards is used for both thermal and acoustical insulation.

2.1.2.1.i Technology

In Germany over the last years, a number of different projects on development of products and methods for building and insulation have been promoted. Some of these projects were working on development of thermal insulation mats made of flax and oil flax and insulation boards made of the pulp of sunflower stalks, others were working on development and optimisation of corresponding innovative production methods.

Within the scope of a R&D project on development of insulation materials for thermal and acoustical insulation made of flax fibres, different methods for processing raw materials and production of fibre mats were tested and the production of fibre mats made of flax fibres was optimised for each product. Furthermore, methods for furnishing mats with bonding and fire protection agents and drying were developed. The properties of the mats and their suitability as insulation material (fire safety, thermal conductivity) were tested.

An intensive fibre preparation, particularly cleaning and breakdown (opening) as a preliminary stage in the production of fibre mats is absolutely required to ensure trouble free production of high-quality fibre mats. Oakum cross-cut to a length of 60mm showed good results.

In fibre mat production according to the aerodynamic method the produced mats have thicknesses between 6cm and 10cm. The machines are fully developed; currently, the output is about 1000kg/h. Different and precise settings make it possible to meet the requirements of different fibre mat specifications and to produce high-quality mats. The fibre mats can be reinforced by either needle-looming or application of synthetic fibre and subsequent heating (thermobonding). These methods can, however, not be accepted for an ecological flax insulation material. For this reason, an alternative method of fibre mat reinforcement by means of potato starch consisting of a spraying and a drying device was installed and used for production of insulation mats meeting the requirements of both the fire safety class B2 and the thermal conductivity group 040. The design was approved and registered.

After termination of the R&D project, a medium-size company was founded. This company has been producing thermal insulation mats made of flax fibres since the beginning of 1997. Thus, the developed product and production method were realised successfully. Currently, an agricultural company and an engineering office are examining – in the form of a joint venture project – the development of insulation boards made of sunflower pulp. The focus is on harvesting of sunflowers and production and separation of the sunflower pulp, and on development of a suitable production method. The product samples produced so far have good properties and make the use as insulation material seem feasible and promising. The R&D work is still in progress.

2.1.2.1.ii Environmental Aspects

The use of insulation material made of biorenewable raw material in both residential and industrial construction and in redevelopment may help in considerably reducing the emission of CO_2, since it makes it possible not only to save heating energy and thus reduce the consumption of fossil fuels, but also to reduce the emission of CO_2 over a long period of time.

The plants which are mainly used for production of insulation material, i.e. flax and hemp, are characterised by a comparatively extensive production while at the same time requiring only very low quantities of fertilisers and pesticides. Thus, they may contribute to breaking up of very tight crop rotation structures. An additional positive ecological factor is the use of recycled or spin-off products of insulation material production, e.g. waste paper, residual timber and timber collected in thinning out of forests.

Furthermore, insulation material made of biorenewable raw material has good organic architectural properties and positive health effects. In general, it can be recycled. Currently, corresponding procedures and methods for recycling and composting are being developed.

2.1.2.1.iii Economy

In Germany, the total market for insulation material comprises 30.6 million m³ of insulation material. The market share of insulation mats amounts to 19 million m³. Insulation mats made of artificial mineral fibres have a market share of 95%. A proportion of about 5% falls to other fibre raw materials, e.g. cellulose made of waste paper, sheep's wool, cotton, flax, and hemp.

Currently, there are three manufacturers of insulation mats on the market: one manufacturer of hemp mats, one manufacturer of cotton mats, and about ten manufacturers of sheep's wool mats. In addition, there are about ten further manufacturers of boards, mats and injection insulation material made of waste paper cellulose or timber fibres. Currently, several other companies are planning to produce insulation material made of biorenewable raw material , e.g. flax/oil flax, hemp, miscanthus and timber fibres.

The required thermal insulation measures are greatly influenced by the location of the building, its shape, its orientation and both its design and its construction. Thermal insulation is, however, the most effective way of protecting a building against thermal radiation. The benefit of thermal insulation may be assessed if one compares the energy that has to be used for production, transport and installation of an insulation material with the energy that can be saved by thermal insulation. The results of such calculations show that all thermal insulation materials pay off after only a few years, i.e. they save at least the amount of energy consumed in the course of their production and installation. A comparison of the total quantities of emitted pollutants also shows that the reduction in pollutant emission achieved by thermal insulation exceeds the quantity of pollutants emitted during production. Thus, a professional thermal insulation is an economically sensible capital expenditure, regardless of whether the insulated building is an old one or a new one. Eventually, the positive ecological balance of a material depends on the degree to which emissions can be prevented or reduced. In this regard, insulation material made of biorenewable raw material is unique, since plants need the CO_2 in the air for growing.

Today, insulation material made of sheep's wool or flax fibres costs twice or three times as much as the controversial insulation material made of mineral fibre which is currently dominating the market. The prices for cellulose insulation material made of recycled waste paper are only slightly different, this is the reason why this material is the market leader amongst alternative insulation materials. The more health-conscious and environment-conscious customers become, the easier it will be for more expensive insulation materials with a durable ecological concept to find a ready market, although this will be in a limited way; this market still must be regarded as niche market. Thus, one can say that insulation material made of biorenewable raw material can be produced in an economically efficient way and that this material is competitive. It is, however, required to determine the potential for cost reduction and to use it to full extent to realise greater sales volumes. Cost reduction can be realised by means of rationalisation in production of both raw material and insulation material and reduction of unit costs while at the same time increasing the production volume.

On account of the increasing number of heat protection regulations the insulation material market is characterised by considerable growth rates. Above-average growth rates are expected for ecological insulation material. A medium-term market share of over 10% is expected for insulation material made of biorenewable raw material . There is, however, only very few scientific evidence and experience on the use of biorenewable raw material for production of insulation material for thermal and acoustical insulation. Compared to its sales potential, the use of biorenewable raw material for production of insulation material is still extremely modest.

The following factors impeding a wide use of this material have been identified:

- high costs for raw materials and production,
- high prices for insulation material made of biorenewable raw material ,
- to date, there is no well-founded experience or test result concerning its suitability for use, its product and long-term properties, and its durability,
- building owners, planners, and administration are not informed about available and suitable insulation material made of biorenewable raw material ,
- construction companies are not informed about and do not have any experience in the particular requirements for installation of insulation material made of biorenewable raw material ,
- there is a risk of warranty claims towards planners and construction companies,
- very often, both logistics and marketing of insulation material made of biorenewable raw material are insufficient,

Based on the known favourable market perspective and ecological advantages of insulation material made of biorenewable raw material the above-mentioned obstacles have to be eliminated. Further study, R&D projects and demonstration projects may make it possible to develop and extend this market segment for agriculture and forestry.

2.1.2.2 Fibre-Reinforced Composites

To improve their mechanical properties, fibres of different origins are very often added to thermoplastic or duroplastic plastics in the production process. Common materials for reinforcement are glass fibres, but also synthetic or plant fibres. A large proportion of the approx. 300.000 t of glass fibre produced and installed in Germany every year is used for production of glass fibre-reinforced composites.

These fibre-reinforced composites can be used for a variety of applications, they are, e.g., used for production of surfacing units in manufacturing of automobiles and wagons, piping systems for irrigation and drainage, ventilation, and in the furniture and leisure industry.

Waste disposal problems are the strongest arguments for an increased use of natural fibre in corresponding materials. Other important arguments are that natural fibres reduce the weight of fibre-reinforced composites, that they can be produced almost completely CO_2 neutrally, and that they are biodegradable.

The introduction of natural fibres is made more difficult by the extraordinarily high standard in production of glass fibre-reinforced materials and the broad range of their property profiles. Nevertheless, the demand for natural fibres for industrial-technical applications has been increasing considerably over the last few years. In addition to the natural fibre materials which have been used for a very long time, such as wool, cotton, coconut and jute, the fibre plants flax and hemp are increasingly moving into the centre of interest in Germany.

Some of the prerequisites for use of natural fibre in production of natural fibre-reinforced composites are very advanced methods of fibre production and preparation.

2.1.2.2.i Technology

The reason for the growing interest in natural fibres for use in industrial-technical applications is the necessary search for materials which may substitute asbestos and glass fibres and, increasingly, synthetic fibres.

A prerequisite for production of natural fibre-reinforced composites (NFRC) is the provision of natural fibres such as flax and – since April 16, 1996 (in Germany) – also hemp with a low tetrahydrocannabinol (THC) content. The BML has been and still is supporting a number of joint venture projects, e.g.:

- "Entholzung von Grünflachs" (removal of wooden particles from raw flax)
- "Flachsentholzung und -faseraufbereitung" (removal of wooden particles from and preparation of flax)
- "Einsatz von Flachs in Reibbelägen" (use of flax in friction linings)
- "Einsatz von Flachs in faserverstärkten Kunststoffen und Biopolymeren" (use of flax in fibre-reinforced plastics and biopolymers)
- "Optimierung der Produktion, der Verwertung und des Recycling von technisch nutzbaren Kurzfasern" (optimisation of production, utilisation and recycling of short fibres for technological purposes).

The model project "Entholzung von Grünflachs" (removal of wooden particles from raw flax) was conceived for testing of an experimental device used for rough removal of wooden particles from flax in the field with regard to cultivation problems, technological adaptation of this technology to high temperature vapour pressure preparation and development of a quality control system for flax.

The joint venture project "Flachsentholzung und -faseraufbereitung" (removal of wooden particles from and preparation of flax) was founded to develop and test – in two phases – concepts for a machine system for continuous separation of wood-free flax particles according to fibre length. New chemical engineering methods for mobile and stationary processing of flax fibres for technological and textile purposes and suitable parameters were developed and measuring methods for quality assurance of flax determined.

The joint venture project "Einsatz von Flachs in Reibbelägen" (use of flax in friction linings) worked on development and testing of brake and clutch linings containing flax fibres for different fields of application.

The aim of the joint venture project "Einsatz von Flachs in faserverstärkten Kunststoffen und Biopolymeren" (use of flax in fibre-reinforced plastics and biopolymers) was to develop a modification method of mechanically disintegrated fibres to achieve good pourability for use in extrusion processes, to develop fibre-reinforced plastics, and to optimise fibre-matrix-adherence depending on the matrix material (thickness, polypropylene, polyurethane, epoxy resin), and to develop a production technology for production of composites for automotive engineering.

The joint venture project "Optimierung der Produktion, der Verwertung und des Recycling von technisch nutzbaren Kurzfasern" (optimisation of production, utilisation and recycling of short fibres for technological purposes) worked on aspects of growing, cultivation, and optimisation of the technology for removal of wooden particles, mat production and development, and optimisation of processing methods for production of NFRCs for automotive engineering.

Some of the above-mentioned joint venture projects resulted in improved technologies for removal of wooden particles and preparation methods. Up to now, only very few of these preparation technologies have been realised. To some extent, the complex quality requirements for natural fibres with regard to their use and unbiased criteria of assessment could be clarified.

2.1.2.2.ii Environmental Aspects

For the field of fibre-reinforced composites aspects of environmental-friendliness and the requirements of the law on cycle economy increasingly move into the centre of interest. Entire production processes – from the selection of raw materials up to production methods and disposal options – must be examined from this point of view.

In addition to their almost CO_2 neutrality, natural fibres have – compared to glass fibres – an extraordinarily low density. This means that by using these fibres, the weight of parts in automotive engineering can be reduced, leading in turn to a reduced fuel consumption. The processing properties of natural fibres result in physiological advantages.

Basically, recycling of natural fibre-reinforced composites applied to thermoplastic plastic matrices is possible. Up to now, this process requires, however, cutting of the fibre to a very short length, thus destroying its mechanical characteristics.

Compared to glass fibre-reinforced materials, disposal of natural fibre-reinforced material is much easier. It is biodegradable, has a high calorific value, and is largely CO_2-neutral, i.e. it can be used for energy generation.

2.1.2.2.iii Economy

Currently, an annual amount of approx. 10 million tons of plastics and 300,000 tons of fibre glass is used in Germany. There is sales potential for natural fibres in the field of NFRC. Whether or not the use of NFRCs is profitable will depend on the supply of natural fibres.

Up to now, cultivation and processing of flax and hemp has been highly subsidised compared to grain and oil crop. This may, however, change with the agricultural reform Agenda 2000. Cultivation of fibre crop may become unprofitable for German farmers. So far and with only a few exceptions it has not been possible to produce the required quantities of high-quality fibres at reasonable prices in Germany. Each step in mechanical processing of the fibres intended to improve fibre quality brings about considerable costs.

Preparation of fibres by vapour pressure may make it possible to produce fibres of a better quality than the currently used methods of raw flax processing. The test fibres produced by means of vapour pressure had a higher degree of uniformity and an improved profile of properties than mechanically prepared fibres. Thus, vapour pressure preparation may make it possible to use this fibre in industrial applications and to supply sufficient quantities of fibre of a continuous high quality at reasonable prices similar to those of e.g. glass fibre or regenerated fibre.

2.2 Constraints and measures to be taken for the development of non-food uses in Germany: Fibre crops

Constraints	Focus	Proposals
Scientific/technical	• Raw materials • Industrial processes and products	• Improve fibre qualities • Improve harvesting and fibre decortification technologies • Improve established and find new application areas and products for different fibre qualities • Optimise logistics of production/processing chain
Environmental	• Environmental impact of activity	• Environmentally sustainable processing practices • Life Cycle Analysis (LCA) of important processing chains
Legislative	• German legislation • European legislation	• Investigate legislation regarding material standards • Measure and standardise fibre and product qualities • Legal frame for utilisation of products fulfilling certain environmental criteria • Durable agricultural policy framework
Economic	• Crops • Industry	• Find more economic production and logistic systems • Find markets for by-products • Optimise industrial process yields • Find high added value markets • Quantification of external costs
Information	• Communication	• Advertise ‘natural’ products • Improve European co-operation

2.3 Prioritisation

In contrast to the sector of vegetable oils, for the area of plant fibres the whole primary production, processing and utilisation infrastructure is not well developed in Germany. Many companies active in this field suffer from a lack of capital, causing difficulties to overcome periods with low revenues. This makes it difficult to transfer the results of numerous R&D projects into practice.

3 Carbohydrate Crops

3.1 Opportunities

3.1.1 Science and Technology

Similar to the oil plants, man uses a vegetable reserve material when using starch plants. Starch is a polysaccharide, which mainly consists of two different classes of molecules: amylose, which is the linear form, and amylopectine, the branched form. Due to the special structure of its molecules, starch is suited for being used in the food and in the non-food sector, which processes nearly half of the starch produced in Germany. The most important starch plants in Germany are potatoes and wheat. The maize cultivated in Germany is not used for producing starch.

For cultivating potatoes for the production of industry starch, other selection criteria are substantial than for cultivating edible potatoes. For example the outer and inner quality can be ignored. Here, the decisive factors are a high starch quantity and an improved starch quality, e.g. by reducing the contents of protein and potassium.

Special industrial applications only need one starch component, amylose or amylopectine. For that reason the quality of starch has been influenced by means of cultivation. By means of genetic engineering, potato plants have been created which produce nearly exclusively amylopectine. The creation of a potato which produces pure amylose starch is the next aim.

There are also efforts to optimise wheat for using it as industrial raw material. The content of starch is increased and the content of protein is lowered. In addition, low input sorts shall be developed to lower the production costs.

Some sorts of peas are also interesting for the industrial usage of starch because of their high content of amylose. For industrial use special sorts have been developed.

In Germany, sugar which is a disaccharide of glucose and fructose is exclusively made of sugar beets. Most of the produced sugar is used in the food sector. A special strain of sugar beets for the production of raw sugar for non food applications does not exist, because the aims of cultivating sugar beets for the usage as biorenewable raw materials are the same as for cultivating them for the food sector, e.g. increasing the sugar share or the resistance to pests.

On the other hand, research scientists try to create a sugar beet which produces inuline, a polyfructane which is interesting for technical usage.

3.1.2 Industry

3.1.2.1 Chemical Products based on Sugar

The production of sugar (saccharose or beet sugar) is a traditional corner-stone of the German agriculture with a quantity of more than four million tons per year. Most of the sugar is used in the food industry. The discrepancy between the use of sugar within and without the food sector is considerably more pronounced than in the areas of starch and vegetable oil. Only 60-70,000 tons per year, which is slightly more than one percent, are used for chemical-technical purposes, but in addition, considerable amounts of glucose which is made of starch and sugar extracted from molasses which are both by-products of the sugar production are processed in the industry.

The most important chemical-pharmaceutical application for low-molecular carbohydrates like saccharose and glucose is based on the fermentative conversion of the carbohydrates by micro-organisms into industrial usable products. Results of the bioconversion by the enzymes of bacteria and yeast are alcohols (ethanol and others), organic acids (citric acid and others), the biopolymers polyhydroxybutanoic acid (PHB) or polylactic acid (PLA), antibiotics, vitamins and others.

Beside the production of synthetic materials, especially polyurethane, and of sugar surfactants like alkyl polyglucosides, N-methyl-glucamides and saccharose fatty-acid ester has reached a considerable amount.

The measures for expanding the technical use of sugars are accompanied by projects in cultivating and genetic engineering. The aim of these projects is to enable the biosynthesis of certain carbohydrates like cyclodextrine and polyfructane (inuline) in traditionally cultivated plants or to increase their yield considerably.

3.1.2.1.i Chemistry

There are two different possibilities of using sugars technically. Using biotechnological methods, sugar can be converted into products of higher quality. In this case, sugar is a nutrient medium for microorganisms. Due to the market potential, primarily the fermentation into alcohols, the production of special carbon acids and the biotechnological production of polymers are interesting methods. These processes are already optimised to a large extent and are used commercially.

Besides, the possibilities for the application in the area of synthetic materials are checked. Sugar derivatives can directly be built into the polymer structure of traditional synthetics or they can be used for producing process materials and additives like emulsifying agents or softeners. Carbohydrates occupy the most important place for the production of biodegradable plastics. By fermenting sugar you can, e. g., get co-polymers of polyhydroxybutanoic/-valeric acid or the monomers for polylactic acid which is a technically relevant plastic. Both polyesters have excellent material characteristics, can be processed with traditional methods and can be decomposed in commercial composting plants after their use.

As the biotechnologically produced synthetics PHB, PLA and other polyhydroxyalkane acids actually are more expensive than the plastics produced in large quantities, the efficiency during production and the improvement of the polymer characteristics are the most important aspects in the development strategies. So the aim of the actually supported joint research projects "Produktion von Polyhydroxyfettsäuren in Nutzpflanzen" (Production of Polyoxy-Fatty Acid in Crops) is the production of PHB as storing substrate by plants. Single steps of the procedure during the processing of lactic acid have been optimised in the project "Entwicklung eines neuartigen Einschritt-Prozesses zur Darstellung von Dilactiden" (Development of a New Single-Cutting Process for Describing Dilactites), the complex compound project "Herstellung von Polymeren auf Milchsäurebasis und ihre Anwendung als biologisch abbaubare Kunststoffe" (Production of Polymers Based on Lactic Acid and their Application as Decomposable Plastics) the whole process from the fermentation of the lactic acid to the creation of the polymers has been examined from the technical and economical aspects.

The direct chemical modification opens up further possibilities of refining sugar. The most interesting aspect for the production of synthetics is its polyfunctionality. The large number of reactive hydroxyl groups predestines sugar among others for the synthesis of polyester or polyurethane. Examples are the use of saccharose or its derivatives as prepolymers for polyurethane HR-foams.

As a joint project   on monosaccharideshas proved, various carbohydrates can also be built in into polyolefines after a derivation. Specific characteristics like hygroscopicity, electrostatic behaviour and others can be improved by sugar.

Beside the low-molecular carbohydrates, the polyfructane inulin also has its importance, because according to first results of the joint research project "Erweiterung des Nutzungsspektrums der Zuckerrübe" (extension of the use spectrum of the sugar beet) it can be processed into softeners for synthetics, complexing agents or surface-active substances.

Unlike the production of new products with specific characteristics, the transformation of carbohydrates into basic chemicals for the most part is not advantageous neither economically nor ecologically for the foreseeable future.

3.1.2.1.ii Environmental Aspects

In the last years, the support of research projects in the field of detergents and cleaning agents has been oriented ecologically. The discussion about the immense use of not or hardly decomposable surfactants, dispersing and complexing agents and other components and the resulting pollution of the biosphere intensified the search for alternatives. In many ways carbohydrates are well suited for substituting conventional components of cleaning agents. For example, after a transformation with fatty acid derivatives, low-molecular sugars like glucose and saccharose can be used as decomposable surfactants which are very kind to the skin. Actually non-ionic sugar surfactants are produced in Germany at approximately 35,000 tons per year. They are offered mainly in three variants on the market. Two of them are alkylpolyglucosides and N-alkylglucamides made of glucose which are used in considerable quantities as surface-active components in modern detergents and washing-up liquids. The third variant is saccharose fatty-acid ester which is mainly used in the cosmetic field. New researches in the joint project "Saccharosefolgechemie" and in the research project "Direkte O-Alkylierung von Carbohydrateen zur Herstellung von oberflächenaktiven Stoffen - Untersuchung zur Gewinnung neuartiger Tenside, Dispergiermittel und Emulgatoren" (direct o-alkylation of carbohydrates for the production of surface-active materials - examination for gaining new surfactants, dispersing agents and emulsifying agents) put special emphasis on the saccharose as surfactant component.

The complexing characteristics of several derivates of sugar have been known for longer. Especially the dispersing and complexing effects of sugar acids, that are selectively oxidated carbohydrates, are interesting as co-builders for reducing the water hardness in suds. The following research projects examine the oxidating procedures and the application of corresponding products in detergent formulations: the project "Polycarboxylate auf Carbohydratebasis als biologisch abbaubare Komplexbildner für den Einsatz in Wasch- und Reinigungsmitteln" (polycarboxylates based on carbohydrates as biodegradable complexing agents for the use in detergents and cleaning agents) for starches, "Oxidative Spaltung nachwachsender Rohstoffe an Heterogenkatalysatoren" (oxidative separation of biorenewable raw materials at heterogeneous converters) for low-molecular sugars like saccharose and glucose, "Erstellung einer Pilotanlage zur Herstellung von Lactobionsäure aus Lactose" (development of a pilot plant for the production of lactobion acid from lactose) for milk sugar. Already far advanced is the development of co-builders based on starch which will probably be introduced to the market in the next years.

The selective oxidation with oxygen or hydrogene peroxide, which are ecological oxidation agents, is not completely solved yet, so actually oxidations have to run mostly by using compounds of chlorine or nitrogene oxides.

Apart from the direct use of oxidised carbohydrates as dispersing agents and others, by means of grafting or copolymerization in future saccharides can also help "traditional" complexing agents to get an acceptable decomposition behaviour.

3.1.2.1.iii Economy

The use of sugar in the chemical-technical area is regulated by the sugar market organisation of the European Union which guarantees the access of saccharose and glucose at world market prizes by production refunds and creates independence from the agricultural internal market of the community. The chemical industry in Germany uses approx. 60 - 70,000 tons per year.

The value of sugar on the world market is between 450 and 550 DM/t. Economically lucrative is the conversion by creating a high added value, e.g. the conversion of sugar into special chemicals or medicine. The production of decomposable polymers by the bioconversion of sugar will soon be economical. They are in direct competition with traditional polymers, so that the broad introduction into the market can be realised by considering their positive contribution on the reduction of waste in a financial way.

Producing ethyl alcohol for technical use in a large scale actually fails because of the economical conditions. Ethanol, which in its pure form or as ethyl-tert.-butylether ETBE is also interesting as fuel component and for chemical usage, could become one of the most important refining products made of biomass, but actually it is not efficient from the energetic and economic point of view so that it had to be subsidised on a large scale.

3.1.2.2 Chemical Products based on Starch

3.1.2.2.i Chemistry

With regard to the quantity of more than 600,000 tons in the chemical-technical sector, starch is already an important agrarian raw material for the industry and is beside wood and vegetable oils one of the most important biorenewable raw materials. In Germany starch is made of maize, potatoes and wheat, but the raw materials generally come from Germany only in case of potato starch and cereal starch. Nevertheless larger amounts of maize from growing areas in southern Germany have been processed successfully in a starch mill.

The basic aim for supporting the research in the field of starch is to increase the quantities of starch in the existing trading areas and to find new ranges of application, using starch in its native, chemically or physically modified form or as hydrolisate as part of new products.

In the last years several projects have been supported which dealt with the development of decomposable materials made of starch. The starch has mainly been used in native form for the production of materials similar to synthetic plastics, only by integrating plasticisers and additives. In this connection basic connections between the structure and the characteristics of the polysaccharides amylose and amylopectine as principal components of starch could be demonstrated.

The research projects which deal with the chemical modification of starch contribute to adapting the agrarian raw material to certain quality requirements derived from the application of the material. Using starch as flocculent or precipitant demands, apart from certain molecular parameters, cationic and/or anionic charges. For this purpose the relatively low substitution degrees realised in the traditional starch treatment have to be increased by means of ecological and economically suitable procedures, including the possibilities of derivation known from the cellulose chemistry as a basis for new methods and procedures.

In a project of the Henkel KGaA, a German producer of detergents, a procedure has been developed which uses nitrogen dioxide as oxidising agent for the production of carboxyl starch. The application technology examinations of the decomposable complexing agent confirm the very good washing characteristics of the product.

Increasing the swelling property as well as the ability of starch to form gel is the basis for the research and development work of the University of Osnabrück to develop carboxymethyl starch as adsorptive materials.

In the traditional application of starch in the paper production, the closed water cycle makes new demands on the paper additives. For that reason higher substituted cationic starch and hydrophobic starch are required. In this field, among others, a joint project is supported in which the basic material for modifications and for the examination of possible applications is not starch but flour, which is a mixture of starch and protein. By using flour it is not necessary to separate the starch, while the protein which is included in the flour can be used as modifying agent which can improve the application characteristics.

The support for research does justice to the importance of starch products as raw material for biotechnological processes in many ways, for example by supporting transforming processes for the production of lactic acid and polylactides, itaconic acid, poly(hydroxydicarboxylic acid) ester, 1.3 propane diol etc.

3.1.2.2.ii Environmental Aspects

Apart from including the native biorenewable raw material, all supported projects claim to develop processes of converting the starch economical and ecologically. At searching new modification processes, the environmental aspects are taken into account from the beginning. New procedures of producing cationic starch derivatives are of no use if the solvents which are necessary for the reaction can only be regenerated with a high expenditure or if they can not be disposed without problems.

The utilisation of the by-products which are obtained during the starch production (protein, fibrous materials) is also taken into consideration and examined.

In future, the biotechnological processes will become more and more important for the production of starch hydrolysates and derivatives, because the used enzymes mostly work effectively under protecting reaction conditions.

The aspects concerning the ecological compatibility of BAW based on starch are discussed in chapter 3.1.2.3. In future, the ecological aspects of products made of the biorenewable raw material starch have to be considered financially to a greater extend to get a solid basis for the technical use of starch. Table 13 of annex 1 compares the effects of cultivating different starch producing plants on the environment.

3.1.2.2.iii Economy

The competitiveness of starchy plants can be determined by looking at the marginal contribution. Comparing the marginal contributions of the most important starch plants on basis of the average product and the prices of 1990, wheat has the best result with regard to the supporting requirement. If the results of the by-product marketing are also taken into account the ranking changes in favour of maize, followed by wheat and potatoes.

The technical processes for the production of starch are economic processes which were established decades ago. The starch producing companies endeavour to optimise the ecology of these processes considering the environmental requirements. An important aspect in improving the economic viability affects the usage of proteins and other by-products obtained in the starch production. During the last years, the processes have been optimised on the self-initiative of the starch producers and the water cycles have been closed to a great extent.

The established derivating processes are developed well enough for traditional chemical-technical applications, but if higher substituted starch derivatives are required, a high technological expenditure is necessary to produce them which often results in the high prizes of the concerned products. For that reason, it is necessary to search for new or improved derivatisation methods.

Primarily, the paper sector has a considerable potential for the application of new starch derivatives. In future, other polymer paper additives can be substituted by new starch products. In addition, starch derivatives can be used as sizing agent in textile applications.

In 1996, in Germany 574,000 t starch were used in the non-food sector, which is 41% of the total consumption. Changes in the market organisation for starch had had a decisive influence on the development of the chemical-technical processing of starch products. Today, further development of the starch sales in the broad sector of the chemical industry can not be estimated reliably, because numerous innovations are still in the stage of development so that no statement can be given about the time and size of a realisation. An additional problem is that especially in the biotechnological sector starch is a direct competitor of sugar.

3.1.2.3. Biodegradable materials

3.1.2.3.i Technology

Biodegradable materials (BM) can be produced from both animal and/or vegetable raw materials and on the basis of fossil raw materials. E.g. in some fields, providers of high-quality food are beginning to use packaging material made of BM.

Research projects in the fields of developing and manufacturing BM from domestic vegetable raw materials such as starch, cellulose, sugar, vegetable oils and natural fibres were supported.

Supported projects in this field are dealing with material development and optimising the procedures that are generally used in plastics industry. On the basis of native and modified vegetable raw materials, both – films and moulded objects – can be produced from BM.

The German company Wolff Walsrode AG has dealt with the development of extrudable, degradable aliphatic cellulose derivatives in various stages. The property profile of polyethylene and polypropylene cannot be reproduced with the help of the examined degradable cellulose derivatives, however, these derivatives come close to the mechanical properties of polystyrene.

Unlike cellulose, starch can be thermoplastically processed either in modified or in its native form. With the help of water or glycerine as softening agent, native starch can be successfully destructurised in the extruder and processed into packaging chippings and/or flat films. An additional modification of starch, the so-called internal softening process, can additionally be used to produce the required water resistance. However, hydrophobising restricts biodegradability. Various projects were supported that dealt with optimising material recipes and detecting the links between the compounds and mechanical characteristics of materials. As BM are destined to be used as packaging material, not only the application characteristics but also the processing characteristics of materials have to be adapted in such a way to make a change to these new materials possible, without major problems and expenditures. Therefore, the Technische Universität Dresden (Dresden Technical University) is examining the processing behaviour and the suitability for packaging machines of packaging materials made of growing raw materials. This project is performed in close co-operation with all manufacturers of flexible packaging materials (films).

Projects dealing with the BM manufacturing via fermentative processes have so far only played a minor role in the project promotion.

3.1.2.3.ii Environmental aspects

BM are controversially discussed in public. With the development of these materials, a positive contribution to some environmental aspects is expected. The most important facts in this public discussion are based on the CO_2 neutrality of the growing raw materials and/or the complete recycling potentiality of biological substances. In addition to the three conventional methods of recycling synthetic materials (i. e. material, raw-material and energetic recycling) BM products provide further possibilities through composting and fermentation. However, a high degree of biodegradability and a good characteristics profile still represent a considerable discrepancy frequently.

The disposal of the already developed products was embodied in the German Verpackungsverordnung (packaging regulation) after long discussions. According to this regulation, BM packaging materials which are fully degradable are temporarily exempted from the compulsory returning system up to 2002. In the time left, a exhaustive compulsory BM returning system has to be built up. To realise this, the use of the Biotonne (i.e. rubbish bin for biological waste) can be recommended. BM made of growing raw materials are regarded as biological waste, as defined by the German Bioabfallverordnung (biological waste regulation).

As a preparation for including this new range of materials within the amendment of the German Verpackungsverordnung, a disposal concept had to be set up. This process was accompanied by the development of all relevant testing methods that are required for certifying the materials according to DIN 54 900 and the possible disposal via composting.

However, the disposal system of BM packaging materials via composting will only work, if customers are informed about which packaging materials are actually suitable for composting. For this reason, the BML supported a research project for "setting up an arrangement for the disposal of biodegradable materials".

Misgivings that a large portion of wrongly disposed of packaging materials are to be expected, turned out to be unfounded from the present point of view. After introducing the "Grüne Punkt" ("green dot"), the problem of wrongly disposed of packaging turned out to be much less severe than had been supposed beforehand. The same development can be expected for appropriately labelled BM.

Objections that the launching of BM would result in a strong rise in compost quantities were expressed. However, since – from a long-term point of view – a third of synthetic material will be replaced by BM, only a 5% increase of biological waste can be expected.

3.1.2.3.iii Economy

Determining the market potentials for BM in the respective applications are currently based on more realistic considerations compared to those of some years ago. According to new cautious estimates, an annual BM potential of approximately 50,000 to 200,000 tons can be expected on the Western European market in the year 2000.

BM have a good chance in those places where their application is technically reasonable, i. e. application focusing on the practical benefit of the degradability under ecological and economic aspects.

For BM that are presently on the market, 5 to 10 DEM per kg have to be paid. Thus, they are often more expensive than comparable materials based on mineral oil. For this reason, in many discussions disposal costs are included in the comparison of materials. For the disposal of synthetic materials via the "dual system", approximately 3 DEM per kg are currently charged. Composting should be realisable for 0.80 DEM per kg.

3.1.2.4 Chemical Products Based on Cellulose

New and improved methods for production of cellulose and wood pulp and chemical use of cellulose are the fundamentals of the product line lignocellulose/wood, which also includes (further) development of derived timber products and new compounds, including production and testing of new glues based on biorenewable raw material and realisation of methods for biological wood preservation.

Cellulose is the biorenewable raw material with the second-largest sales potential (quantity) following the direct processing of timber. The main fields of application for cellulose are production of paper and cardboard, textile industry, building industry, and plastics industry.

On account of different general conditions the situation in Germany is very unfortunate, since three quarters of the annual demand for approx. 4 million tons of cellulose for the paper and chemical cellulose industry have to be imported, and – on the other hand – there is no corresponding sales market for timber of poor quality and timber from thinned out forests. Therefore, an important aim has to be the restructuring of these conditions and thus the elimination of these discrepancies.

3.1.2.4. i Chemical Industry

Compared to the cellulose used for paper production, the cellulose used by the chemical industry has to be upgraded by transformation, e.g. in the viscose process, or by further upgrading resulting in derivatives in the form of ethers, esters, etc. In recent years, activation, transformation, and production of derivatives have been of particular importance for the use of chemical cellulose in chemical processes. New methods for production of reactive cellulose and their advantages for further processing were examined in the joint venture project "Aufbereitung, Aktivierung und Derivatisierung von Zellstoffen im Technikumsmaßstab" (Preparation, activation and formation of derivates of chemical wood pulp for technical purposes).

Increased efforts are made to find an alternative for the established viscose method for transformation of cellulose into textile fibres or foils. Several different methods using the solvent N-methyl-morpholine-N-oxide (NMMO) were developed and partially put into practice. Another point of increasing interest is the transformation of cellulose together with other escort materials to improve the properties of specific products. Thus, the project "Erzeugnisse aus Polysaccharidverbunden" (products made of polysaccharides) proved that e.g. compounds of cellulose and starch or other polysaccharides can be produced using NMMO.

New materials made of wood pulp are a second important topic. Here, the main aim is to add new products with interesting properties to the classic material cellulose tetracetate. For more than a century, cellulose tetracetate has been the most important thermoplastic material made of cellulose, which – due to its chemical stability – is not biodegradable. The search for cellulosic thermoplastics that can be decomposed by microorganisms under appropriate conditions resulted in materials with suitable polymeric properties meeting the requirements of thermoplastic processing and biodegradability determined in the project "Extrudierbare, kompostierbare aliphatische Cellulosederivate" (biodegradable aliphatic cellulose derivates for extrusion). These materials may, e.g., be used as matrices in fibre-reinforced compounds. Developments in the project "Biologisch abbaubare cellulosische Verbundwerkstoffe" (biodegradable cellulosic compound materials) also resulted in thermoplastics based on wood pulp which may be used for fibre compound materials.

Another important aspect is described by the use of true or regenerated cellulose fibres in fibre-reinforced compound materials. Both long and short cellulose fibres can be used for reinforcement of thermoplastic matrices. The suitability of cellulosic short and long fibres for co-extrusion with thermoplastic starches and the creation of improved material properties resulting from this were, e.g., described in the project "Optimierung von Stärkepolymeren für die Verarbeitung im Polysaccharidblend" (optimisation of starch polymers for processing in polysaccharide blends).

Basic work on structural properties and the development of new methods for selective formation of derivates is currently being carried out in an extensive programme of the Deutsche Forschungsgemeinschaft (German Society for the Advancemant of Scientific Research). For this reason, the BML has only supported study in this field in single cases over the last years. An example is the continuation of the "Polysaccharidverbund" (polysaccharide association) with reduced extent. In the years to come, the results of the DFG-programme must, however, be used and further developed after thorough examination to give a fresh impetus for derivation or transformation of cellulose for industrial purposes.

The use of cellulose cannot be separated from the use of its coupling product lignin which is a by-product of the timber preparation process. Most preparation methods use lignins for heating in reclamation of chemicals and energy production. Despite this fact, the number of experiments carried out to make lignins usable for higher upgrading is very high.

The use of technical lignins as polyol components taking into account the phenolic structures for production of polyurethanes, particularly of high-resistance foam, is quite successful. According to the results of the project "Entwicklung und Erprobung von Holzwerkstoffen auf Basis von Phenoloxidase- und Peroxidase-aktivierten Ligninen" (development and testing of derived timber products based on phenol oxidase and peroxidase-activated lignins) prepared lignins may also be used as glue components for derived timber products, since they may be coupled to polymeric structures after application onto fibres or shavings.

3.1.2.4.ii Environmental Aspects

In the last years, the production of cellulose as an intermediate product for the production of paper and further processing by the chemical industry has been discussed in public several times from the ecological point of view. In the late eighties and early nineties, the considerable pollution of the biosphere by waste water and emission led to the closing of 16 of the original 22 cellulose plants and to a capacity reduction of approx. 50% to the actual capacity of 730,000 tons per year. This reduction concerned, among others, all German producers of sulphate pulp, so actually the German sulphate pulp processing industry is totally dependent on imports. As a result, the amount of imported sulphate pulp grew from 2.8 million tons in 1990 to 3.3 million tons in 1994.

Apart from the waste water and air pollution by classic procedures, the bleaching procedures for celluloses also are of crucial importance for the public discussion and therefore for marketing. Using elemental chlorine as a traditional and cheap bleaching agent is the most important point of criticism because it is physiologically questionable and pollutes the processing waste water considerably with halogen. During the last decade bleaching procedures have been developed which use less dangerous compounds of chlorine (ECF-celluloses, elemental chlorine free) or which work completely without chlorine or its compounds (TCF celluloses, total chlorine free). The fact that 80% of the world-wide production of TCF celluloses are sold in Germany shows the special sensitivity of the German market for this subject.

The negative environmental aspects mentioned above led to a further development of the classic pulping processes with the aim of closing the process cycle as far as possible to reduce the pollution of waste water and the emissions clearly.

In parallel with that several alternative process variants have been proposed, which are able to separate the fundamental elements of wood (cellulose, lignin and hemicellulose) by using organic acids or alcohol. To the group of these Organosolv processes belong the processes Acetocell, Alcell, Asam, Formacell, Milox and Organocell, which enable simple pulping of the wood components as well as chlorine free bleaching processes at a mostly closed cycle of water and chemicals and which also work economically with small, non-central production capacities.

The concept of semichemical thermomechanical pulping of fast growing types of wood with low extracts while adding alkalis and peroxides (APTMP procedure) is a concept which breaks totally new ground in the joint project " Modellvorhaben STORA - Pappelanbau für die Papierherstellung" (pilot project STORA - cultivating poplars for paper production). With this procedure woodpulps can be produced which can substitute traditional long fibre celluloses in particular paper qualities.

In parallel with establishing the modernised traditional procedures, new procedures are developed which could lead to a decentralised production of chemical conversion pulp with integrated further processing. In the research project "Hochdruck-Chemiezellstoff" (High-Pressure Chemical Conversion Pulp) for example the conditions for a pilot plant are to be created in which wood can be processed to highly reactive chemical conversion pulps, using the technological principle of steam explosion pulping.

3.1.2.4.iii Economy

The total consumption of cellulose in Germany is approx. 4.2 million tons per year and is dominated by the paper pulp market. The market for chemical conversion pulp covers about 180 - 200,000 tons per year. The products made of chemical conversion pulps which are established in the market can be divided roughly into the four classes viscose products, acetates, cellulose ether and nitrates, relating to their importance. With a market share of 60 %, viscose products like viscose staples, filaments, cord, cellophane etc. are world-wide some of the most important chemical conversion pulp products, but the market trend has been negative in the last years. This trend is a result of the high cost-push of the synthetic fibres and films, the competition with natural fibres and also additional costs during the viscose processing due to ecological aspects. On the other hand, the consumption of cellulose acetates, which are actually the second most important product group with a share of 20% on the world market, has a positive trend. Most of all the increasing demand for cigarette filters in the developing countries is the reason for this growth. Cellulose ether also possess an increasing sales volume, which is realised most of all by the main product carboxymethylcellulose (CMC).

Profitability examinations for celluloses and their chemical derivatives are firmly linked to the price fluctuations for chemical conversion pulps. Due to the high quality demands the prices for chemical conversion pulps, which are actually between 1,000 and 1,300 DM/t, are about 20-30% higher than the prices of paper pulps. This is the figure with which the described tests concerning the integrated cellulose production are compared with economically. On the other hand the comparatively high basic quality makes clear that products made of chemical conversion pulp have a high added value and that they have to realise this value by means of suitable characteristic profiles.

3.2 Constraints and measures to be taken for the development of non-food uses in Germany: Carbohydrates

Constraints	Focus	Proposals
Scientific/technical	• Raw materials	• New raw material qualities • New applications
	• Industrial processes	• Integrated production and processing units
Environmental	• Biodegradability and ecotoxicity • Environmental impact of activity	• Environmentally sustainable cultivation and processing practices • Life Cycle Analysis (LCA) of important processing chains • Closed water and material cycles
Legislative	• German legislation • European legislation	• Investigate legislation regarding introduction of new chemicals • Adapt legislation regarding biodegradable waste • Legal frame for utilisation of products fulfilling certain environmental criteria • Durable agricultural policy framework
Economic	• Crops • Industry	• Find more economic production and logistic systems • Find markets for by-products • Optimise industrial process yields • Find high added value markets • Quantification of external costs
Information	• Communication	• Advertise 'natural' products • Improve European co-operation

3.3 Prioritisation

Equivalent to the sector of oils and fats, Germany has good natural conditions for the primary production of starch or sugar containing crops and cellulose. The processing industry is highly efficient. In 1995, 9 starch companies produced in 17 plants, mainly in North Germany and East Bavaria. Also the sugar processing industry has undergone a concentration process during the last ten years. Both industries are highly research and innovation oriented. Also the standard of the German chemical industry in utilising carbohydrates is high. So future activities should focus on expanding existing and finding new applications for carbohydrates.

German cellulose producers, with only six remaining plants, satisfy only 17 % of the paper pulp demand and 10 - 15 % of the chemical pulp demand. Therefore the expansion of production capacities is in the planning stage.

4 Other plants - Speciality Crops

4.1 Opportunities

The following section focuses on plants used for dyeing as well as medicinal plants and spices.

4.1.1 Science and Technology

Various dyeing plants, such as woad and madder, were of great importance for agriculture in the Middle Ages. However, their cultivation came to an end as a result of imports and the development of synthetic pigments, so that the state of cultivation of most plants corresponds to that of wild plants. As a result of a changing consumers awareness, natural pigments, particularly in textile dyeing, have had a renaissance in recent years. In order to meet the resulting demand, evaluations have been carried out to find out which species are particularly suitable for cultivation and use. Meanwhile, basic plant material has been made available for primary colours red (e.g. madder), blue (e.g. woad), and yellow (e.g. golden rod), that is now being processed more intensely by growers.
From the group of approximately 80 medicinal and spice plant species which are arable in Germany, there are only few cultivable species with a high performance potential. In order to realise the required homogeneity of the raw material and to create the preconditions for the required standardisation of pharmaceutical preparations, an intensivation of cultivation research is urgently needed. First approaches for this were undertaken with different plants, such as echinacea purpurea and St John's wort.

4.1.2 Industry

4.1.2.1 Pigments

The introduction of producing synthetic colours at the end of the 19th century led to the almost complete breakdown of dyeing plant cultivation in Central Europe. It was now possible not only to produce low-cost colours, but also to produce every hue homogeneously, non-fading, wash-proof and in reproducible form. In Europe, the dyeing plant cultivation survived only in small niches. In Germany, the dyeing plant cultivation and market for natural plant colours broke almost completely down.
In recent years, however, a comeback of using natural pigments occurred, mainly due to the increased environmental awareness of the population. However, at present the cultivation of dyeing plants is hard to find in Germany, so that the demand is almost exclusively covered by imports. Due to the not estimable contamination of the imported raw materials, which are mainly coming from low-wage countries, with crop-protection and fertiliser residues, heavy metals and other undesirable substances, the still developing ecological textile branch is increasingly interested in purchasing dyeing and fibre plant material that is grown in controlled domestic cultures. This situation provides new opportunities for German agriculture.

This aspect was picked up by the research support department of the BML and other institutions. The result was a literature research and a cultivation field study with 53 potential dyeing plant species. This test series showed that madder, woad and dyer's weld (*Reseda luteola*) were particularly promising.

These results were enhanced by further projects. In this context, the cultivation and suitability of dyer's woad, which has a long tradition especially in Thuringia, were examined. Dyer's woad does not only supply the indigo pigment but also alternative wood preservatives with fungicidal and insecticidal effects which were successfully used for refurbishing historical buildings. Due to these efforts, it was possible to re-establish successfully woad cultivation at least partially in Thuringia. The woad acreage increased from 25 hectares in 1992 to 80 hectares in 1997.

The cultivation tests with the potential dyeing plants showed enormous earning fluctuations and varying yields which can be traced back to the genetically extremely unbalanced plant material. For this reason, projects were started based on classical approaches of plant cultivation (selection, cross-breeding, combination cultivation) with the aim to use the variability of the available plant material to uniform basis material. At the same time, it was necessary to work out cultivation guidelines for those production methods which were almost forgotten in order to assist the farmers in building up a modern, ecological production.
Also on processing level it was important to define the required call for action for new and environment-friendly colouring methods. The result of these efforts, a wide-ranging project group was implemented under the title "Entwicklung einer Technologie zum Färben von Cellulose- und Proteinfaserstoffen mit einheimischen Pflanzenfarben" (development of a technology for dyeing cellulose and protein fibre materials with local plant colours) based on refined technological and environment-relevant studies on the production and application of pigment concentrates. The native dyeing plants, dyer's weed, Canadian golden rod, dyer camomile, madder and dyer knotgrass are included in the examinations. From different plant sections, pigment essences are to be gained which are then to be cleaned with the help of various diaphragm separation and enzymatic procedures. The use of poisonous compounds, such as chromic compounds, is omitted wherever possible. Dyeing tests with the obtained essences are to be used to analyse and evaluate the performance characteristics (e.g. resistance against humidity and light), the environmental compatibility (human toxicity, process water contamination) and the basic procedure parameters (repeatability, storage stability, etc.).
From the current point of view, the following plants appear promising for different colours:
yellow: dyer's camomile, dyer's weed, centaury, golden rod, safflower
red: madder
brown: wild marjoram, greater celandine
blue: dyer's knotgrass, dyer's woad

All summed up, on account of the previous activities the efforts to establish the dyeing plant cultivation in Germany were successful. Follow-up studies will show to what extent the cultivation of the above mentioned plant species will be profitable and how access to German agriculture can be gained, so that in the medium-term 1% of the pigment market can be regained.

4.1.2.2 Pharmaceutical Substances

The research association of the pharmaceutical industry mentions a market volume of prescription-free phytopharmaceutical products of 4.8 billion DEM (in 1996) which is approx. 30% of the total turnover for prescription-free pharmaceutical products. The demand for medicinal plants, and/or its essences, which are preponderantly used for natural remedies with only few side effects which are particularly suitable for self-medication and prophylactics, has continuously increased in recent years. As a result, the cultivation of medicinal plants also underwent a positive development. In Germany, there are currently approx. 70 different medicine and spice plant species grown on a surface of 5,600 hectares (compared to 2,200 hectares in 1987). The increasing demand for raw drugs and plant essences, however, is still covered by the pharmaceutical industry by imports (90%).

Strict quality requirements are valid for the plant raw materials which are used for natural pharmaceutical products with regard to homogeneity and purity of the raw material, minimum content of effective components, limit values for plant-protective agent residues and microbial contamination. The greatest opportunities lie, within the frame of a controlled contract cultivation, in the further expansion of the domestic cultivation scope.

Competitive advantages for the local production can also be found in preserving and expanding the available scientific-technological lead in the fields of production and post-harvesting processing.

The expenditures required for evaluating the cultivation of new domestic species is especially worthwhile in those places where the collecting of non-cultivated drugs is to be substituted. This can be necessary if the market availability of these plants is threatened by political crises in the countries of origin or because of vanishing natural habitats.

Current projects are mainly focused on the following medicinal plants:

Press juices of the medicinal plant *echinacea purpurea* are among other things used for stabilising the body's own defences when battling infections. Although *Echinacea* products belong to the top group of phytopharmaceutical products, up to now its cultivation, harvesting and extraction are realised without profound knowledge of factors which are influencing its product quality. Commercially available preparations with strongly varying quality were the result. Under the title "Untersuchungen zur Verbesserung der Produktqualität von *Echinacea purpurea*-Preßsaft unter besonderer Berücksichtigung von Erntebedingungen, Preßvorgang und Lagerung" (Investigation for improving the product quality of *Echinacea purpurea* press juice with special regard to harvest conditions, pressing processes and storage) it is attempted in exemplary fashion to evaluate scientifically modern analysis procedures for cultivation and extraction tests. Especially for determining the optimum time for harvesting, practice-relevant results could already be found out.

The economic opportunities of starting the cultivation of greater celandine, a medicine plant which up to now is not cultivated in Germany, were examined within the frame of a " Machbarkeitsstudie zum wirkstoffoptimierten Schöllkrautanbau (*Chelidonii herba*) in Deutschland" (Feasibility study on the cultivation of greater celandine (*Chelidonii herba*) in Germany with focus on optimising active substances).

The cultivation is mainly based on strongly regionally orientated contract farms with only little experience which led, in the case of several cultivated plants, to alarming phytosanitary difficulties. For this reason, the field cultivation of St John's wort is increasingly coming into difficulties due to a wilting disease. Harvest losses of up to 50 percent were registered. In order to prevent that the cultivation of this medicinal plant comes completely to a halt, the problem was the topic of a project group working on the subject "Welkebefall verschiedener Accessionen des Johanniskrautes (*Hypericum perforatum)*" (wilting infestation of different accessions of St John's wort (*Hypericum perforatum*)), determining above all the resistance characteristics and the value-defining components.

In addition to the application in the human medical field, the essences of medicine and spice plants can also be used in technical fields.

The results of a particular project treating the cultivation and use of *Reynoutria sachalinensis* led to the development of a marketable plant stabiliser that is especially effective against phytoparasitary fungi.

Another project with the title " Untersuchungen zum Einsatz fraktionierter etherischer Öle und Extrakte von Heil- und Gewürzpflanzen als Schutzkomponente in Werkstoffen gegen mikrobiellen Verderb" (Analysis on the application of fractionate essential oils and extracts of medicinal herbs and spice plants as a protective component in substances used against microbial spoilage) concentrated on the effectiveness of secondary plant components on germs etc. Biodegradable materials made of biorenewable raw materials, such as packaging materials and insulation materials, are in general microbiologically strongly endangered and a good culture medium for insects and rodents. The use of different essences from spice plants showed a good protective effect against a great number of pests. In a follow-up project, it must examined to what extent secondary active plant substances also show hygienic characteristics and are therefore suitable to be used as supplementary substances in the BM used in the food industry.

The cultivation of medicinal and spice plants cannot only be an effective alternative for agriculture, it can also contribute to the reasonable supply of the domestic pharmaceutical industry with high-quality raw materials. This means for agriculture that in individual cases the safeguarding of earnings of farms with suitable areas and an appropriate work capacity can be ensured. In this context, it is also understandable that the development in the field of "medicinal plants" can only play a minor role within the framework of the public research funding. Nevertheless, selected priority projects will be supported in future in the relevant fields.

4.2 Constraints and measures to be taken for the development of non-food uses in Germany: Dyeing and pharmaceutical crops

Constraints	Focus	Proposals
Scientific/technical	• Raw materials • Industrial processes	• Improve agronomic production systems • Investigate secondary metabolites • Improve extraction technologies • Find new, high added value applications • Improve production/processing chain
Environmental	• Environmental impact of activity	• Environmentally sustainable production and processing practices • Measure and standardise product qualities • Life Cycle Analysis (LCA) of important processing chains
Legislative	• German legislation • European legislation	• Investigate legislation regarding material standards • Legal frame for utilisation of products fulfilling certain environmental criteria • Durable agricultural policy framework
Economic	• Crops • Industry	• Find more economic production and logistic systems • Optimise industrial process yields • Find high added value markets • Quantification of external costs
Information	• Communication	• Advertise ‘natural’ products • Improve European co-operation

4.3 Prioritisation

Dyeing and pharmaceutical crops are ‘niche’ activities, but might have high importance for individual farmers or regions. In the field of natural dyes, the reintegration into the industrial processes of the textile industry is of major importance. Reliable supply in sufficient quantities and defined, good qualities are necessary to improve the market position of natural dyes.

In the field of pharmaceutical crops, a huge market for ‘natural’ remedies is existing, and several companies are active in this field. Competition exists between collected and cultivated natural raw materials as well as synthetic substances. Reliable, high quality supply is necessary. Crop protection is a specific problem, as few pesticides are available for niche cultures and pesticide residues would be particularly harmful in the case of a pharmaceutical. For all efforts, the market size has to be considered.

5. Outlook

In 1998, 500,182 hectares were used for cultivating growing raw materials in Germany. The most important raw materials which were cultivated on this area are: starch (140,000 ha), rape oil (220,200 ha), linseed oil (95,240 ha), sunflower oil (22,400 ha), sugar (11,000 ha), flax and hemp fibre (4,000 ha) and medicinal herbs (4,000 ha). In total, approximately 4.5% of the entire area of arable land in Germany were used for growing raw materials in 1998.

What will the future development of the cultivation and use of growing raw materials will look like? The difficulty of answering this question becomes clear if the different parameters which are influencing this development are considered:

Presumably the development of the prices for energy and raw materials coming from **fossil resources** compared to the price development of agriculturally produced raw materials will have the greatest influence on the future development of the cultivation of growing raw materials. It is to be expected that – at least on a short or medium-term base – the prices for fossil raw materials will not significantly increase. Mineral oil, natural gas and coal will still play a dominating role in supplying the chemical and power-supply industries with raw materials. This means, for example, that basic chemicals that are made of growing raw materials will only become competitive if the price for mineral oil prices doubles. Since a such rise in prices of fossil raw materials is not to be expected in the coming years, the demand for growing raw materials will not increase.

Considering the price development of the **agrarian raw materials** for a industrial applications, one has to bear in mind that the production of food will still be the most important task of agriculture. Against the background of an increasing world population which, according to expert estimations will increase from today 5.6 billion people to approximately 8 billion in 2025, agriculture bears an enormous responsibility for supplying the world's population with high-quality food. This rapid population growth is accompanied with a continuing loss of arable land available for food production goes due to the increasing urbanisation and industrialisation, soil erosion, steppization and salinification: In 1950, 0.51 ha were available for one person, in 2025 only 0,17 ha will be left. Faced with the increasing adjustment of European agrarian prices to the world market prices and the even narrower linking between the prices for growing raw materials and the relatively increasing food prices, also in the domain of primary agricultural production there will be no direct advantage for an increased production of growing raw materials for the time being.

Both factors, prices for fossil resources, which will remain roughly stable in the foreseeable future, and the major obligation of agriculture for food production will limit a rapid development of the industrial application of raw materials made from plants.

Compared with this, there are also factors which will boost the sales potential of growing raw materials: On the one hand, in the past there were **agrarian-political measures** which resulted in the current extent of cultivation of growing raw materials in Germany. These include, for example, the regulation of the cultivation of growing raw materials on land that is no longer regularly used for agriculture and the regulation for the production remuneration for sugar and starch. The Agenda 2000 and the White Paper of the EU will play a significant role, in particular for the agrarian policy of the EU and thus for the cultivation of growing raw materials. For example, in the White Paper which was introduced by the EU Commission on 8th December 1997, it is aimed for doubling the section of renewable energies from 6% to 12% of the overall energy consumption. In this calculation, biomass will be of decisive importance due to various measures.

A second factor which might have a positive influence on the opportunities of growing raw materials is the **research & development** in the area of growing raw materials which is supported, in the context of governmental provision politics, by the support of research. This government support must include basic research as well as the market launch of growing raw materials with the help of specific programmes. Faced with the increasing opening of European agrarian policy towards the international market, this research and development will play a very important role: Only thorough research and development will make it possible to develop new and competitive products made of growing raw materials with a high added value. If one does not succeed in establishing products and procedures in this field that are cheaper and more efficient than comparable products made of fossil resources, national supporting programmes and favourable cultivation conditions for growing raw materials will have no avail.

Summing up, it can be stated that the opportunities of growing raw materials in Germany cannot be evaluated without considering the development in the EU and the international markets. No rapid development can be expected; it will rather depend on the stepwise development of products and procedures with high added value which can compete in the long run with products on fossil basis.