Nature's own chemical plant

The chemical industry is largely based on raw materials created by geological processes that took place on Earth many millions of years ago: petroleum, natural gas and coal. Only about ten percent stem from renewable resources, i.e. plants. In the next few decades, industry will have to reduce its consumption of limited resources, but Fraunhofer researchers are on hand to supply the necessary know-how for "white biotechnology".

One thing is sure: Reserves of fossil fuels are diminishing rapidly. But while the experts are still in disagreement as to when it will no longer be profitable to mine existing reserves of petroleum and coal, the chemical industry in the USA has already begun to change its policy: By 2030, it intends to produce one fourth of the raw materials currently obtained from fossil sources from renewable resources. European chemical firms are also focusing their activities on the conversion from fossil to renewables.

But it won't be an easy transition, because the whole chemical industry is based on interlocking processes that depend entirely on fossil materials. It starts in the refinery, where petroleum is broken down into its constituent components, which are in turn refined to produce the basic feedstock for industrial processes. Chemical engineering plants then transform these secondary raw materials into the multitude of chemical products we use in our everyday lives: solvents and paints, adhesives and plastics, detergents and drugs. To find alternatives from the vegetable kingdom for all of these categories of materials, industry will have to invent entirely new processes. One of the important elements in this transition will be the use of microorganisms and enzymes in the production of chemicals – hence the term of industrial or "white" biotechnology employed in professional circles.

EU and industry favor white biotechnology

The need for further research in this area of technology has not only been recognized by industry. The EU has made it one of its priority research themes in its 7th Framework Programme, and national governments have also launched their own research initiatives. The Fraunhofer-Gesellschaft has also decided to pool its resources in this particular field in the form of a strategic research alliance coordinated by Professor Thomas Hirth of the Fraunhofer Institute for Chemical Technology ICT. The aim of this network is to represent every link in the process chain – starting with the cultivation of crop plants and finishing with the market-ready product, with the aim of establishing an integrated bio-based materials cycle.

The first link in the chain consists of raw materials produced by the agricultural and forestry sectors. Cultivated plants are a valuable source of important organic chemicals that they produce naturally by means of photosynthesis:

– Carbohydrates (e.g. starch, cellulose)
– Proteins
– Oils and fatty acids
– Lignin, the natural polymer in wood
– "Secondary" vegetable products such as aromatic essences and dyes accompanied by pharmaceutically active ingredients such as antioxidants, vitamins and alkaloids.

The existing methods of processing raw materials concentrate for the main part on extracting only the principle active agents. In the opinion of biologist Dr. Michael Menner of the Fraunhofer Institute for Process Engineering and Packaging IVV in Freising, this is a waste of valuable resources: "We should make as much use as possible of nature's own chemical factory and harvest all of these valuable compounds," he says. His team of researchers is therefore concentrating on the development of less crude fractionation techniques that not only allow the oil to be extracted from lupin or rapeseed plants but also harvest a pure extract of their proteins. The oil can be used for culinary purposes, or as the basic ingredient in

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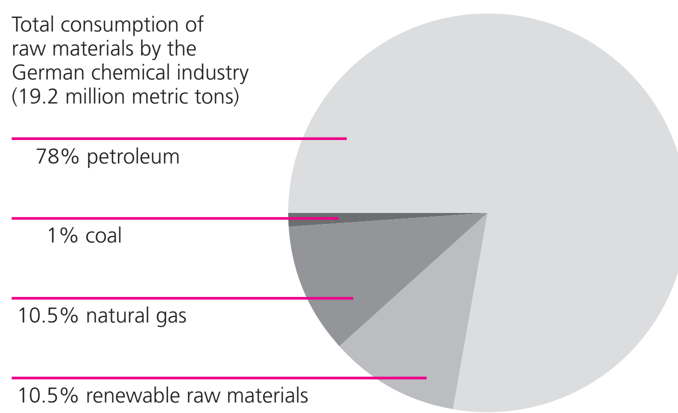
biodiesel fuel, or in many other industrial applications. In addition to their nutritive value, vegetable proteins have qualities that make them suitable for many other useful functions in the food processing industry: for example, as emulgators or as an alternative to animal sources of gelatin. Smaller protein molecules, such as those extracted from soybeans, often have a pharmacological function such as reducing blood pressure or cholesterol levels. But this requires that they be available in their natural state.



Until now, the chemical industry has been largely based on petrochemicals.
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Source: VCI

Another method used to harvest useful compounds from plant material involves the use of supercritical fluids such as carbon dioxide or water. Carbon dioxide is already used widely in the food industry as a means of extracting caffeine or the bitter flavorings from hops. "There is a huge store of untapped potential that could be used to harvest raw materials from renewable sources in the interests of integrated bioproduction," claims Thomas Hirth. Two Fraunhofer Institutes, the ICT and UMSICHT, are working on the development of processes using supercritical fluids.

The quest for new enzymes

But not all substances found in plants can be used by industry in their natural state. Many have to be transformed into intermediate products, using non-aggressive processes to preserve their valuable qualities. Here, too, nature can help in the form of enzymes – the molecular agents employed by living cells to metabolize certain substances. By natural synthesis, enzymes are capable of producing useful compounds for the chemical industry – referred to as platform chemicals, which include lactic acids and a variety of dicarboxylic acids. A team of scientists at the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB in Stuttgart, led by Dr. Steffen Rupp, is searching for undiscovered microbial enzymes. This work has immense potential, given that many strains of bacteria are impossible to grow in the laboratory and therefore pass unnoticed in the more usual type of screening tests.

In their Screening Center, the Stuttgart researchers have developed a new technique that involves isolating bacterial DNA rather than the microorganisms themselves from soil or other samples. The DNA is then broken down into thousands of individual fragments to form a gene bank. The individual sequences can be "translated" into synthetic protein molecules with the aid of genetic engineering, and then tested simultaneously for enzymatic activity. "We don't even need to know which microorganism was responsible for producing the enzyme – it's enough to obtain the appropriate DNA sequence," relates Steffen Rupp, underlining the biggest advantage of the process. The research team has already achieved positive results, identifying enzymes on behalf of BASF AG which promise to lead to some interesting new translation products. Another group of scientists at the Fraunhofer Institute for Molecular Biology and Applied Ecology IME in Aachen is also exploring the possibilities of enzymes for the chemical industry. "The plans for our new premises, due for completion at the end of 2005, include a production plant for industrial enzymes," reports the institute's director, Professor Rainer Fischer.

Researchers at other institutes are using microorganisms to convert raw plant materials into platform chemicals. For instance, a team at UMSICHT is using bacteria to produce succinic acid from glucose, which itself is obtained from corn starch by means of an enzymatic reaction. But the raw solution obtained from the fermenter is still far removed from the pure succinic acid that the chemical industry uses as the raw material for "ecological" solvents or in the manufacture of nylon. It still contains remnants of the biomass that have to be filtered out. Only then can the solution be used for the next phase of the process, a physical separation process such as distillation, to obtain the pure chemical. "Biotechnology can only serve industry if the costs of the separation process are sufficiently low," states Dr. Görge Deerberg, scientific director of UMSICHT, reminding us of the often underestimated importance of the downstream processing stages. At present, the purification process can account for up to 80 percent of the final cost of the product.

White biotechnology offers a means of producing new and improved industrial enzymes.
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Constituent products for plastics

The purity of the intermediate product ultimately determines whether or not it is suitable as a raw material for chemical synthesis. Lactic acid, for instance, can only be processed into the biodegradable plastic polylactic acid if it contains no chemical impurities or enantiomorphous components. At the Fraunhofer Institute for Applied Polymer Research IAP in Potsdam, the research group led by Dr. Gerald Rafler is investigating process engineering and the appropriate process parameters for the manufacture of polylactic acid. The final reaction product is a molten mass that is further processed by injection molding, thermopressing or spinning. "The important factor for industrial users is that they should be able to use their existing plant and machine tools," states Gerald Rafler.

Other platform chemicals include polyols, hydroxy acids and amino acids, which are useful components in the manufacture of industrial plastics such as polyurethane, polyester and nylon. As part of its materials and process research, the Fraunhofer ICT is developing processes to extract these compounds from starch, sugar, cellulose or lignin and to convert them into plastics. For example, in collaboration with an industrial firm, the institute has developed a process for manufacturing bio-derived polyols that can be used to produce polyurethanes. Plastics derived from renewable raw materials have not yet captured more than one percent of the market, but experts estimate their potential market share to be ten times higher. According to UMSICHT, the production of plastics from renewable resources in Germany can be expected to reach about one million metric tons by 2020, of which 40 percent will be accounted for by polylactic acid. Growth in this sector will create new jobs and offer opportunities for the export of advanced technologies – or so the interim conclusion of a study on the economic impact of white biotechnology being drawn up by the Fraunhofer Institute for Systems and Innovation Research ISI.

Category	Typical products	Applications
Amino acids	Glutamate; lysine	Flavor enhancers; additives for animal fodder
Acids	Citric acid; acetic acid	Detergents; household products; foodstuffs
Basic chemicals	Acrylamide; ethanol	Intermediate products; fuel additives
Pharmaceuticals	Antibiotics; vitamins	Drugs, foodstuffs
Plastics	Polylactic acid	Packaging, textile fibers

Source: Weiße Biotechnologie – Chancen für Deutschland,
Policy paper published by DECHEMA e. V., Frankfurt am Main 2004

Plastics represent just one of the many groups of products where the chemical industry can be served by white biotechnology. Elsewhere, biotechnological processes are already being used to manufacture solvents, amino acids and vitamins (see boxed text). Biotechnology currently accounts for somewhere between one percent (in plastics) and 16 percent (in fine chemicals) of chemical industry output. But these proportions are rising, placing the chemical industry up among the leaders in the trend towards a more sustainable approach to the utilization of natural resources.

Hellmuth Nordwig