Growing green, benign by design

Master thesis, Applied Design Research, Ecological aspects of Industrial Design

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Topic: The application of materials from renewable sources for sustainable product development
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Modified gourd: box mould with text (designed by author 1996)

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Abstract

The project is an attempt to cover the aspects of production and application of materials from renewable sources, for sustainable product development. The report is divided into three parts describing the role of renewable materials in the past, present and future.
The first chapter, named Chemurgy, places the topic in a historic perspective. The word Chemurgy was introduced in the thirties to describe a branch of chemistry which dealt with the application of natural raw materials, especially from farm products. As a result of agricultural over-production and the advent of the economic depression, American farmers were in search of new outlets for their produce.
Industry (especially the newly created automobile industry) on the other hand, was in great demand of materials. One of the important car manufacturers at the time was Henry Ford. He was a Chemurgist, whose vision it was to grow cars from the soil. His cars included many components from renewable materials, such as gluten or soy plastics and used alcohol for fuel, which was gained from vegetables. Presently, cars in Brazil use alcohol for fuel, extracted from sugar cane. Two of the most important chemurgic plants were soy and hemp, the latter of which was banned in 1937. The two plants (both originate from Asia) were cultivated on a large scale, primarily for non-food purposes. Many important discoveries had been made, which found wide application still in use today.
The chapter concerned with current development consists of two parts, i.e. renewable materials and sustainable ways of production. The part about renewable materials is divided into five areas of consumer application. Of particular interest to industrial designers are natural fibers and bioplastics. In the area of natural fibers, the PLATO manufacturing process seems a promising development. The technique upgrades wood or plant fiber to make it more strong, more light-weight and more resistant to rot. Plant fibers which have been treated are finding application in the car industry. Moving on to bioplastics, the first generation of bioplastics, which still contained some synthetic material, has been superseded by a generation which is totally biodegradable. Most bioplastics,

which are currently available, are designed to be thermoplastic, to be processed by conventional industrial machinery. A particularly interesting development is the production of a plastic like Biopol (Polyhydroxybutyrate), by plants instead of bacteria.
The second part of this chapter is about methods of production. There is a shift noticeable towards the utilization of transgenic plants or bacteria to produce materials. Biotechnology assists in the improvement of production efficiency and product quality. An example of this is corn and potato which have been modified not to produce amylase, so the process of starch extraction has become easier and cleaner.
The third chapter begins with an assessment of the developments towards sustainability, including economical, technical, social, and ecological aspects.
In the race towards a sustainable future, there are two scenarios, i.e., Aquafication and Prosumerism, put forward for consideration. Presently, agriculture for industrial purposes does hold the promise of sustain ability. However, if it were to be applied on a grand scale, it would pose two major problems in the near future, i.e., a shortage of fresh water and a shortage of land.
There have been successful attempts in transplanting bacterial genes into plants, which enables them to be salt-tolerant. This way, it would be possible to shift agriculture for industrial purposes to sea (aquafication). The plants would be grown on the sea surface and its industry would make use of the natural forces readily available for its energy needs, like wind-, water- and solar power.
Alternatively, in a cocooning society (F. Popcorn), with working at home becoming more common and leisure time increasing, self-sustainability will become a possibility. The prosumer household, (producer/consumer, A. Toffler) will be self-sufficient in all its needs, like consumer goods, food, cosmetics, medicine, fuel, clothing, etc. All these goods will be “grown” through the application of fast-growing plants.
To test the feasibility of this concept I have conducted several experiments. For example, Giant Jersey Cabbages have been grown into shapes, suitable for furniture application. Tree-free furniture from local resources will become a possibility. Similarly, bottle gourds have been grown in moulds which have taken on geometrical shapes for packaging purposes.
Some other experiments have been carried out with “dead” natural materials. One example is that of mussel shells, (a waste material from the seafood industry) which I have applied into building materials. Another example is the fiber of the Loofah gourd which has been compressed into shapes for shock-resistant packaging or other purposes.

Keywords
Benign-design, biobased design, biobased materials, biodesign, ecological design, green design, green technology, renewable materials, sustainable product development (s.p.d.).

Relevance to Design Practice
This research probably has the most relevance in concept stage of product design, in choice of sustainable materials and greener production techniques. But it may also influence the designer’s awareness and responsibility of the impact his product will have on the environment.

Prologue

Within the area of SPD (sustainable product development), this project is concerned with "benign-design" through the application of materials from renewable sources.
Benign-design implicates sustainability in all stages of the life cycle of a product. This includes its source, its production, its use, and its waste phase. Materials from renewable sources are basically natural materials which have plants or animals as their source. Living organisms reproduce, so provide for a renewable source. These "living" sources can provide raw materials, prefab materials, or complete products, ready for use. The materials from these sources are largely non-toxic in fabrication, use and as waste. Indeed, most of these materials are bio-degradable, compostable, or even edible.
This research is written primarily for industrial designers. It is neither set out to be a dictionary of materials or plants, nor a manual for green design. The approach of the topic has been from the designer's standpoint. The project is partly intended to show the reader the multitude of opportunities, materials from renewable sources have to offer.
One aim was to investigate the feasibility of largescale agriculture for industrial purposes and to discover its opportunities. Areas of application not directly related to industrial design, such as clothing, cosmetics and fuel are included to show the possibility of complete self-sustain-ability which is explored in one of the scenarios i.e., Prosumerism. The topic has been placed in a historical, economic, social, technical and an ecological context. Political aspects have been emitted, as they are to temporary effect, mostly. Also, a comparison between of materials from renewable sources and those from non-renewable sources has been avoided.
The project has mainly involved desk research. Some research institutes have been visited and experts in certain fields have been consulted. Some experiments were conducted involving the application of waste materials, like shells, fiber materials, like loafs and parts of plants, like cabbages and gourds. The project also includes 2 scenarios about future situations concerning sustainable product development.

1st chapter Chemurgy

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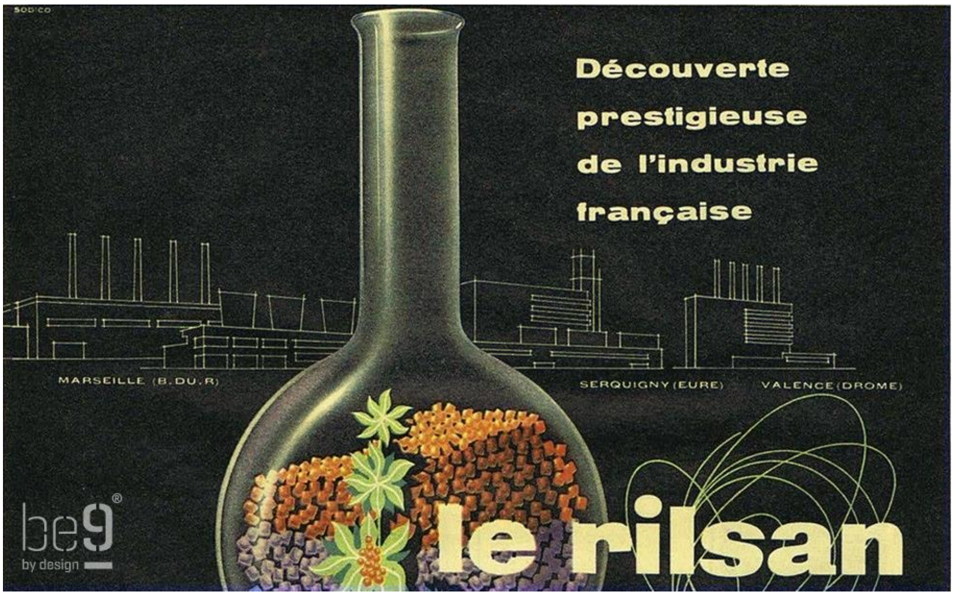
An introduction

One interpretation of the origin of the word Chemurgist is that it is made up from the two words: chemist and metallurgist. Actually, the term "Chemurgy" was introduced by the publication of a book in 1929, by Dr. Hale. Chem originated from an Egyptian word. Ergon came from Greek which meant to put chemistry to work for the farm. The name chemurgy was changed to biochemical engineering in the sixties *1.
A definition: Chemurgy is a branch of chemistry that deals with the industrial application of organic raw materials, especially from farm products (as in the use of soybean oil for paints and varnishes and of Southern pine for paper pulp) *2. Chemurgy dealt with carbohydrates, which are abundant in organisms, while hydrocarbons are from petro-chemical origin. A Chemurgist slogan: "Anything made from Hydrocarbons can be made from Carbohydrates."

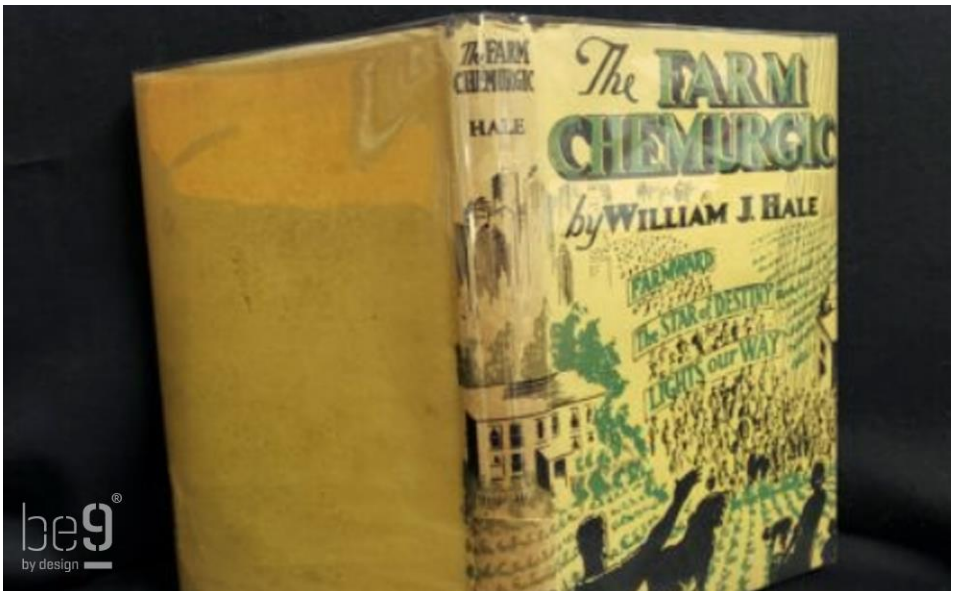
A brief history

Chemurgy, which started in the beginning of the twentieth century, was an initiative which began in America. After the start of the depression in 1921, farm recovery was slow. Farmers were overproducing food at dump prices. Meantime, industry especially the car industry, moved into high production and demanded a lot of material. A speech by J. Barnes in Chicago in 1924 suggested possibilities of non-food outlets for food surpluses. Already there were many products made from farm products by that time, like pen barrels which were made from casein.
W. McMillen was editor of Farm & fireside and published articles about utilization of farm waste products. In 1926 he received $50,000 from E. Hoover for research in this area. In 1927 W.J. Hale, an industrialist with a PhD in chemistry at the Dow Chemical Company wrote an article for the Dearborn Independent in which he predicted that industry would turn to annual crops as a major source of raw material. Mr. Hale and Mr. McMillen met and lectured around the country. In 1928 McMillen met A. Edison (the inventor of the light bulb) and H. Ford (the car manufacturer) in Dearborn and all agreed to promote support to get research underway.



Polyamide 11 (PA11) developed from Castor oil in 1942 and patented as "Rilsan" by Organico France in 1947. Many products were made with PA11 bioplastic.

In 1929 McMillen wrote a book entitled "Too many farmers" and Dr. Hale wrote book entitled "The Farm Chemurgic". With this book a new word was introduced: "Chemurgy". By 1934 there was not much more achieved. So, in 1935 a conference on agriculture, industry and science was held in Dearborn, at which about three hundred people were present. It was a great success. The foundation, to which P. Garvan was president, changed name to the Farm Chemurgic Council, to which later the word National was prefixed. The foundation received money from confiscated German patents on chemicals after the war, which was now to be used to finance two initiatives. It was discovered that alcohol could be obtained from corn or other starch crops. The alcohol could be mixed with gasoline. The other project involved making newsprint from slash pine.



"The Farm Chemurgic" by W.J. Hale, 1934

However, politicians and industry, particularly the petroleum industry, were not pleased with these developments and were slowing down any progress. To add to all this, the energetic leader of the Chemurgic movement, P. Garvan, suddenly died in 1937. The Farm Chemurgic Council, of which McMillen was now president had a deficit of $20,000. McMillen had the task of interesting industry and the politicians again. The latter proved more difficult, as there was a conflict of interest, regarding the policy of that certain administration. A magazine called the "Chemurgic Digest" was launched *1.
G.W. Carver was a Chemurgist who developed 118 industrial products from agricultural products, including a rubber substitute and over 500 dyes and pigments, from 28 different plants. In 1927 he invented a process for producing paints and stains from soybeans, for which 3 separate patents were issued *4.

G.W. Carver visiting the Soybean Laboratory, Greenfield Village, 1939

Some Chemurgic plants
Besides farm residue, which was used for industrial purposes, a new development was beginning. Some crops were grown especially for new areas in non-food application, like component parts, consumer products, or fuel.

Soybean
This oriental wonder bean was introduced to the U.S. in the early part of the nineteenth century. Henry Ford was one of the pioneers in the thirties, to grow soy primarily for non-food application i.e. his own cars. (see further along this chapter for more information about Ford)

Henry Ford in a suit made from Soy-fiber

Hemp

Hemp, which originates from China, is a very versatile plant with thousands of applications. There was a booming industry. It provided the world with one of the strongest and most durable fibers. It found application in the production of paper, textiles, and construction materials. Its seed oil was applied in many products such as cosmetics and plastics. However, in 1937 U.S. Congress passed the Marihuana Tax Act, to prohibit the use of the drug, but in its enforcement the growth of industrial hemp was also forbidden *3. (for more information about hemp see chapter 2 The home. Agri fibers).

Industrial Hemp, fiber, oil, fabrics

Flax

Flax originates from Europe. Around 1936, the company Straus began experiments with flax straw to be applied in cigarette paper. These were successful and by 1939 other paper products were being produced, like writing paper and even U.S. military currency was printed on this paper. Cigarette paper made from linen rags, was normally imported from France. By the start of the war, soldiers smoked cigarettes, the paper of which was from American flax origin *1. (for more information about flax see chapter 2 The home. Agri fibers).

Flax, linen, linseed oil, Linoleum

Corn
It is a native plant to America. Corn was and still is a major food crop in America. However, it was discovered that its starch could be applied as a non-food material for plastics, paint and soap. (for more information about cornstarch see bioplastics further along this chapter). Corncobs and oat hulls were agricultural residue, which were previously sold for very little as livestock feeds or as fuel for factories. In the early twenties Quaker Oats was researching a new application for oat hulls. Furfural was the final product which found many successful applications. War required lubricants and soon the demand for furfural exceeded the supply. An alternative was found in corncobs *1.

Its products

Oils
Besides vegetable oils for food, there were also oils which could be of use for industry. Linseed oil from flax and soybean oil became popular in printing ink and paint industry. Castor oil was extensively used for lubrication and hydraulics, during the war.

Ricin oil from Castor beans

The tung nut was new to America. When pressed, it yields an excellent quality oil, which finds application in the paint and varnish industry *1.

Bioplastics

At the start of the twentieth century many bioplastics were in use, such as: cornstarch, soy, (wheat)gluten, casein, whey, gelatin, cellulose, and natural resin-based materials.

A Casein based plastic called "Galalith" was discovered in the early 20th century. It was used for buttons and buckles, pens, knitting needles, combs and brushes, handles for knifes and umbrellas, piano keys, electrical goods like telephones, and gemstone imitations in Art Deco jewelry

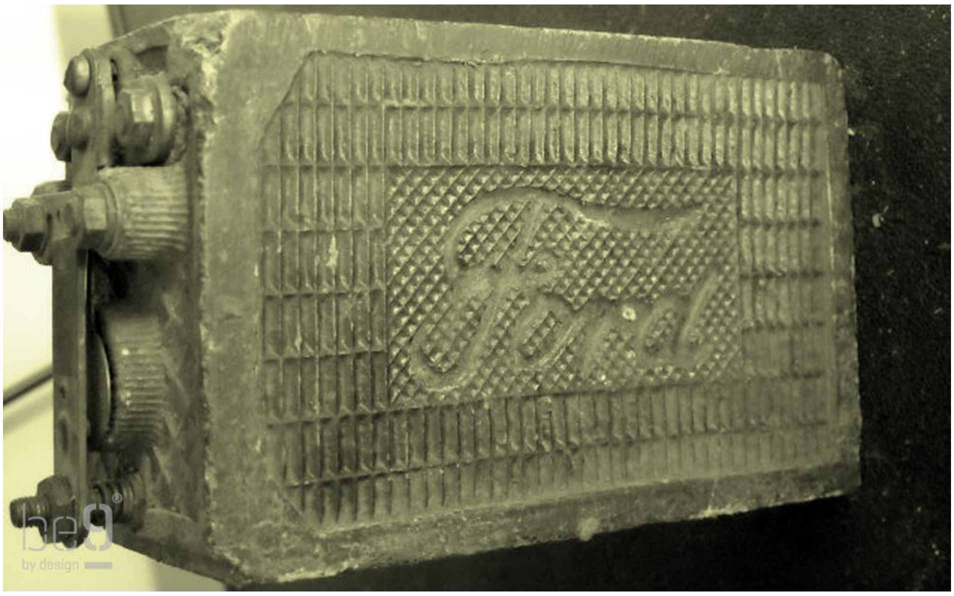
Cornstarch

Starch from corn held some interesting possibilities. Cornstarch already was being applied in non-food products like pharmaceuticals, paint, soap, etc. When dry starch was heated at about 100-250 degrees centigrade for up to 15 to 20 hours a product called “Dextrin” was formed. Dextrin’s proved to be insoluble in alcohol but soluble in water, which wasn’t the case with starch. Dextrin is sticky, so it was applied as an adhesive in envelopes, stamps, labels, but also in wood veneer glues. Allyn starch was a new product applied as a coating or adhesive, which after heating is not affected by most chemicals. There was a Starch Round Table meeting being held every year, in the Dearborn Inn, from 1940 onwards, supported financially by the Corn Industries Research Foundation *1. (for more information about starch see chapter 2 Disposables and packaging).

Cornstarch bioplastic products

Gluten

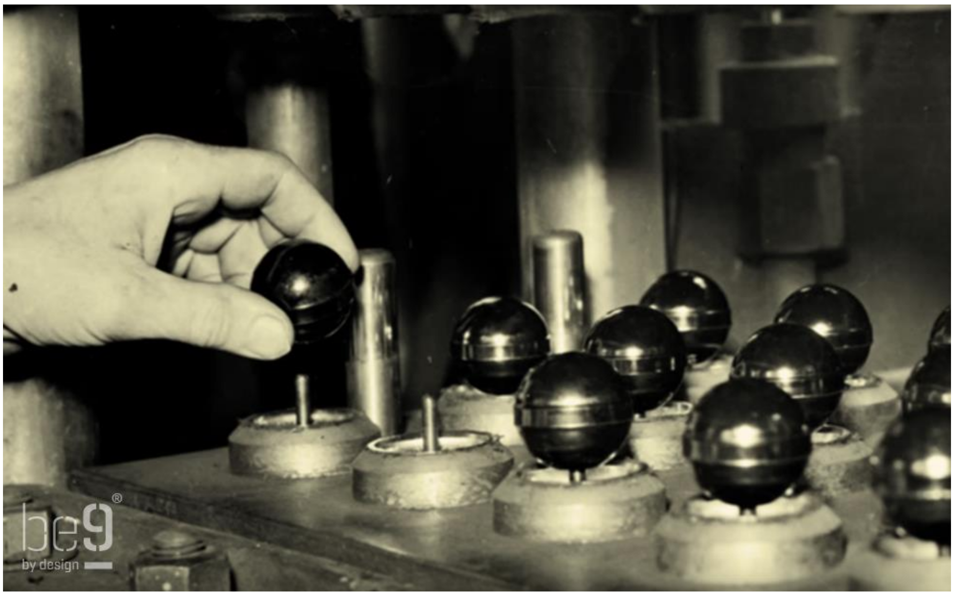
Gluten is a non-starch product obtained from corn. It contains about 60-70% protein called Zein, which is chemically inert, soluble in alcohol and thermoplastic. It was applied as a coating for paper against grease before the war. Ford applied the material in cars as early as 1916.



Wheat gluten plastic sides for T-Ford coil 1917-18

Soy

It was discovered that soybean contained a high level of protein and the exceptional property for nitrogen fixation, which made it very suitable for plastics. It contains about 20% oil, which is semi-drying. Around the beginning of the twentieth century there were many discoveries being made concerning soybean. A whole range of applications was the result, including paints and varnishes, waterproof glue for plywood, washable wallpaper, soap, car parts, linoleum, fire foam, printing ink, etc. Already in 1908 a chemist by the name of I.F. Laucks had produced a waterproof glue suitable for plywood application, gained from soybean oil. But industry was not equipped and could not adapt readily to the new technique needed for this glue. It was not until the mid-twenties, when the car industry began applying plywood in their products, that industry adapted to the new technique replacing cold press machinery for hot press ones.



Early car gearshift knobs made from soy-based plastic.

R. Boyer, working with H. Ford, was the creator of a man-made fiber produced from soybean. It was almost as strong as wool. There was also transparent film for wrapping paper being developed at the Drackett Company laboratory. Often soybean protein was combined with chemicals, to comply with certain demands from industry. In the thirties a soybean exhibit car was realized by actually making use of component parts produced from soybean. The car conceived by Mr. East, travelled throughout America by rail, promoting these new products. Two hundred thousand people visited the exhibit. The bean was one of the first crops to be intentionally grown for industrial purposes *1.

G.W. Carver holding Soy-fiber

Fibers
Rayon is the foremost chemurgic product among fibers. It's made from cotton linters or wood pulp. Hemp and flax are described above. Ramie was called the wonder fiber because of its mostly superior properties. It originated from China. It is moisture, mildew, and bacteria resistant. It is light, unabrasive and good at holding grease. Other fibers were considered like milkweed stalks, castor bean plant fiber, Sansevieria, Okra and Button weed, etc. but they were never applied in larger production. However, jute was considered but it was imported from Bengal *1.
(for more information about fibers see next chapter the home).

Fuel
It was discovered that alcohol could be obtained from most plants including farm vegetables. This meant that farmers could be self-sustainable in their fuel needs. Presently, in Brazil cars use alcohol for fuel, obtained from sugar cane. Also, research on seed oil-based fuel seemed worth the effort. Rudolf Diesel had designed his engine in 1896 for vegetable or seed oil use, due to its superior quality. Nowadays, rapeseed oil is being produced in Europe for environment conscious drivers. (also see chapter 2 Transport for more information).

Industry

Ford

Henry Ford supplied the world with affordable cars, enabled by the introduction of the assembly lines. He was aware however of the impact and consequences his mass product would have on the environment. In the depression of the thirties there were agricultural surpluses which were largely wasted. The situation was that farmers were producing too much and industry too little.

"Hemp mobiles"

Ford's vision was to build cars from the soil. He grew his own soy for the production of component parts. Hemp and soy were used in parts of the bodywork. The cars, like his tractors, were to use alcohol extracted from local vegetables for fuel. Before W.W. 11 a large part of industry was oriented on natural materials. Glues and plastics were for a large part animal or plant based.

Henry Ford testing the strength of a Soy-based boot lid with an axe

In 1916 Ford set up a laboratory for mechanical, botanical and chemical research. Agricultural waste products and even household refuse was researched for possible application. Hemp and soybean were researched for use in car parts. The Ford motor company was also experimenting with biomass fuels, including hemp. Ford also set up a network of farmers, who ensured the availability of the required raw materials. The farmers were ensured of extra income by growing crops like hemp for industry. Ford himself owned a lot of land where he began growing soybean in the thirties. In 1939 he even attended a chemurgy conference dressed in a suit made from soybean fiber. He also started a network of local town-industries, many of which were water powered, for the manufacture of his car parts. In 1915 the induction coils of his model T were made from a plastic based on wheat gluten. In the thirties there were engine, insulation and interior parts like control knobs made from plastic based on soybean.

In 1937 Ford cars included 1kg of products based on soybean produced in a special factory *5. In the forties he introduced a car which had body work panels made from natural materials. The parts like fenders were reinforced by hemp fiber, wheat, or straw combined with soybean plastic *3. The car used alcohol for fuel, gained from local crops. Ford's tractors already used alcohol from vegetables, which enabled farmers to be self-sustainable *5.

The Hemp fiber and Soy-plastic car in 1941 being half the weight of steel bodied car from that time.

Carbohydrates vs. Hydrocarbons
At the start of the nineteenth century in America, agriculture and industry became rivals. Great market opportunities in the area of industrial application seemed to apply to both fields, yet there could only be one winner. Products from fossil fuel are generally hydrocarbons, while products from plants are carbohydrates. The battle was mainly fought between fossil oil and hemp. The opportunities of products from hemp seemed endless *6.

General motors / DuPont / Standard Oil
However, a small group of industrialists and some politicians began a campaign against hemp, which led to a prohibition bill by 1937 and the destruction of the domestic American hemp industry. Hearst the newspaper tycoon (with interests in the timber industry) supported the petro-chemical campaign against hemp, by printing unfavorable articles. General Motors had a major share in the American car market. This ensured a great market for DuPont products, such as paints, plastics and rubber. A. Mellon (the later founder of Gulf Oil) was the major financial backer and politician who held the key to its success *7.

Its glory & demise

During W.W.2, chemurgy came to the rescue in several instances. Hemp began to be grown on a large scale, after a five-year ban, because of a fiber shortage. In 1942 the US. Army and the Department of Agriculture launched their “Hemp for Victory” campaign and by 1943 over 100,000 acres were grown *3. The U.S. Navy used Loofah sponge gourds as filters for their engines, which they bought mainly from Japan. After the bombing of Pearl Harbor, the fruit became a strategic material, which resulted in America growing its own *8. Milkweed which normally was a menace as a weed in agricultural fields, was now being applied in lifejackets.

Banned in 1937 a campaign was started encouraging farmers to grow Hemp for the war effort from 1942

During the Second World War the Allies were cut off from many natural material supplies such as latex rubber for tires. A synthetic alternative held obvious strategic advantages. The chemurgic movement faded after the war. The ban on hemp was reintroduced after it did its national service. The constant supply of raw materials from natural sources was perhaps less reliable to industry, because of its reliance on seasons and vulnerability to climatic changes. Above all, its materials were not compatible to industry. After the war, fossil oil was in cheap and abundant supply. The petrochemical industry was booming. The possibilities of its materials seemed greater and their exploitation seemed more practical. Its industries were centralized, and its technology promised a new age of synthetics. People were attracted to the novelty of its products and were chasing the American dream.

• In conclusion

Chemurgy is a branch of chemistry which deals with the application of natural raw materials, especially from farm products. Basically, because of over-production and the advent of the economic depression, American farmers were in search of new outlets for their produce. Industry was in great demand for material. One famous Chemurgist was Henry Ford, whose vision it was to grow cars from the soil. Many important discoveries were made by Chemurgists which found application, e.g. alcohol was gained from vegetables to serve as fuel for cars. Presently, in Brazil

cars run on alcohol gained from sugar cane. Two of the most important chemurgic plants were soybean and hemp, the latter of which was banned in 1937. After the war, the flourishing chemical industry provided factories its materials, which were more compatible, more fashionable, and cheaper.
In practice, chemurgy held several advantages, i.e.:

- Non-food outlets for surplus food products.
- Farm residue was turned into high-grade non-food products.
- New or other crops were grown for non- food purposes, so easing the pressure on the heavily subsidized cotton and wheat cultivation.
- Self-sustain ability: tractors used alcohol for fuel, gained from vegetables.
- The great demand for material by industry was met.
- Industry obtained materials locally, reducing transportation costs.
- New industries for new products were initialized.
- The source of natural (grown) materials is inexhaustible.

• Remarks

Personally, I was quite surprised to learn that soy- and wheat gluten-based plastics had already been applied in industrial products, in the beginning of the twentieth century. Especially the properties of soybean-based plastics seem to offer many possibilities. I read that the bean contains a very high protein level, and it has an exceptional quality for nitrogen fixation, which makes it a very suitable base for plastics. Its water-proof qualities make it a remarkably interesting substitute for many synthetic plastics. The soybean is America's second largest crop, but also in Asia it still is a major product. Presently, with the reluctance of consumers for buying food products containing genetically engineered soybeans, there are opportunities for application in the non-food area.

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2nd chapter Current development (in materials from renewable sources)

Material fields

- An introduction
- Home - building materials
- Disposables & packaging
- Transport
- Cosmetics, detergents & medicine
- Clothing

Engines of production

- An introduction
- Insect living factories
- Bacterial trans mutators
- Powerplants
- Nano assemblers

In conclusion

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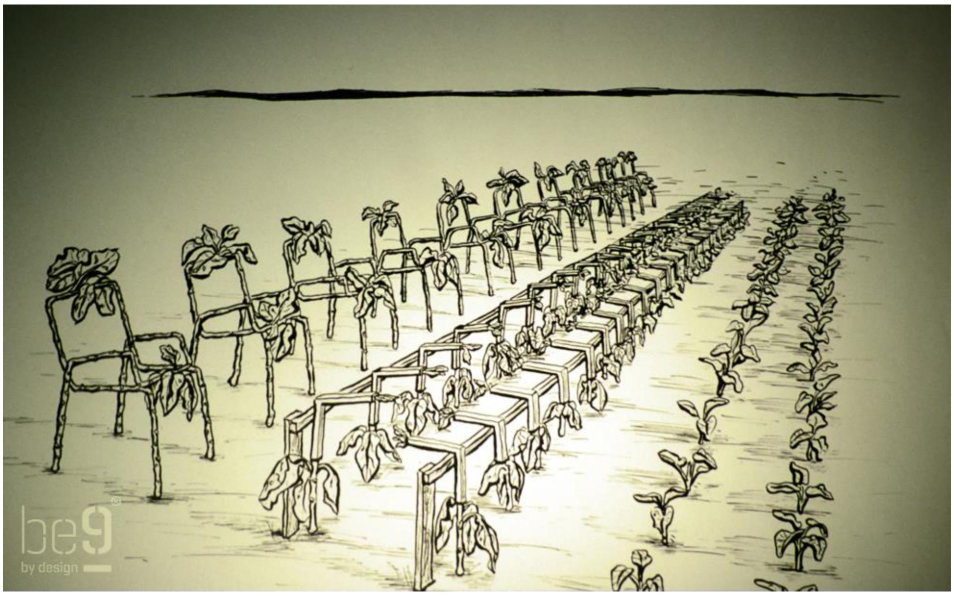
Material fields

I have tried to approach this topic from a designer's standpoint, by choosing for 5 user fields where renewable materials are being applied, rather than starting a dictionary of renewable materials which would be a more botanical or scientific approach.

This chapter is divided into two parts. The first part material fields is about renewable materials the second part engines of production is about manufacturing processes. Besides areas common to designers, I have also included other areas of sustainable development like cosmetics and fuel. This is because the third chapter covers these areas in which the prosumer is self-sustaining.



Walkingstick cabbage field (by author)

An introduction

As said in the former chapter after W.W. 11 the emphasis was laid on the petro-chemical industry rather than on agriculture for industrial purposes, in a chase to materialize the American dream. At the end of the sixties people began to worry about its toll on the environment. They reverted to basics and nature. There was a revival of use of natural materials. The name chemurgy was changed to biochemical engineering. In the nineties there is a renewed concern for the environment and subsequently interest arose for the use of renewable materials. Perhaps this is a reaction to the results of the Rio de Janeiro Summit, held in 1992. In the Netherlands a new name appeared for agriculture for industrial purposes i.e. “Agrificatie”.

Pioneered in Russia in the 30’s, rubber tyres made from Dandelions (Taraxacum kok-saghyz). Continental has developed a modern car tyre “Taraxagum”.

Agricultural crops for non-food purposes are grown mainly for their fibers, oils and carbohydrates. These materials find non-food appliance in quite different areas. However, there are two large areas of opportunities, i.e. composites (fibers) and disposables (bioplastics). For both areas there is a search for the ideal bulk material which can compete with and offer an environmentally sound alternative to petrochemical or tropical wood products, as the case may be.
In the bio-technological area there is a general shift noticeable from the way in which materials are being produced. Presently, bacteria are applied as the engines for production of bioplastics, even genes are being transplanted into plants for higher production. In effect, there is a growing concern towards the (ab)use of nature for human exploitation. There are heated debates about the ethics of transgenics and cloning.

Home - building materials
This area includes a range of natural based materials used for constructional or cosmetic purposes in the home. As this area is rather extensive, a choice has been made and it is far from complete.

Cellulose based fibers
In the past 7000 years around 2000 plants have been used to produce natural fiber. Different parts of plants are used for fiber production, including bast, leaf, seed, or fruit fibers. There are mainly three marketing areas for fiber crops i.e. paper, textiles and building- composite materials, the last one of which is relatively new *16. Plant fiber holds several advantages over artificial fiber including their strength and their ability to stretch *29.

Bleached pinecone chips with a biobased binder (by author)

Cellulose ($C_6 H_{10} O_5$) is the world’s most abundant polymer. The structure is quite like starch but very complex. A team of researchers in Japan have synthesized cellulose, which can lead to a whole range of cellulose-based designer polymers in the near future. Plants derive their rigidity from the way component glucose molecules of cellulose are joined *18. There is a distinction noticeable concerning the source of renewable fibers, i.e. agricultural waste fibers mainly from food crops and fibers which are intentionally grown for non-food application. These fibers intended for technical application are so called Agri fibers *15.

Waste source fibers

In North America, agricultural waste fibers like bagasse, cereal straw, corn stalks, cotton stalks, kenaf, rice husks, rice straw and sunflower hulls and stalks, are used for composition panels. However, the quality of these panels are inferior to those made of wood. But blends with wood will improve quality *14. There is a OSB (oriented strand board) available which consists of such waste materials. Along with wood chips the waste is pressed together under high temperature, so there is no need for glue *2. Cereal straw can include straw from wheat, rye, barley, oats and rice *14 . Straw can be used in fiber board, and for cardboard and paper products *16 .Corn cobs were used in the production of the first nylons *12 .

Bowl made of chips from Larch cones and a biobased binder (designed by author)

Rice husks and coffee husks are agricultural residue, which is made into particle board in India *25 . In India, particle board is made from bagasse without addition of a binder. Bagasse is the residue fiber remaining when sugarcane is pressed for sugar extraction. Abaca are banana leaves which are applied into roof board. It is an alternative for the asbestos material *19. By the development of a machine which removes the fiber from leaves more efficiently, pineapple (Ananas cosomus) fiber can now be commercially gained from the plant, whereas in the past it was simply burned. Resinous residue can easily be cleared from the fiber, after which it can be spun. One possible application is that of reinforcement for concrete *23. Nearly 50 billion coconuts are harvested each year, of which only 3-8% is recovered for collection of fibers. Coconut fiber, or Coir, is known to be strong and durable and has long been applied in domestic products such as mats, carpets, brushes, and as filler for mattresses and furniture. However, recent new areas of application seem to offer new opportunities, e.g. geotextiles (mats for waterworks, earthworks, etc.), insulation materials, shock-absorbent packaging materials (also in combination with natural rubber), in technical appliances as a dust-filter (Cocolok), humidifiers, etc.*20 *21.

Agri fibers

Biomass can be defined as anything which grows from seeds, water, soil, sunlight and fertilizer *2. It is predicted that Agri fibers like hemp will eventually replace synthetic fibers like glass- and carbon fibers in composite materials.
In the Netherlands research is being done on these fibers, at ATO-DLO, in conjunction with industry, to establish or modify their properties. Parallel to this some Agri fibers are also researched for possible technical and commercial significance in the paper industry. Especially hemp is being investigated. Some fibers like flax and hemp are nearly pure cellulose and contain a minimum of lignin. Agri fibers have many good properties which compare favorably to synthetic or ceramic fibers. The fibers are light, strong, flexible, non-toxic, cheaper, and even the energy put into the production can be returned by incineration *15. Besides, moulds show less signs of wear when natural fibers are applied *28. Areas of application are as reinforcement for bioplastics or other materials like cement, geotextiles, or as insulation *27.

Table made with pinecone chips and a biobased binder (by author)

Composition panels made from agricultural fibers are divided into several categories, including low density insulation board, MDF (medium density fiber board), hardboard and particle board. Binders may be synthetic thermosetting resins or modified naturally occurring resins like tannin or lignin, starches, thermoplastics or mineral *14. Ruckstuhl is a producer of natural fiber carpets, which include jute, flax, coir, sisal, wool and horse hair and even paper thread. A selection of fibers grown for industrial purposes is described below: (See also the article on transport further along).

Hemp

Hemp (Cannabis Sativa) originates from China and has been cultivated there since long before 4000BC. The strength of the fiber is 25% greater than that of flax *22. It has two different qualities of cellulose i.e. bass fiber which is of very good quality and wood fiber which is of less quality and contains more lignin *15. Hemp is, amongst other things, processed in a variety of insulation products, geo-textiles and light-weight panels.

Hemp fiber door panel for the BMW i3

Flax

Flax (Linum Usitatissimum) has been traditionally grown for linen in the textile industry and its oil (linseed oil) has been applied in linoleum. Flax has been and still is applied into fiber board similar to chipboard. Other applications could be panels for facades, ceiling panels, parts for window frames, reinforcement in concrete, or insulation/ soundproof panels instead of glass wool or rockwool. One major advantage of flax is that there is no need for a binder because it contains hemi-cellulose and pectin *16.

"Platonic love"

At Ceres B.V. in Wageningen the durability of flax fiber is being improved by a process called PLATO. The fibers are light-weight and are more resistant to decay *27. (the process of PLATO is described further along the chapter in the article about wood).

Elephant grass

Elephantgrass (Miscanthus senensis giganteus) is a fast-growing voluminous crop which originates from China. Potential applications are in geotextiles, thatched roofs instead of reed and in paper products as its fibers are similar to those of wood *12.

Elephant grass from the garden with a biobased binder pressed into blocks (by author)

Jute

Jute is a strong, non-polluting and absorbent fiber. Jute is traditionally applied in food packaging, as woven sack material, carpets, furnishing and bags *24. However, some segments like potato sacks have been partially taken over by synthetic materials. So other applications are being looked into. One option is composites, like jute mats in combination with synthetic resins for window panes, using a process called pultrusion *28.

Chair made from pinecone chips and Jute and a biobased binder (designed by author)

Bamboo

Bamboo is split into slices and glued together for parquet floors. The floors are very durable and can compete with tropical hard woods. An advantage of using bamboo is that it only takes 4-5 years

to mature in order to be applied in floors *2. There are other products based on bamboo available in China like plywood, fiber- and particle board, composites and even veneer *13.
At the Technical University in Eindhoven research is being done on bamboo as a cheap construction material. A social housing project was begun in Costa Rica in the late eighties *10. In Kyoto, Japan, a center was established after the war, for the development of bamboo building materials *14.

Bamboo bookcases (designed by author)

Loofah gourds
Loofah gourds have been grown on an industrial scale on Sardinia in 1992, as part of an EU funded experiment. Further research will conclude whether it would be worthwhile to increase production for industrial application in sound / warmth insulation panels *26.

Horsehair and coir fiber
Horsehair and coir fiber is mixed with natural rubber and applied padding in the upholstery industry. The latter one is also used in filters (cocoloc) *21. Other tropical fibers include kenaf, sisal, mauritius hemp, kapok, ramie, rattan and datepalm.

Natural composites
Composites are combinations of materials. Natural based material composites are made up of natural fibers and a natural binder. Bioplastics are dealt with in the next piece about disposables and packaging. Sometimes, fibers are pressed together by pressure and heat and an additional binder can be left out. Nature produces complicated ready-made composite materials also, for example wood or bamboo. Man-made composites in general are still child’s-play in comparison.

Wood
Wood is one of the foremost natural composites. There is an ever-increasing demand for durable wood. However, the supply of tropical wood cannot continue at this pace and chemically treated wood isn’t doing the environment any good either. One option is to up- grade the wood of local,

fast-growing low-grade trees.

"Fair and square"
A Japanese scientist has invented a process by which tree stems turn into square logs. In a specially designed micro-wave oven, the logs are cooked to around 100 degrees Celsius after which they are pressed into a square shape, using minimal pressure. When the logs cool down, they keep their new shape. The strength of the wood is improved, and the density is increased. Using this process, cheap, low quality wood can be upgraded. Ordinarily, about 50% of timber would be lost in the sawmill. Crooked trees which would otherwise be wasted, can also be of use now, as they can be straightened *3.

Poplar chair (designed by author), Poplars grown into poplar plywood

"To platonise" (the word has been admitted as a new word in Dutch dictionaries). At Shell Research a process had been developed, called PLATO (short for Providing Lasting Advanced Timber Option). Wood which has not been dried is heated till 200 degrees Celsius for about 30 minutes. At this stage the water evaporates, and the wood is like paste, so it can be pressed into any shape. Afterwards it is heated till about 180 degrees Celsius which hardens the wood *4.
The process upgrades low quality wood, whereby the larger cellulose molecules are left intact, and the smaller ones are destroyed or form larger molecules. The resulting wood is rot-proof, less moisture absorbent and much stronger. The wood handles the same as before though *6. Cr&dO is commercializing the process with some financial aid from the Dutch state. An experimental manufacturing plant has already been built *5. The process is being exploited by Plato-Hout B.V. in Wageningen and they hope to produce commercially in 1997.

Bamboo
Bamboo has been the major construction material in the orient. Bamboo is the common name given to about a thousand varieties of woody grasses (Gramineae). Some varieties grow as fast as one

meter per day. Bamboo has many good properties and therefore many applications *10.

"Bamboozle"
In the quest for compatibility to industry, square bamboo is being grown in Japan. Usually Moso is selected and used because of its thickness. A rectangular frame consisting of two halves is placed over the bamboo shoot. When the shoot has reached the top of the frame, the frame is simply slid up. The square bamboo is cut down between October and December of the year it has been formed. Lengths of square bamboo are very much sought after and are quite expensive. They usually find application in Japanese homes as an ornamental post for the tokonoma -the most important part of the living-room *11.

Man-made composites
Imitation of nature seems to be an option to reach strong designed structures in materials. Bionics or biomimetics is the art of copying living designs which are known to be mechanically optimized. At the Centre of Biomimetics at the University of Reading scientists are for example researching the structure of coconut shells, for crash helmets *9.

"Biomimetics"
C. Mattheck has studied the mechanism of adaptive growth in biological load carriers (like trees and bones) and has incorporated his findings into a program called CAO (Computer Aided Shape Optimisation) which is a tool for engineers and designers.
Natural composites grow to strengthen themselves. When the load is increased on a branch, it will gradually become stronger. The tree will self-optimise by growth. During this process it will create a state of constant stress. It will restore its optimum state by attachment of more material at overloaded points. In trees only the outermost growth ring adapts to mechanical loading by reactive growth. Also these composites are able to restore themselves. Following the principles from nature, he has redesigned and improved the common steel screw *8.

"Products alive"
Schliekelmann predicts that our dead, man-made composites may one day grow stronger under pressure. Imagine a bridge which improves its own construction according to an increase in traffic. After all, growth is an electro-chemical process, the basics of which are known to us *7.

Disposables & packaging
Until 1900, natural materials were applied in almost every product. The first generation of plastics weren't petroleum based but were made of casein or modified cellulose *28. As dealt with in the previous chapter, there were also applications of gluten and soy based plastics in the automotive industry. In the present consumer society there is a growing need for disposables and packaging which are biodegradable. Natural fibers, bioplastics or a combination of the two (composites) can be applied in both areas.

Fast food packaging, Albumen and gelatin (designed by author)

Trays and containers
Flax, coir, jute or hemp fiber is pressed into shapes for vegetable or fruit trays without the addition of binders. The lignin present is mostly sufficient. A granulate called Fasal made by IFA in Austria is being marketed. It’s made of wood chips, crushed corn and natural resins. It is thermoplastic and biodegradable. Sometimes large leaves like banana leaves are enough to serve as packaging material. There are even orange peels which have been pressed into square shaped containers and dried.

Paper and cardboard products
Hemp has a higher yield per acre compared to trees. The fibers are longer, which results in a high-quality paper. The paper resists decomposition and yellowing as it ages does not occur. Because of its low lignin content bleaching can be done without chlorine. Hemp paper can also be recycled more often because of its longer fibers *1. Teabags, tissues, carbon paper, quality paper made from Agri fibers *15. Elephant grass is a fast-growing plant which reaches 3-4 meters in height. The structure of its fibers are similar to those of wood. So the obvious application is in the paper and cardboard industry. Straw is also a fiber which is used in the paper and cardboard industry, particularly in Denmark and Britain *16. The fibers of Kenaf (Hibiscus cannabinus L) are easily extracted and bleached and can serve as pulp for newspaper production. When it is combined with recycled paper it can upgrade it *12.
Bio pulping involves fungi to convert wood chips to paper pulp, which means a considerable reduction in energy and pollutants normally associated with paper production.

“Paper chase”
Zeneca, Shell Research and Nippon Paper Industry are working on genetically modifying lignin in paper pulp trees. This way lignin will be easier to remove from cellulose, which makes paper making less energy and chemical intensive. Nippon Paper Industry is also researching eco-

bleaching by white fungi *30.

Shock-absorbent packaging material

Any cellulose based fiber can be turned into a foam material like hemp or elephant grass. Cocoloc is a composite consisting of coir bound by latex used for packing delicate products. Straw is also applied as shock-resistant material.

On Sardinia, an experimental project was started in 1992, to see whether loofah gourds were suitable to be grown in this Mediterranean climate. The reason for this experiment, which was funded by the European Union, was that loofah as a fiber source, could have many non-food applications the most important of which is shock-absorbent packaging material for delicate products. The fruit consists of 60% cellulose, 29% hemicellulose and about 11% lignin. One cubic meter of loofah weighs around 10 kg which is about the same as polystyrene foam. By compression or heat the fruit can obtain any shape. It can also be combined with various other materials from natural sources *32.

Bags

Bags of linen, cotton or jute are very common.

Biopolymers

Biopolymers, or bioplastics, are biodegradable by biological processes through microbes as bacteria or fungi. They are very suitable for short life-span products, such as packaging or disposables. However, some bioplastics are also perfectly suited for longer life application. Biopolymers are often more heterogeneous than synthetic ones and their structure offers greater opportunities of modification *27.

Golf tees, sand and gelatin (designed by author)

They are sometimes seen as an outlet to get rid of agricultural surpluses. *32. Most bioplastics can be modified to suite industrial processes for petroleum-based plastics. They can be applied as coatings, produced as foams, or injection moulded, etc.

Starch

The properties of the different sources of starch vary in strength, transparency and flexibility. For instance, pea starch produces a stiff and strong plastic. On the other hand, potato starch leads to a less strong but flexible plastic *33. Potatoes contain around 20% starch. Potato starch is generally more expensive than wheat starch but is of better quality *16. Starch forms a good barrier to oxygen but absorbs moisture *37. There are several crops which are grown for starch production. Some of the important ones are corn in the United States, potato and wheat in Europe, tapioca and rice in Asia.

Starch peanuts

"Corny"

At a corn flakes factory in America a material was produced by accident which looked much like polystyrene packing peanuts. It was expanded and was flexible *42. With a little modification Eco-foam (National Starch) was born *45. It has been commercially produced since 1991 *12. The Dutch company Avebe produces potato starch in Holland, wheat starch in France and Sweden and tapioca starch in Thailand *12. There are mainly two groups of commercial starch products i.e.:

Expanded starch

The most common way to produce expanded starch is like the technique used for baking wafers developed by Biopack of Austria. The doughy mix in the mould is baked in an oven. As the water evaporates, a foam-like material is left *44. Loose-fill and trays can be produced this way. Usually, additives are included such as puffing agents like Guar *38.

Starch flowers expanded in microwave (designed by author project with Avebe)

Thermoplastic starch
To be applied as a thermoplastic material, starch needs an agent like glycerol. This substance makes it possible for starch to melt, and makes it more flexible. It is colourless and has no scent *15. It is available for about 3ECU/kg. *12. It can be extruded into film or sheets, or injection moulded using conventional machinery *44. Avebe offers a starch product called Paragon which expands in the microwave. Of the two components in starch amylase and amylopectin, amylase is of no use to the starch industry. Splitting starch costs a lot of energy and produces a lot of waste.
One of the disadvantages of potatoes is their weight. It is therefore not worth while to extract potatoes outside a certain radius from the starch factory *41.
Because of the hydrophilic and low mechanical properties of starch there are only a few areas of application. Warner Lambert in America was the first company to come up with starch as a bioplastic *12 . At K'92 a plastics fair held in Düsseldorf they introduced Novon, made from corn and potato starch, which was applied in golf tees, loose-fill and as bin liners *43. In America, Cargill manufactures a line of corn-based cutlery and plates *1. In Belgium de Ster produces starch cutlery for passenger airlines. In the Netherlands biodegradable trays made of starch are produced by Suntray in Helmond. Biopack in Austria also produces expanded starch products. Lyckeby Biopack, founded in 1991, a Swedish/Austrian company, provided the disposables for the Lillehammer Games in Norway in 1994. Hamburger boxes and french fries trays were made of pure starch. Plates however, were provided with a coating of cellulose, vegetable oil and natural resin. The cutlery was made from corn starch imported from America. Cornstarch bin liners were also provided. From the beginning of 1993, the Austrian MacDonalds serves certain meals on starch plates *36. Lozer produces trays for German chocolates *39. Biotec produces sheet material which is thermoplastic and can be moulded *35. Novamont-Feruzzi in Italy produces compostable bags, films for wrapping, loose-fill, cotton swabs, nursery pots and diapers from

“Designer spuds”

Researchers in Holland have come up with a genetically modified potato which only makes amylopectin *12. Already a similar modification was applied to corn in the United States for starch production *40. Mater-Bi starch. Biros made of Mater-Bi, consisting of 50-80% starch and the rest of synthetic materials. However, there are 4 grades being produced by this company, one of which is purely natural, the others have a certain synthetics content *33 .

Other products which are being produced include capsules and several other medical products, diapers, tampon applicators, ear swabs, seed coating, abattoir aids, (vegetarian) dog bones, toys, candle sticks and ornaments for churches, fireworks rocket tips, shotgun shells, (starch)clay pigeons, fishing lures, golf-tees, trays for candy or biscuits, paper clips and windows for envelopes. Starch is biodegradable and can be turned into compost. It is also easily separated from synthetic plastics. At incineration starch emits no toxic substances and dissolves into water and carbon dioxide *44.

PHA / PHB

In 1929 it was discovered that bacteria produced polyester as a reserve. This group of materials which consists of many variations, is known as PHA. The material is gained by the process of fermentation. The material has good properties, such as high resistance to water and it can be applied in most industrial processes like extrusion and the production of films *34.

Biopol: biodegradable bioplastic PHB (Polyhydroxybutyrate)

ICI Zeneca was producing one of these plastics, named Biopol, commercially from sugar *15. Biopol is now being produced by Monsanto of Italy. It produced in a variety of plastics with different melting points varying from 136 to 162 degrees centigrade.*27

In 1990, the German cosmetics brand Wella introduced a biodegradable bottle made from Biopol produced by ICI *32. The manufacturer made an experimental batch of 200,000 bottles. The plastic is commonly applied as a coating mostly on paper products *28. A problem though was the relatively high price of Biopol (in 1990, it cost 8x as much as conventional plastic bottles) *34.

There is quite a low output of bio-polyester compared to the level of input of food like glucose or starch on which the bacteria feed. For every kilo of Biopol 3 kilos of sugar is needed and the process is quite slow *28. The bacteria store PHB within their cell walls, up to 90% of their total weight. To harvest the bioplastic the cell wall has to be ruptured, without damaging the plastic. This is quite a delicate procedure as the plastic is destroyed at temperatures above 70 degrees and an acidity of higher than pH value 8. A solvent was used but proved too expensive *29. The bacteria can also feed on fossil fuels. At Zeneca bacteria fed on natural gas *43. ATO-DLO has also done research with these bacteria but they feed on vegetable oils, like rape seed oil. The advantage is that it is cheaper and they claim a bigger production of PHA. Even more important is the diversity of vegetable oils. Interestingly, the diet and general conditions influence the properties of the eventual plastic *31. PHB has a high melting point and can with stand steam. It can be applied in diapers, coffee cups and cutlery. Also pens and disposable razors have been produced *52.   In 1989, it was discovered that plants could be used for the production of speciality chemicals and polymers. These products were being produced by bacteria, but plants should increase their yield considerably *29.

"Plastic plants"

At the Michigan State University in East Lansing researchers have succeeded in having a plant produce a plastic similar to Biopol, by transferring the genes of the bacteria to this plant *32. Arabidopsis was engineered to produce granules of PHB and survives whilst storing it like the bacteria do *29. Similarly in Stanford at the Garnegie Institution mustard plants were injected with genes to make PHB. Most plants when dried could provide around 20% plastics besides their "natural" products. The discovery was sold to Monsanto in St. Louis.

Poly lactic acid

Lactic acid is a solid at room temperature. There are 2 types i.e., D-lactic acid obtained by the action of bacteria on meat extract and L.lactic acid from the fermentation of sucrose by bacteria. A mix of the two is obtained from sour milk. Bacteria act on lactose in milk and excrete lactic acid.

Cat casket made from bioplastic including PLA and wax. The lining is non-woven hemp

Pure lactic acid was synthesized in 1913 for the first time. Copolymerization produces polymers with a wide range of properties. These thermal polyesters are biodegradable and can be processed using the conventional melt processing technology *17. In Holland, Purac and Hycail produce this material. Due to high costs, mainly because of the price of sugar, it was initially applied in medical products only. However, in the United States poly lactic acid was being produced cheaply by using waste from potatoes or whey *27. This new Biolac process has been patented and is marketed by a Japanese company Kyowa Hakko *82.
Lactic acid polymers have a long shelf-life but can be considered moisture sensitive as they degrade slowly. This may vary between 6 months and 20 years *28. Polylactides are high quality plastics. There is also a transparent variety available *35. Biolac is the common name for this polymer *47. Due to high prices the application was limited to medical products, but recently these prices have dropped. However, scientists have demonstrated the process for converting potato waste to lactic acid. Other types of food waste like cheese whey, fruit, corn, grain or sorghum would be interesting for the production of bioplastics *48. Application for packaging is a possibility when a long shelf-life is required. Film, trays and boxes are suitable applications *28. Transparent cups have been produced *35. A combination with other materials is also possible.

Casein
Milk proteins like casein are presently applied into light sensitive paints for televisions and in certain glues for attaching beer labels. In the past, casein or whey was applied as plastics in combs and buttons and was processed into yarns for clothing items like ties *46. It was often used as a substitute to imitate ivory or tortoise shell *12.

Some Casein-based bioplastic products from the early 20th century

Inulin
The polymer inulin (produced by chicory a blue-flowered plant) does not dissolve in water nor in many chemicals, so it might be an interesting material for cosmetics packaging. A sugar company in

Holland (CSM) has begun a factory to produce inulin from chicory *15.

Gluten

Found in corn and wheat, gluten is a vegetable protein. It can be chemically or enzymatically modified in order to be applied for non-food purposes *15. The production of wheat gluten is still growing but the demand stays stable. So there is room for industrial application too. The price can compete with other plastics. TNO in Holland has researched its possibilities and found it could be made thermo-plastic so it can be industrially processed. It can be extruded into fibers, films or tubes. It can also be used as a granulate for injection moulding or used in vacuum film.
The material breaks down within 24 hours at room temperature by addition of an enzyme (5%), so it can be called biodegradable *31. Some applications include bioplastics, packaging materials, biodegradable coatings, glue, slow-release materials and heart valves *27.

Gelatin

Gelatin is made from bones and hides and is applied into certain paper products like bank notes and capsules.

Jelly pen made from gelatin, felt, alcohol-based ink (designed by author)

Agar

Agar-agar is the gelatinous extract of seaweed or algae *50. American scientists have discovered a way to develop a solid which is lighter than air and is based on agar. The agar is dissolved in water and an organic solvent is added together with an emulsifying agent. The gel sets and is freeze-dried. The material could be applied as insulation packaging or slow-release capsules. *51.

Chitin

Chitin occurs in exo-skeletons of anthropoids and in the walls of fungi. It is similar in structure to cellulose *17. In Japan, the shrimp industry is quite large and the many peels are a waste product. Scientists have succeeded in making a semi-transparent film for packaging, from a combination of chitin and cellulose. The material has good properties such as moisture resistance and good biodegradability. The researchers were working on making the film transparent *49.

Vegetable oils

Plastics, coatings, paints. cosmetics, detergents and lubricants are some of the products made from vegetable oils. Bicarbonic acid are supplied by microbes and applied into plastics *35. Crambe oil produces a kind of nylon, which is an excellent base for durable light-weight components for the aviation or marine industry *12. Some important oil producing crops include rapeseed, soybean, sunflower and castor. From castor oil small substitute body parts (like testicles) are made *49.

Jelly pen with vegetable oil-based ink (designed by author)

Transport

As seen in chapter 1 on chemurgy, natural materials have been applied in car parts right from the start.

Car materials

Following in the footsteps of Ford half a century earlier Mercedes has introduced a car, the E-class, which includes interior panels made from flax and sisal fiber. (Although the formerly East German made Trabant's bodywork was also made of flax fiber). Interior parts like door panels, dashboards, rear shelf, sun vizors, sound-proof / isolation material, roof and dashboard upholstery, seat upholstery and carpets.

A-class Benz

But even reinforcement in wheel arches and bumpers are possible applications for natural fibers. The Smart car and the A-class cars will include flax fiber reinforced parts instead of glass fiber ones. In Holland, KIEM, is designing an interior for Volvo Car, which will probably include platonised flax fiber parts. This material has the advantage of being moisture- resistant, lightweight, sound-proof and more safe than glass fiber. In Holland a truck is being developed, the body work of which will be consisting of unto 80% renewable materials. The weight is expected to be reduced by up to 1000 kg.

Modern Soy-based foam seat for the Ford Mustang

Some innovative processes have been developed like pultrusion by which fibers with binders are dragged through a mould to produce profiles. Other processes are injection moulding, or conventional press techniques. It has been proven that natural fibers are indeed an improvement technically, when compared to glass fiber *63. Flax fiber is very light weight, so when applied in a

significant quantity it could safe quite a bit on petrol consumption. Under the bonnet flax could be applied as a reinforcement fiber in brackets and hoses *19. But flax fiber can also be applied in exterior components like car bumpers. I suppose the use of natural fiber with use of natural binders or without binders is limited to interior use. However, when a suitable natural binder which is water-resistant is found, perhaps the outer body work will be sustainable as well.
The prospects of polylactic acid seem promising. The properties are quite similar to ABS plastic so it might be applied into car bumpers or other products which need to withstand wear *64.
(for further information about fibers, see The home).

Fuel
Fossil fuel reserves will almost certainly be depleted in the 21st century. On top of this, the exponential growth of car use world-wide results in an increase of carbon dioxide emissions *53. As discussed in the chapter about chemurgy the diesel engine was originally designed to run on bio-fuel. However, it was decided to opt for fossil fuel as sources seemed endless and was relatively cheap to attain. The consequences of this decision are all too clear a century later.
Biomass can be used in several ways to produce energy:

- Incineration or vaporisation
- Oil from biomass
- Fermentation: bio-ethanol

“Timber!”
Because of petrol fuel restrictions, in war time France there were cars on the road that burned timber for fuel. Service stations sold wood for the gazogène or “gazos” *57.

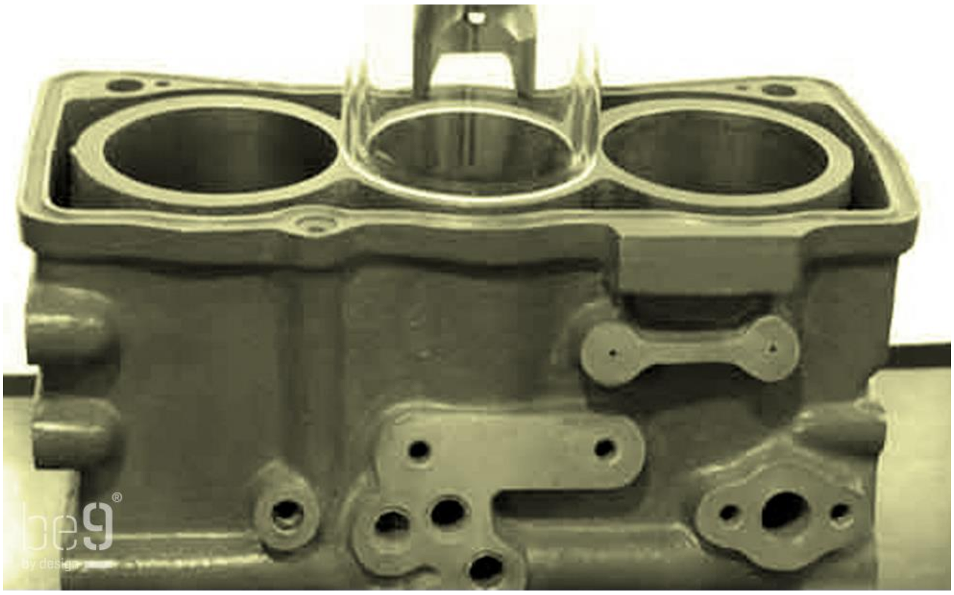
A Gazo truck running on timber for fuel in war years

Incineration or vaporisation
One method is to burn or vaporise the matter. By incineration, heat and electricity can be gained. By vaporization also methanol can be extracted which has many applications in the chemical field.

Nowadays, some fast-growing plants are especially grown as a source of energy such as hemp or elephant grass *53. Agricultural waste can also be used such as straw. In Sweden a generator was designed for maximum output (95%) of energy called the Biocomb-cyclon-burner *16.
In Britain an experiment has been conducted in which seaweed was grown in tanks, dried and burned to produce electricity. The carbon dioxide which is produced is redirected into the tank which speeds up growth of the seaweed *59. However, without government help it will not be able to compete with the cheap fossil fuels *56.

Oil from biomass

Rape seed is especially grown for bio-fuel in Europe and contains about 45% oil. In the EEC in 1988 5.2 million tonnes was produced. The EU have decided to keep these fuels free from tax *16. The emission of carbon particles which can cause cancer is more than halved. Also the carbon dioxide which is produced is absorbed by the rapeseed so the ecological chain is closed. Another advantage is that spilled biofuel is bio-degradable *62. Shell has developed a process (Hydrothermal Upgrading) by which about 40% oil is gained from the biomass, but it's even possible to use household organic refuse or agricultural waste material. This could make the fuel cheaper and is the cheapest green alternative to using fossil fuel *53.



A modern Elsbett 3-cylinder car engine designed to run on strait vegetable oil

The Elsbeth-engine was specially designed to run on vegetable oils but is very similar to the ordinary diesel engine. This engine enables the farmer to be self-sustainable if he grows his own fuel *16. Amongst other car manufactures Volkswagen is supplying a diesel engine which is also suitable for biofuel, but the fuel is not readily available yet *58. It is quite easy to adapt a conventional diesel engine to suit biofuel *61. However, the engines life span might decrease by about 2% *62. In Japan an experimental ceramic engined car (Isuzu) has been tested. The engine is lighter and can withstand more heat than a metal one and is therefore more efficient *80.
Oil extracted from biomass, has been proven economically worthwhile. But the main problem

associated with this biofuel is the amount of space it takes to supply enough fuel for consumers *55.

Fermentation: bioethanol

As seen in the previous chapter, Ford was experimenting with alcohol derived from vegetables as a fuel for his cars. Usually “dry” crops are used for burning and “wet” crops like potato or sugar beet are used for fermentation *16. In Brazil corn, sugarcane and sugar-beet are grown for the extraction of alcohol *54. This country is the largest producer of bioethanol (12 billion litres a year) *53. In Britain genetically modified bacteria increase the production of ethanol by about 30% *58. In a research report for the EU it was concluded that it was not really worthwhile to extract alcohol from plants as there was as much energy needed to recover the alcohol *55.
In Stockholm, Sweden, there is an experiment being conducted involving city busses running on cheap Spanish wine. Permission was granted by the EU to use five thousand tonnes of surplus wine for fuel purposes *60. So in the near future our cars may have ceramic engines running on wine or rapeseed oil, and have their body work and interior made up of natural fiber and bioplastics.

Cosmetics, deterents & medicine

A lot of cosmetics ingredients from biological origin, have a healing effect as well. Herbs and natural oils often contain substances which can cure. The classic ingredients for detergents and some cosmetics were sand, soap and soda.

Cosmetics packaging using modified bottle gourds (by author)

Plant oils, herbs and weeds

Today, about 15% of all detergents are plant based. Often natural materials like flax or coconut oil are applied. Flax can be grown locally and needs little fertilizer or pesticides. Plant based cosmetics take less energy than those from fossil oils *65.
Hemp oil extracted from hemp seeds is known to assist the body’s natural ability to heal. It contains essential fatty-acids and vitamins. Also soap and shampoo is made of hemp *1. Jojoba oil is

currently the new economic wonder oil for the cosmetics industry. Besides being used in food, herbs are extensively being grown and applied in cosmetics and holistic medicine. One interesting product is a pillow filled with herbs and spices to ward off insomnia and cheer the soul *68. In holistic medicine old recipes are being consulted and there is a revival in the herbs industry. New, alien or forgotten herbs are being grown, for example Ginseng is being cultivated in Holland.

Industry
The Bodyshop sells many plant-based cosmetics for which sometimes special (trade-not aid) production projects are started, mostly in third world countries. Ecover a brand in detergents makes products based on vegetable oils or whey which are completely biodegradable. In the first years there was a growth in turnover of more than 400% *16.

Opportunities
Sometimes rare and even endangered species of animal or plant are exploited by drugs companies for a special chemical they produce. With the help of biotechnology, the desired product can be provided locally, in larger quantities and without threatening endangered species.
By the conventional method, genetically engineered bacteria produce the antibodies in fermentation vats. This is expensive because sterile conditions are needed. In another process genetically modified plants generate antibodies in their leaves. A big disadvantage of this method is that the antibodies have to be extracted immediately.

"Growing medicine"
In Germany botanists of the Institute for Plant Genetics and Culture in Gatersleben have discovered a cheap way to grow antibodies in seeds and store them indefinitely. The researchers used the tobacco plant but are now experimenting on the pea plant. The main problem however, for large scale production of antibodies will be its extraction from the peas. Perhaps it will be possible in the near future to pick your own antibodies *66.
At Mogen in Leiden (Holland) potatoes have been engineered to produce the human protein and serum albumin. The production by potatoes is cheaper than at the chemical industry *26.
In France a team of researchers at INCERM have succeeded in genetically modifying certain plants like rape seed, tobacco and corn for the production of human blood. The plants produce amino acids in their leaves, which form the basic structure for hemoglobin. After its extraction, iron is added. Early next century it might be possible to produce pure blood cheaply on an industrial scale, by applying plants for its production *67.

Clothing

"Denim returns"
Presently in France (the country of origin of Denim jeans, named after the indigo colour process developed in the city of Nîmes), coloured cotton (shades of yellow, green and brown) will be

cultivated in the wine-region of Languedoc-Roussillon, thanks to research and development results at CIRAD. The cotton plant has been modified to endure the changeable European climate *83.

Traditionally, many natural fibers have been applied in the textile industry, such as cotton, silk, wool, and linen. the production of silk is described in the following article engines of production. Viscose and rayon fiber are made from wood fiber but are chemicals and energy intensive.

Cotton

Cotton has a bad reputation, but it remains the most important textile fiber. "Ordinary" cotton is yielded with the help of defoliate chemicals which rids the plant of its leaves.
Pesticides and insecticides are often used. The cotton is bleached and coloured, made shrink- and crease-resistant and softened which involves a lot of pollution and energy *73. However, there is organic cotton being produced with natural colours, described further along in opportunities.
In recent years though, since the Eco-fashion trend had started, fibers have been applied from uncommon sources such as weeds. Alternative natural fibers are often far superior to and more environment-friendly than cotton.

Hemp

Hemp fiber is stronger, longer, more lustrous and absorbent compared to cotton fiber. Hemp textile regulates temperatures very well, so keeping the wearer warmer in the cold and cooler when it is hot. Clothing made from hemp fiber has proved to be exceedingly popular in Germany and the United States. However, the fiber is too thick to be processed in existing spinning and weaving machinery. But in the near future we can expect hemp T-shirts *1. Hemp fiber is currently being used in jeans clothing. The original jeans made by Levi Strauss in 1850 were also made of hemp (canvas).

Peat

Amazingly enough, clothing items, covers and pillows are being made from peat. Peat is basically plant fiber which has been pressed together by age. Often peat is combined with fibers like silk or wool and spun to fiber.

Peat casket (designed by author)

Milkweed
Similarly, milkweed is considered a nuisance as a weed, but it is currently being grown by the Natural Fiber Corporation in America to be applied in covers and pillows *69.

Pineapple
Pineapple fiber is spun and woven into clothing. Thanks to the development of a new machine with UN funding fiber can be gained from the plant's leaves *71. The fiber seems to have good moisture regulating properties and improves the quality of the air.

"Blue genes for blue jeans"
Genetic engineers at Agracetus plan to transplant genes from an indigo plant to cotton plants for the production of blue cotton. The genes would be engineered in such a way that they would be active only in the cotton fibers, so only the cotton boll would turn blue. The colouring of cotton is polluting for the environment and requires energy. Indigo was the original pigment to be used before a cheaper, synthetic alternative was found *70.

Industry
In the seventies a new concept (in which Archizoom from Italy was involved), for the production of garments was developed. This involved a machine which knitted tubes instead of flat sheets. A garment normally consists of a series of tubes *72. Several companies like Esprit have marketed Eco-fashion made from organic cotton, which is not dyed, linen, wool or other natural fibers. The demand for organic cotton exceeded the supply *73. There are companies emerging specializing in the field of hemp or peat fashion.

Opportunities

Besides these new fibers there are some positive developments in the traditional fiber like wool and cotton as well. Natural coloured wool is available nowadays, sometimes from more exotic animals than the common sheep. The American Churro sheep can yield four different kinds of wool simultaneously *81. In America, Sally Fox has succeeded to create machine-spinnable coloured cotton (browns and greens), by crossing several varieties of cotton. She is also working on improving the fiber quality in other colours. Her coloured cotton is now being spun by commercial machines and woven into shirts, jackets, sheets and socks for major clothing companies.
There are two American companies: Agracetus and Calgene, which are researching cotton to improve the quality of its fiber. The fiber is being engineered to be stronger, longer, finer, warmer wrinkle-free and even pre-coloured.

Engines of production

An introduction

It seems most production and processing of renewable materials for industrial purposes is still relying on energy intensive, conventional methods. Especially bioplastics are designed or modified to meet the requirements of industrial processes. For example, starch is modified by the addition of glycerine, which raises its melting point. However, there are processes being applied from other areas like the food industry. Sometimes completely new ones are applied, which have been specially designed to process natural materials, such as pultrusion. With the advent of biotechnology, we may have arrived at a transitional stage. Desirable materials can be produced by the transplantation of alien genes to rapid replicators like bacteria or plants. The following piece explains several options of manufacture.

Insect living factories

Insects have been cultivated throughout history as living factories, producing materials for man. Three examples are silk moths and lac lice and the honey bee.

Silkworms

The production of silk(beta-keratin), or sericulture originated in China, around 3000 B.C. Of the four hundred different types of moth, there are two varieties which are most common for silk production, i.e. Bombyx mori and for wild silk, Antheraea pernyi, which is not domesticated *17. The silkworms feed on Mulberry leaves and produce cocoons from which silk fiber is taken. Silk yarn is produced by the reeling of cocoons, which float in a tank filled with hot water.

Lac lice

The Kerria lacca is a small parasitic insect which is cultivated in India for the production of shellac. They secrete a resinous substance on branches. They are tiny and it takes several million to produce one pound of lac. Shellac was applied as isolation material for electrical equipment, in varnish and in the manufacture of gramophone records.

Honeybee

The bee is of course a well-known example. It has been cultivated for thousands of years for its products, like honey, queens jelly and wax.

Bacterial trans mutators

Bacteria of course have been used in the past in various processes for food production, such as dairy products. Bacteria are also known to clean polluted soil or water by breaking down chemicals *74. The Kuwait desert was very polluted by oil spills as the result of the war. The cleaning up of the oil in the sand was difficult and not making much progress involving complicated and expensive machinery. However, in 1995 there were wild plants with yellow flowers growing on the polluted soil. A biologist went to investigate and found the roots to be completely free from oil contamination. This was because of bacteria in the root which feed on oil. Actually, the bacteria feed on nitrate-nitrogen after which the oil is broken down into carbon dioxide and water. Since its discovery the plant has been spread to other parts of the desert.

But researchers in Japan have come up with another method by applying bacteria straight to the soil. This way it works quicker and better, as the polluted sand is turned into fertile garden soil. But there is a problem i.e. the bacteria can't stand the high desert temperature. Fertilizer is mixed into the sand and water cools the mixture. So, the Kuwait desert is cleaned up and is turned into a fertile agricultural area, by the work of bacteria. As shown in the chapter about bioplastics it had been discovered early this century that bacteria can produce plastics. Today it is being commercialized as Biopol initially by Zeneca, now by Monsanto.

Only recently it has been possible to transplant genes from one organism to another. Once the genes are identified which are responsible for the making of a desirable material or substance, they can be transplanted into bacteria for high production. The bacteria produce a pulp of the material.

"Alchemist bacteria"

Bacteria are even applied in extracting gold from rocks. These bacteria feed on iron sulphate (pyrite) leaving gold.

Two interesting examples where bacteria are involved as a means of manufacture are described below:

Silk

Spider's silk is much stronger in comparison to the strongest man-made fibers like Kevlar. Several Universities in America and even the U.S. Army (since the late sixties) have been experimenting with transferring genes responsible for making silk in spiders into bacteria. The bacteria produce large protein molecules which are similar in structure as silk. The bacteria make silk pulp, from which it can be shaped into any form. Basically, the bacteria are cultured in water at around body temperature and fed on a diet of amino acids. *75.

“Bullet-proof vests of silk”
In theory a scaled-up net of silk could catch a fighter-jet in midair. One application could be that of bullet-proof vests.
By inserting genes into micro-organisms, researchers have been able to express, or produce essentially identical molecules. In fact, any material can be tailor-made using this method. Other proteins which are interesting are elastin, collagen, alpha-keratin *76.

Mother of pearl (nacre)
Researchers of the University of Washington are trying to identify the proteins which are responsible for forming nacre (a protective inner layer in shells) such as in abalone. This material is twice as strong as any ceramic. If they succeed the gene will be found and can be transplanted into the bacterium Escherichia coli. The bacteria will produce the proteins in sufficient quantities. Scientists have also researched and mimicked the principal of nacre, which is to deflect pressure through its many layers. The resulting material is very tough and could find application in rotor blades for jet engines.

“Nacre coatings”
Perhaps it will be possible to provide products or objects with a nacre coating by immersing them in a solution of the proteins and necessary ions *77.

“Bioplastic plants”
Researchers at the Garnegie Institute have successfully transplanted a gene, which makes proteins from which bacteria produce PHB, into mustard plants. They say that in the future most plants will be suitable for the production of plastics. Besides growing their “normal” products, they will also provide a harvest of plastic. The plants contain about 20% degradable plastics once dried. Monsanto Co. bought the rights and it is believed that in about five years or so the first products from genetically modified plants will be commercially available. This development will reduce the costs greatly for this biodegradable plastic.

Power plants
Woods have been the engine for civilization from the start. The cultivation of plants goes back a long way, but cultivation on an industrial scale for non-food purposes probably began in colonial times with the development of plantations, for natural rubber for instance.
For the first time, plants are being used as hosts for alien material production. The reason being is that plants can produce materials in large quantities, without much attention and at low costs. As seen in the previous chapter, a plastic similar to Poly hydroxybutyrate (PHB) or Biopol, which was being produced by bacteria, can now also be produced by plants. Besides, material production, other substances can be produced by plants using similar techniques. For example, antibodies can be grown in huge quantities and stored indefinitely if they are produced in the seeds *66.

Nano assemblers
Perhaps the disadvantage of living engines is that they eventually die and have to provide for successors. Although my research is about biological processes, I want to include nanotechnology because it could also apply to biological materials.

The well-known physicist R. Feynman mentioned in 1959 the application of small machines to build smaller machines. The smallest machines would be able to assemble atoms.
Nanotechnology (nano= one billionth) involves building materials on a molecular level. Atoms which are the smallest parts of matter, are selected and assembled into molecules, by small machines. These machines, which resemble robotic arms, are themselves made up of molecular parts containing several thousands of atoms. Each assembly step is a chemical reaction.
The process is basically the same as the growth of a tree. Just as the self-replicating molecular machinery of a seed can make a tree, so a properly programmed replicating assembler will be able to make a tree, so a programmed replicating assembler will be able to make a micro-computer or a full-sized car. This way it is possible to build designer molecules to any specification.

"Diamond- fiber composite"
In theory, carbon atoms could be assembled in a certain way to produce diamond- fiber composite. (Diamond is the strongest material known to man). It would be possible to create a virtually indestructible and light-weight product. The material can be assembled directly into the shape of the eventual product so there is no waste material. (K. Eric Drexler) *78.

In conclusion

In the field of materials from renewable sources, there are mainly two areas interesting to designers, i.e. bioplastics and natural fibers. In the area of bioplastics, the so called first generation, which mostly contained a certain percentage of non-biodegradable materials, has been largely replaced by a new generation of bioplastics, which are completely biodegradable. Due to price reduction in recent years, through scale enlargement, bioplastics are gradually becoming competitive. The application of bioplastics is generally limited to the field of disposables and packaging and the medical field. One particularly interesting development, although it still is in an experimental stage, concerns the production of a plastic similar to Biopol, by plants.
In the area of natural fibers, the PLATO process seems an interesting development. It basically involves a change in the structure of wood or plant fiber, brought about by cooking the matter. The resulting material is lighter, stronger and more durable than the original. Natural fibers are finding sustainable application particularly in building materials, in the paper industry, in eco-fashion, as an energy source and most recently in the car industry. Projects like the one on Sardinia involving the large-scale cultivation of Loofah gourds are a good initiative. In the case of production processes, I feel the processing of natural materials is still in a transitional stage. Presently, the material has to

be modified to meet the specifications suitable for industrial processing. However, there are processes being developed specifically for dealing with natural materials, like pultrusion.
One big step further is the production by biological processes, such as the application of bacteria or plants as rapid replicators for materials. Biotechnology will assist in the improvement of production efficiency and product quality. An example is corn and potato which has been modified to produce no amylase, so starch extraction has become easier and cleaner.

Remarks

Of all renewable sources, I think the waste source is often being discarded. A lot of natural materials waste from the food industry for example, which is normally burned or buried, could be applied into products. I find the concept of applying plants or insects for the manufacture of parts or complete products fascinating. Imagine consumer goods being grown instead of being manufactured. In this area I have done some experiments, the results of which are to be found in the next chapter.

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3rd chapter 2 Scenarios

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- Technical aspect
- Social aspect
- Ecological aspect

Aquafication
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An introduction

We are in crisis at the moment. We have an environment crisis. The way in which the West uses science and technology in relation to nature has catastrophic effects. There is also a moral crisis. Ethics seems to have become a matter of personal taste. Both are an expression of estrangement between man and nature *6. At the end of the second millennium and at the beginning of the Post-Industrial Era there is a need for a global (damage) assessment and a plan for recovery. As our natural resource stocks are dwindling, a wide application of materials from renewable sources seems the only option. As the problem of waste disposal is increasing and locations for landfill sites are getting fewer, there is a growing need for biodegradable products. Presently, plants and bacteria are being employed to clean industrial polluted soil and water.

An assessment

Economical aspects

Renewable materials have to compete with materials derived from petro-chemicals which at the moment are still cheaper to produce. On the long run though, with all stages of the products' life cycle considered, it will be proved feasible to apply renewable materials from an economic standpoint. For example, in some countries there have been laws created to counteract pollution and the growing waste problem. In Germany, the DSD taxes for synthetic packaging are 15 times as

high as for natural materials. So it pays to apply biodegradable materials.
Because of the environmental measures, industry must comply to new standards, companies are made to re-think their production methods. Often, this may result to innovation, the effects of which might cut production costs. Obviously, the economic situation of the agricultural sector would improve. The market as it is today, is quite limited and is mainly food oriented. So the market will be more diverse with the supply of agricultural materials for industry.
Another advantage of an agriculturally based economy is that of greater national independence. Many countries do not like to be too reliant on goods from other countries.
Since the advent of biotechnology there has been a switch in corporate investment to agricultural research, particularly by firms that produce agri-chemicals. Reasons being that plants won't need any chemicals in the future as they will be made by the plants themselves by genetic modification. The chemical industry which sells the package-deal (modified seeds together with the herbicide) makes the agricultural industry more dependent. The farmer buys the seed because of high yields and of low crop maintenance. The seeds however are mostly hybrids, requiring him to purchase new seed every year. Indeed, patent may prevent the use of farm-saved seed. It is predicted that 12 large multinationals such as Sandoz, Ciba-Geigy and Pioneer Hi-bred will dominate the global seed business shortly after the year 2000.
Furthermore, the chemical industry will have a better grip on the food industry. Food and pharmaceutical companies are interested because plants can be adapted or be tailor-made to meet their needs *1.

"Nature patents"
Industry will shortly have total control over the seed business. A few super crops will dominate agriculture. Biodiversity is being threatened. Besides this, [modified] life is being patented.

Technical aspects
The production techniques for bioplastics and natural fibers rely mostly on conventional methods. There have been some new techniques introduced which are specifically developed to handle natural fibers like pultrusion. However major developments are being made in the area of biotechnology. There is a distinction between old and new biotechnology. Old biological processes include brewing, bread and cheese making, while the new ones include techniques like genetic engineering *1. Biotechnology, as defined by the Office of Technology Assessment of the U.S. Congress, includes any technique that uses living organisms (or substances of living organisms) to make or modify a product, to improve plants or animals, or to develop microorganisms for specific uses. Dan Clickman (American minister for agriculture) pleaded for a second green revolution in which biotechnology would play the major role. Without it a lot of forest would have to be cut or agricultural fields will be exhausted, to supply in the demand for food and materials.
(The first green revolution was the widespread use of chemicals in the seventies, which meant the industrialization of agriculture) *2 .

“Genetics: tailor-made products”
A plant can be genetically modified to grow anywhere. It can be made tolerant to temperature extremes. Genes from deep sea flat-fish which are found near the poles were transplanted into tobacco plants. The gene stimulates production of an enzyme which controls the flow of water. So now the plant is able to grow in colder regions. Furthermore, crops can be made to survive heat and drought *2 . For regions which are commonly flooded plants can be made tolerant to salt water *4. They can also be made to change colour, as described in a previous chapter. The genes of the indigo plant were transplanted into a cotton plant, so blue cotton can be harvested for the jeans industry without bleaching it first *5. Amongst other plants Cassava has been made disease resistant. It is manipulated further to stimulate production of pesticide by its own. *8. A plant can also be made herbicide resistant. A soybean has been made resistant to a herbicide manufactured by the same company *2 .

Social aspects
The population is increasing 2 % per annum or doubling every 30-40 years. It was calculated the earth could support 22 billion people at the most. Today’s situation in the Europe, we are faced with agricultural over-production. There are agricultural surpluses and farmers are subsidized not to produce more than agreed to. In effect, the surpluses could partly be used for non-food application. Also, a lot of agricultural land lies fallow, which could be used for non-food purposes *3. It has been predicted that job opportunity will increase, as the demand for natural fibers like flax will continue to rise. In Holland, the flax production chain which is currently being set up will offer several new jobs.

Benefits of plants and renewable materials:
Directly, the benefit that plants bring us supply us with oxygen and filter the air. In this respect large-scale agriculture for non-food purposes can do its share by providing society clean air.
In our homes or offices equipment such as copy machines and printers emit a lot of dust. Sick-building syndrome which is caused by bacteria in the air-conditioning system, can be helped by introducing plants. Plants with large leaves will help humidify the space *2. NASA has experimented with sansevieria which they say breaks down toxic substances in the air and feeds on it *7. Also, the purely visual aspect of plants have proved to have very positive effects on humans. People seem to get cured faster and are less prone to stress *2. The use of natural materials in the personal environment have proved to regulate humidity and neutralise excesses like noise, electrostatics, smells, etc. Also psychologically speaking, natural materials are known to have a positive effect. One example is the use of wood and leather in car interiors. Apart from the traditional healing powers of certain plants and herbs, plants seem to be the ideal hosts for alien genes responsible for the production of substances for medical purposes and replicating them. Besides this, the production of bioplastics by means of production through plants, seems also to be worthwhile.

Possible restrains for use of renewable materials:
Large scale agriculture for industrial purposes would increase the demand for water and jeopardizing water supplies for human consumption. Also, with an exponential growth of the population, space is becoming a scarce commodity. The priority for space will be for housing and food production. The way some crops are being managed today like cotton leaves much to be desired. The best description would be chemical warfare, including actual defoliating techniques for easy access to the cotton.
A most recent example is the soybean which has been treated to withstand a herbicide which kills off all weeds in the area. A gene of a soil bacteria (agrobacterium) which produces a protein which is immune to the herbicide is transplanted into the DNA of the soybean. The seeds are sold as a package together with the herbicide by Monsanto in America *2.

Ethics concerning biotechnology:
There are pressures from consumers directed to companies and governments to take responsibility on certain social issues such as the environment and public health. There is particular concern on the issue of biotechnology. The public wants to be informed about the dangers to health and is also stuck with ethical questions, like:

- Can life be patented?
- Isn't cloning a danger for the diversity?
- Is there a possibility of cross pollination with cultivated or wild varieties?
- Is genetically engineered food really safe?
- Is it fair to exploit life for human demands?
- When is the labelling for information about genetic modification going to be introduced?
- Should everything scientifically possible be carried out, just to have return on research investment?

Most ethical questions probably concern non-food products as well.

Ecological aspects
Having arrived at the 2nd millennium in the post-industrial era, we are assessing the damage caused by the effects of the Industrial age. Natural resources have been plundered for a large extend. The landscape is scarred and eroded. Forests are scarce. The soil, air and water are polluted. The temperature is rising globally, and the sea level is rising. Land, air and water are polluted.
Today we use 10 times as much energy as 100 years ago, globally. Coal was the main source of power until the first world war. Oil, natural gas and nuclear power are the sources for energy right now. Biodiversity is threatened and a mono-culture is the result. Some desirable plant species are intensively cultivated, while others are exterminated. For example, out of the original 12.487 varieties of rice about 7000 have already been lost.
The seed market is being controlled by large multinationals some of which have their main business in the supply of agri-chemicals. Shell, the oil company, is the world's largest owner of forests *18.
In Holland, a private initiative called ”Hof van Eden”, has been set up to collect the seeds of most

plant species from around the world to safe the bio-diversity. Some plants are actually applied to help clean polluted air, soil and water.
Large scale agriculture for materials for industrial use will have its effects on the environment. Beneficial is the renewal of the oxygen supply, removal of chemicals from the atmosphere and the absorption of CO_2. Increased agriculture partly for industrial purposes will have a negative impact on the environment, such as soil erosion and exhaustion. About 13,4 billion ha. is available world wide for agricultural use. The availability of land for non-food agriculture largely depends on the demand of for food and living space. The other problem may be that of drinking water supplies. Of the total water reserve only less than 0.7 % is fresh water. The oceans contain 97.13% of the total amount of water. Around 2% is locked in ice caps and glaciers. One suggestion was to transport icebergs to where water would be needed. Large reserves of water lay beneath the earth's surface. In the future, hydro power, solar power, wind power and power from biomass will be important energy sources in the future.

Options:
Desert agriculture is one option in the future. Deserts are expanding at the moment. It is possible to make plants survive in drought areas, by genetic modification. However, irrigation will still be necessary. Agriculture in space seems unlikely in the near future because of high harvesting / transportation costs. But conditions in space seem suitable to many plants. Experiments are being conducted with aid from NASA on vegetables like potatoes and also an Alga called Spirulina amongst other crops. Another option is farming at sea. Already, the sea has proven to be a rich source for medicines in particular. New developments allow for terrestrial plants to be salt-tolerant through genetic modification. This could mean that agriculture might be possible on the sea surface.

Aquafication

For our material sources we are land oriented. Alternatively, the sea offers a rich source for materials. There are already some non-food applications of aquatic materials. Waste materials like fish skins, are applied in fashion items as an alternative for lizard or crocodile skin. Seashells are used as isolation in houses. Certain cosmetic products are being made from algae.
Besides waste as a source for materials, water provides another interesting area which is not really explored yet, i.e. agriculture for industrial purposes. We rely on terrestrial plants for starch and proteins in bioplastics, while aquatic plants could provide an interesting option. As a source of fibers, marine plants are already being processed into carpets. As about 80% of the earth's surface is water, the sea seems an interesting option for further exploitation. It is rich in renewable resources and the elements can provide energy (solar, wind and hydraulic power).
Aquafication is a scenario where the conventional concept about agriculture for industrial purposes is maintained, but the location or situation has moved to sea. Here, the scale of production could be significantly enlarged and realized.

Aquafication (by author)

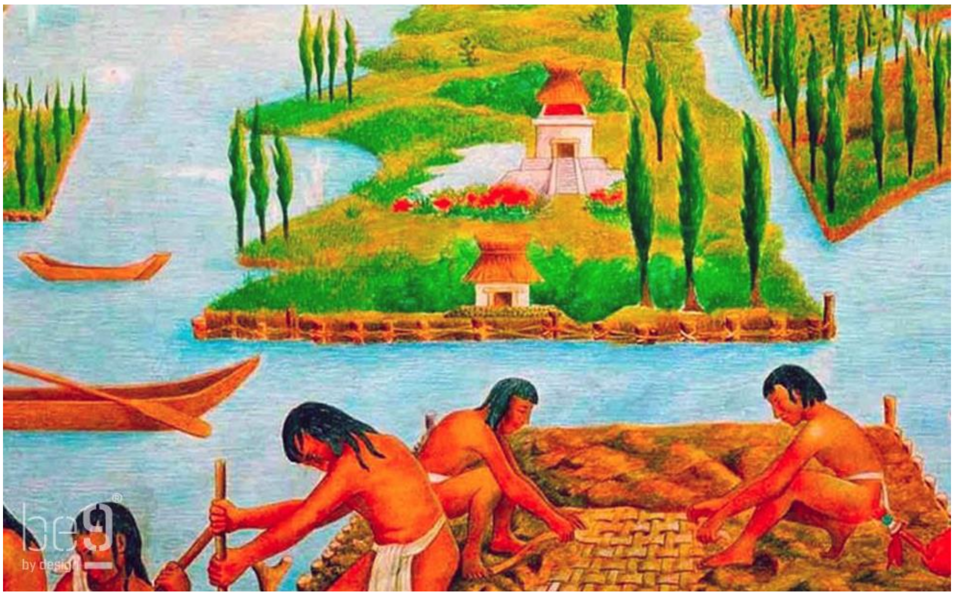
Agriculture on fresh water

In the past there already exist several examples of agriculture on water.

The Aztecs introduced floating gardens called Chinampas, which provided its population with food and materials. The Aztec chinampas probably originated in Mexico in the 13th century. By the 15th century chinampa fields in Xochimilco, were constructed on a large-scale. They were about 30 meters long and 2.5 meters wide. The fences were made from wattle. To stabilize these plots tall slender willows were planted around the perimeter. It provided the Aztecs with food crops like maize, beans and chile peppers. A particularly important non-food crop were gourds or squashes for the production of containers. Also herbs and flowers were grown there *1. Today, the gardens are anchored by the roots of the candle willows *4.

In China, gourds are planted on the banks of village ponds. The plants grow over a bamboo framework erected over water. This method provides abundant water for the plant and the framework over the water permits the land to be used for other purposes *2.

In more recent times, hydroponics has grown more popular. This is the technique where by plants are being grown on rockwool and water, on an industrial scale. The advantage is that the cultivation can be regulated and largely automated and there is no weed problem.



Chinampas (in Mexico)

Agriculture on salt water

Halophytes such as eelgrass grow in sea water and contain many seeds. The protein and starch content compares favorably to major terrestrial economic grains. The Seri Indian harvested the seed and ground them into flour. The advantage of this plant is that it probably doesn't need any fertilizer or pesticide. The problems of maintaining and harvesting a plant which is submerged in tidily active water is a challenge. Once mastered, farming at sea will be possible *5. There has been an experiment conducted involving halophytes under irrigation of sea water to see if economic yields were possible *6. Perhaps starch could be produced for bioplastics by halophytes, instead of potatoes. Potatoes are quite heavy and should be collected within a radius of 50 km. from the factory, otherwise the transport costs are too high.

In Holland and in Portugal experimental fields have been set up for the domestication of certain saline crops, such as Sea lavender (Aster triplium) or Sea kale (Crambe maritima) for food purposes. The fields are irrigated by sea water, which is pumped up from 35 meters down into a storage basin, through a closed circuit of drainpipes. These vegetables can be grown in saline or brackish soils which are unproductive or less economical for traditional crops *14.

Because of the threat of a freshwater shortage in the future and a space problem on land agriculture for industrial purposes could move to sea. There are interesting developments in the area of salt-tolerance in plants. It may take some time before terrestrial agricultural crops are fully salt-tolerant, to be grown on the sea surface, but it open up new possibilities. It would not apply to food crops as the taste may affect the product because of the salt content. So I think aquafication will apply for non-food crop production only.

If plants could be made salt-resistant or tolerant, many important fiber plants and crops for bioplastics could be transferred to sea for production. The plants would grow on floating gardens similar to the Aztec which would be connected to one another. Advantages are that at sea there are no weeds, probably less insects, more sunlight and a constant supply of water. Harvest would be quite simple by dragging the gardens to a central place. Its processing industry should also be located at sea, where many forms of energy are readily available, such as solar power, wind power and waterpower.

"Salt-tolerance"
Plant cells mostly burst in salty water because of a build-up of osmotic pressure. In Sweden, biochemists have transplanted a gene for salt resistance from the bacteria Escherichia coli into a tobacco plant. The gene which is called betA produces an enzyme called choline dehydrogenase. This enzyme converts choline into an amine called glycine betaine. This works as an osmolyte which is a compound that protects some bacteria and higher plants against the effects of salt. But there are probably more genes needed to make plants sustain salt-water floods *3.

"Growing products"
In his novel Hitchhiker's Guide to the Galaxy, Douglas Adams, described a forest where the trees grow ratchet screwdrivers as fruit. "Very few things actually get manufactured these days, because in an infinitely large universe...most things...grow somewhere" *79.

Pitchfork (used in France)

Prosumerism

An alternative scenario to aquafication is that of prosumerism, a word introduced by A.Toffler in his book The third wave. The word prosumer is a marriage of producer and consumer. He predicts that in the future the consumer is going to be self-sufficient in all his material needs. He grows his own food in his apartment through the use of genetically engineered seeds, which do not need much light. He can provide in his own user products by the application of a very advanced Cad Cam system. He imports the specifications to his taste into the computer and the complete product rolls out the other end, ready for use.
On Sardinia there was an experiment conducted, involving loofah gourds for shock-absorbent

packaging materials. The skin disintegrates to leave fibers. By compression and heat the fiber of the fruit can obtain any shape. It can also be combined with other materials. Other applications include shoe soles and engine filters. There are several well-known examples of ready-made products such as pitchforks grown in Africa, walking sticks grown in Jersey and gourd bottles grown in Asia, America and Africa.

The Livingroom project (in Nuenen the Netherlands) growing chairs

F. Popcorn introduced the word cocooning in the early eighties, describing the trend we are experiencing at the moment. We are working at home, growing our own food and doing home improvement ourselves. In this prosumer scenario, the prosumer is self-sustaining in all his material needs, but these products are grown. In his "living room" his chairs are growing. Cabbage stalks are growing into furniture frames. Fast-growing willow branches of the species Salix viminalis, are tied and woven into a dome where chairs are affixed. The branches keep on growing, blooming and expanding through the room *25.

The aquariums in his home are functional. In his aquarium, bowls, cups and plates are being produced. Shellfish like abalone, produce layers of crystals of calcium carbonate and layers of proteins which interlock to form a very tough material. At the moment researchers are not able to control the shape of growing crystals. But it might be possible to grow the crystals inside molecules containing cavities that act as templates *22.

The terrariums in his home are functional. Social insects like termites build structures inside moulds, to serve as containers. The lighting is provided by fluorescent seaweed in tanks on the ceiling and luminescent fungi in boxes with dead wood in the walls of the room. Some fungi are known to be naturally luminescent. In Scandinavia pieces of dead wood with these fungi were used as lanterns to illuminate paths. Some species are known to be quite powerful in luminescence, like Mycena lux-coeli from Japan or members of the Agaricus *23.

Scientists have transplanted the genes responsible for making certain jellyfish glow, into tobacco plants. Similarly, the gene in fireflies has been transferred to plants, to make them glow in the dark

*24. He picks his own antibodies from a pea plant, and his cosmetics from herbs grown in the bathroom. His coloured cotton is growing in the bedroom. At the heart of his cocoon will be a biocomputer, regulating the ideal conditions of the direct environment. In the field of smart materials, scientists have discovered intelligent gels which respond to external stimuli like electrical shocks and temperature change and act accordingly. These materials may form the basis for a new kind of machine *21. As an experiment I have tried to realize parts of this scenario. I have grown packaging by employing moulds round gourds and I have tried growing chairs by modifying cabbages.

Experiments

Mussel shells

Introduction
I have applied mussel shells into building materials as a filler material but also for its aesthetic value.

Source
Mussel shells are a waste product from the sea food industry in the south-west of Holland. The season for mussels starts in autumn and ends in summer. The mussels are cooked and processed into jars. The subsequent mountains of smelly shells take up a lot of space, but they are finally deported in summer. The shells are too tough to serve as poultry feed and are subsequently shipped and dumped at sea sometimes as far as the coast of northern France. I found out the mussel shells do have an ecological part to play as a base for oysters.

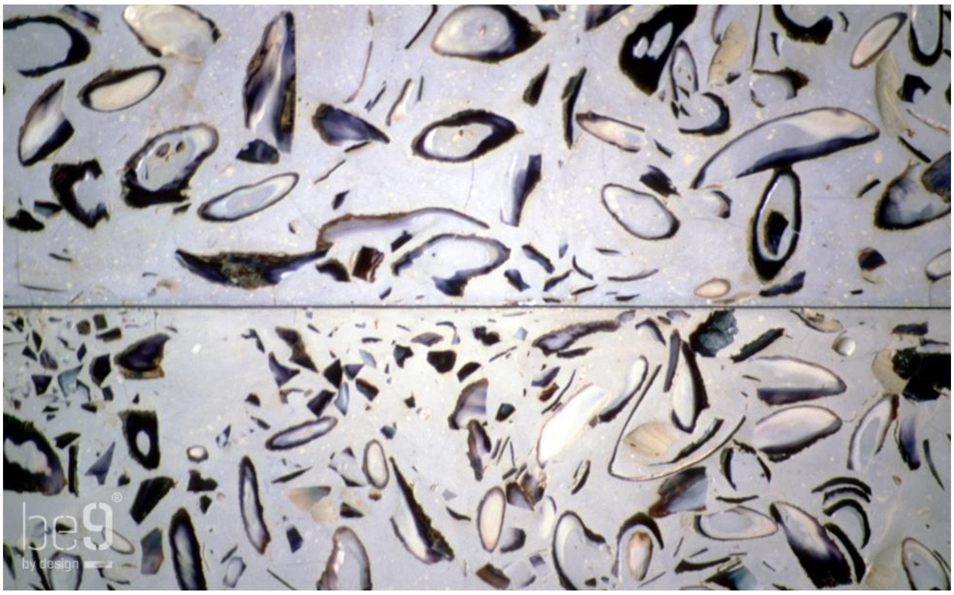
Heap of Mussel shells at sea food factory

Experiment

After many experiments with different binders like gelatine, casein with chalk and a vulcanic material with chalk, I had found cement to be the best option. As for colouring, I found light blue to be the most suitable combination. I did some experiments with natural pigments and dyes, like indigo, but the result was not up to expectation. Mineral pigments, like ultramarine performed better.

Process

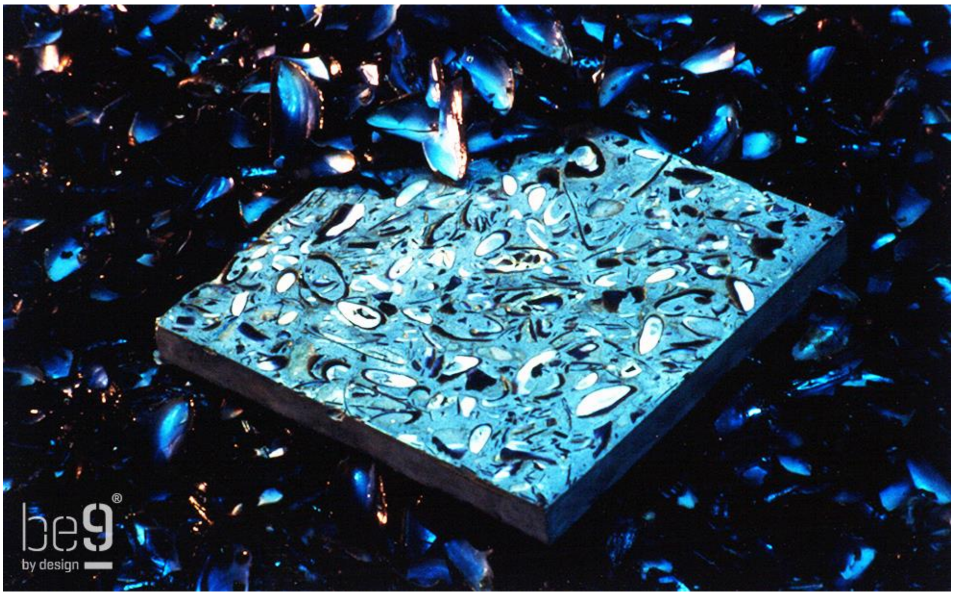
The casting of shells with cement requires a different technique to the one common in traditional terrazzo manufacture. The shells are too fragile to be mixed in a cement mixer, so the cement is prepared separately. The shells tend to sink to the bottom of the mould, so the eventual product is face-down. The shells are cleaned first of all, before they are put into the mould. White cement is mixed with ultramarine powder and is added to the shells. The product can be reinforced with steel and small fibers. The material should be left to dry about 5 days. The product is then freed from the mould. The material is ground until the top layer has gone to uncover a decorative pattern of shells. The surface can be polished further and treated with wax.



Building blocks with Mussel shells (design by author)

Application

The shell material is quite strong and can be applied in products like building blocks for building walls or as elements for facades. However, as the surface of the material is not resistant to ware, it is better not to be applied as tiles. The production could be done by the existing terrazzo industry.



Mussel shell tile (design by author)

Opportunities

The cement can be made from chalk by burning mussel shells, as was done in the past, before the age of Portland cement. Shells are a sustainable source. As reinforcement for concrete, natural fiber could be used. As mentioned in the previous chapter, pineapple fiber could find application for this use. However, natural fiber does need preparation before being applied in cement. Usually this requires the fibers to be boiled in water. The colour pigment should be from a sustainable source as well. I did try several natural pigments, but they are mostly too light and tend to float to the surface.

Loofah gourds

Introduction

The name Loofah comes from Arabic. The fruit has been widely used as flesh-brush or sponge. Its fibers have also been applied for technical purposes as filters for engines, as upholstery filler or even in shoes as soles.

Source

Loofah is an annual plant, which grows in warm climates. It originates from south-east Asia, but its cultivation has been spread to most warm parts of the world. Within Europe, it's mainly cultivated in Greece and Bulgaria *19.

Experiment

I found the fibers of the loofah gourd could be compressed into a mould after it had been soaked in warm water. Once dry, its fibers retain the shape of the mould.

Process

The mature gourd is left to dry, after which the skin and seeds are removed to leave a cylindrical structure of fibers. The fiber structures are soaked in a bath of warm water and pressed into a mould. The water escapes and the fiber is dried. The mould is removed to reveal its new shape.

Application
Besides its traditional applications there are new areas of application to be explored. The technique for altering the shape, opens up new possibilities. Environment friendly packaging as shock-resistant material is one area of particular interest.

Opportunities
As described in the previous chapter, Loofah has been subject of an experiment financed by the EU on Sardinia, for fiber production.
One of the options for application is for packaging purposes, but there are plans for application in acoustic/thermal isolation panels. The fiber can also be applied in combination with bioplastics to make composites.

Giant Jersey Cabbage

Introduction
One experiment concerns a certain type of cabbage, the Giant Jersey Cabbage (Brassica oleracae longata) which I intended to grow into prefabricated furniture frames by using various techniques. This cabbage is a fast-growing plant, which turns woody when dried.

Source
The origin of this cabbage is thought to be Portugal, where it has been grown as a food crop since Roman times *16. In the past, the stalks have been used as construction material for barns, for palisades and fences *15.

Jersey Walkingstick Cabbages (by author)

The cabbages have been grown on Jersey for the production of walking sticks for nearly 2 centuries. Particularly in the nineteenth century this was a thriving arts and crafts industry. The sticks have also found application as crutches for use in English hospitals and are very popular, due to their strength *16. These days, the cabbages are grown in an area called L'Etacq, in the north-west of the island. Here the crop is grown for making walking sticks from the stalks. At the local wood shop L'Etacq Woodcrafts, the owner Philip Le Gresley, follows on his family's tradition of growing walking sticks, behind his wood shop. The leaves on the vegetable are used to feed cattle. Twenty plants is sufficient to feed one cow the whole year through *15.

Experiment
At the start of 1996, I began growing around 50 cabbage plants on a field of a farmer who tended them. I had built a frame around the plants in order to guide them to grow straight up.

Shape
To attain a shape of a chair frame, I first planned leading the stalks through moulds with an opened end through which sunlight could enter. The result was no good, as the front leafs got entangled and blocked the passage.

Jersey Walkingstick Cabbage (by author)

Another possibility I tried was to rotate the plants into certain directions at certain times while they grew. The cabbage stalks kept their shape as they grew towards the sunlight. This way any desired angle or shape can be attained in one piece of wood. This method proved a lot more effective, and a fair degree of accuracy could be reached. One useful result was that when a stalk was chopped mostly two new shoots appeared. This fact is interesting to the possibility of a design of an upside-down chair.

Joints
These experiments explored the possibility of making connections between stalks, involving grafting and other techniques. In one case I've peeled away the outer skin up to the cambium of two plants and bound them together to see if the stalks would join. The purpose of this is to create a stronger stem. In another experiment I had grafted one stem on to another one, to make cross joints possible. In another case I had drilled a hole in one stalk and led another stalk through it, the roots of which were left in soil. The hole was covered with tape, to ensure a good connection. In most cases the connections seemed to work but when the tape was removed there was no real sign of integration. This might be a question of time.

Strength
To increase the strength of a stalk I have bound weights around it. By gradually increasing the weight the stem might thicken.
However, there was no sign to suggest any change in thickness after 6 months. There were differences in length and thickness already between the individual plants.

Process
The seeds are sown at the end of the winter and the sticks can be harvested at the end of next autumn. They will be about 150cm long. However, they can be kept for another season if the winter allows. The stalks reach a height of about 3 meters, although there have been exceptions known of lengths of up to 6 meters.
The stalks are light-weight and strong once dried. The sticks are dried horizontally, after which they are prepared. They may be sanded down and varnished.

Application
The area of application is furniture. The dried stalks have good properties like strength and lightweight.

Opportunities
There are several advantages to applying cabbage stalks, e.g.

- Speed
  Cabbages are fast growing plants. Furniture could be designed and produced to specification while you wait. For a piece of furniture made from cabbage stalks you would have to wait one season. This compares favourably to one made from wood which would take at least 10 or 20 years.
- The optimization of materials
  Because the cabbage plant grows directly into a product, the amount of waste will be minimal. While there is about a 50% loss of material when wood is cut into planks.
- Local European material
  There are other alternatives for wood of course which are being successfully applied in the

furniture industry, like rattan, ramie, and bamboo. But these materials are not attained locally and have to be imported. The giant cabbage can be grown in most European climates.

- The environment
  The eventual product is "tree-free".
- Experience
  The expertise for growing cabbage plants is already there. European farmers grow a wide variety of cabbages, I'm sure the giant cabbage doesn't differ that much from those cabbages.

Bottle gourds

Introduction
I have started this project several years ago, but each year I try to improve the technique and hence the final product. The experiment started out as an idea for an environment-friendly packaging design for cosmetics. There are mainly two kinds of gourd, i.e. ornamental gourds and bottle gourds. Ornamental gourds are generally smaller and more vulnerable, while bottle gourds (lagenaria siceraria) have a tough outer shell, which is water-resistant, with a soft lining.

Source
Gourds have been used as containers for storing food or drink, throughout history, across the world. Besides containers, gourds also serve other purposes for instance as musical instruments or floats for fishing nets. The origin of gourds is not certain, but it is either Asia or Africa.

Modified bottle gourd (by author)

Process

Gourds are annual plants. The seeds are sown in March and the seedlings are transplanted outdoors in May or kept in a greenhouse. Outside, pollination will occur with the help of bees. In a greenhouse, the female flower is usually hand- pollinated. The fruit develops beneath the female flower around July. The small gourds are led into box shaped moulds, which they fill within two or three weeks. Around September the moulds are taken off and left to mature. The gourds are harvested around October or November when their stems have become wood-like. The gourds are then dried, emptied and prepared.

Application

The area of application is packaging for cosmetic products like bath oil, bath salt and powder soap.

Cured bottle gourds (by author)

Opportunities

Both process and final product are completely environment friendly. Nature manufactures packaging. The gourds plants grow rapidly and are suited to most conditions. In warmer climates there is the possibility to have more than one yield a year. The plant could be optimized, by utilizing the oil extracted from the gourd seeds, for the production of cosmetics. Other parts of the plant like the stems, leaves or flowers could also be of use in cosmetics. This way, the packaging is not transported empty. In a discussion with C. Snijders (researcher at CPRO in Wageningen) it was suggested a possibility that in the future gourds could be grown in square shapes without the aid of moulds. In gourds there are variations known of fruit with three, four or five chambers. The four chambered gourds could be grown and selected consistently, until a near-perfect shape is reached, without the involvement of genetic modification. This is what happened with the common green and red peppers which have been developed box-like to make storage and transport easier.

In conclusion

In this chapter there is a short assessment on the state of the world and the benefits of applying agriculture for industrial purposes. In conclusion I found two major problems which will effect the future, i.e. a shortage of living space and a shortage in water supply. There are two scenarios suggested. One scenario involves traditional agriculture for non-food purposes which takes place on the sea's surface. Its scale is industrial, and its products are to a large extent pre-fabricated. For reasons of renewable energy availability and of transport costs, its industry is also located at sea. The second scenario, Prosumerism, is based on a concept introduced by A. Toffler in his book The Third Wave. The consumer is also producer. In my scenario the prosumer grows all products himself and is thus self-sustaining in all of his material needs.

Remarks

The possibility of realisation of either of these scenarios, depend to a large extend, on progress in the field of biotechnology. Nevertheless, the effort of the public, particularly in the prosumer scenario will also play a crucial part in its realisation.

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Epilogue & recommendations

Having done this research project, I have a better overview on renewable materials and sources. I have learned to place the topic in historical, economical, technical, social and ecological context. The following developments are worth investigating more closely, I think.

Soybean plastics

One of the areas that raised my interest in the first chapter was the early application of plastics from soybean. In 1908 a waterproof glue was realised and was applied in plywood. Also transparent film was developed on soy base. Today, the soybean is mainly grown for the food industry. In America, the soybean has been genetically engineered to withstand herbicides. In Europe there is some reluctance to import this bean for the human consumption. Here may lie opportunities for application in the non-food area. I spoke to M. Engel of ATO-DLO, who is part of a two-man team investigating the opportunities for soy plastics. Soy plastic is still not totally waterproof. It can be modified to be thermoplastic by addition of glycerine to make it more flexible and to raise its melting point. The soybean protein is imported to Holland but is cultivated elsewhere in Europe. The price of soy protein granulate is about Hfl 4 per kg. With an additional material the price can be lowered to Hfl 3 per kg. Application of soy plastic lay in the area of packaging and disposables. This is unless a way has been found to improve the susceptibility to moisture.
Scanning current development in the area of renewable materials, I thought the EU project on Sardinia involving the growth of loofah gourds on a large scale, was a good initiative. The remaining fibers can be compressed into any shape, by the simple use of heat and moisture. The process is quite low-tech and does not need a lot of energy.
Staying in the field of fibers, I think the application of pineapple fiber seem to have great opportunities. An interesting development in manufacture is the PLATO technique of "cooking" wood or plant fibers to upgrade its quality. The fiber is made more resistant to decay and its weight is reduced significantly. The paste-like material could also be pressed into shape.
With the aid of biotechnology the production of PHB (similar to Biopol) is now made possible by plants. Modified plants seem to tolerate the bacterial gene and produce plastics beside their "normal" products. The prospect of using nature for the production of complete products I find

fascinating. There are several artists working with willow presently. It is possible to weave large structures which, when stuck in the ground keep on growing. After several years the structure is able to carry the weight of humans. This may be an interesting topic for research for landscape artists, as an idea for street furniture.

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