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INDUSTRIAL USES OF AGRICULTURAL PRODUCTS PRESENT AND FUTURE POSSIBILITIES

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SUMMARY

It is technically possible to build a chemical industry on agricultural feedstocks, but at present it is not economic to do so. In part this is because the chemistry is difficult, the competition (oil) is relatively cheap and the common feedstocks, carbohydrates, are highly oxidised. There are many new developments in technology, which coupled with new feedstocks such as vegetable oils could change this. Biotechnology offers one of the best prospects and already it is exerting increasing demand for raw materials. Most of the new products are towards the higher value end of the market and development of the technology to bring it towards bulk products should be encouraged.

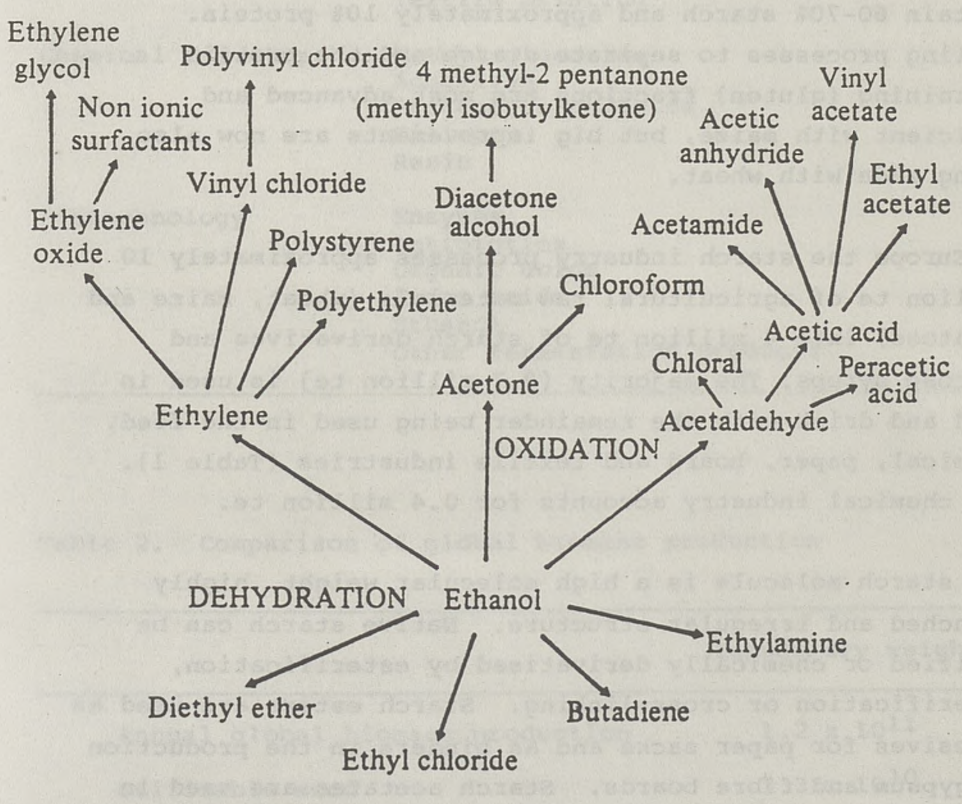
The last decade has seen feasibility studies, research and debate throughout the world on the development of agricultural products as industrial feedstocks. This has been in part due to the growth potential seen for biotechnology, which uses these raw materials, but it was triggered off by the 2 major oil price rises in 1973 and 1979/80 and a longer term decrease in the price of agricultural products relative to oil. Since then, oil prices have fallen again in real terms and there is uncertainty about the potential for agricultural products. Oil is the principal industrial feedstock in most of the world and is the benchmark against which comparisons must be made. It is a non-renewable resource which must eventually be replaced, but over what time scale is unclear. It is possible given sufficient energy to convert agricultural products, notably carbohydrates, to almost any product that can be obtained from oil using, for example, routes via ethanol or methanol (Figure 1). The substitution of petroleum based products by carbohydrates is often both economically and technically difficult. The future does hold promise for the development of agricultural feedstocks, but they must be examined carefully.

Requirements for a feedstock

A successful industrial feedstock must meet a number of conditions: it must be technically acceptable, it should be stable for transport and storage, be available year-round and be obtainable in sufficient quantities at a competitive price. In general, the cheaper a manufactured product, the greater the proportion of its production cost is attributable to raw materials. High value finished goods (such as pharmaceuticals) are less sensitive to the cost of feedstocks. There is too, in general, an inverse relationship between value and volume of production. The low cost products are made on a large scale and thus they consume greater amounts of feedstock.

There is another factor in comparing and pricing feedstocks which is particularly significant here, that is their oxidation state. Most agricultural feedstocks are carbohydrates and are highly oxidised, particularly in relation to petroleum products. In other words we need to remove a considerable amount of oxygen in order to convert carbohydrates to many chemicals of use to industry. This can be illustrated by reference to the production of ethanol from glucose and from its petrochemical precursor, ethylene. Thus at least 2kg glucose are required to produce 1kg ethanol by fermentation, but this may be chemically synthesized from only 0.6kg ethylene. Hence, approximately, the price of ethylene will need to reach $0.8 per kg - equivalent to an oil price of $40 - 45 per barrel, before ethanol from sugar at $150 per tonne can become viable. In Brazil an ethanol based chemicals industry is developing, but only as a result of government subsidies.

Figure 1. Ethanol as a chemical feedstock



Available feedstocks

1. Starch crops

Many agricultural crops contain starch, but large scale industrial applications are restricted at present to maize, wheat, barley and potatoes. Cereals are preferred to potatoes for further industrial processing because of year round storage and lower moisture content. In general grains contain 60-70% starch and approximately 10% protein. Milling processes to separate starch and the protein containing (gluten) fractions are most advanced and efficient with maize, but big improvements are now also being made with wheat.

In Europe the starch industry processes approximately 10 million te of agricultural raw materials (wheat, maize and potatoes) into 4 million te of starch derivatives and glucose syrups. The majority (2.7 million te) is used in food and drink with the remainder being used in the feed, chemical, paper, board and textile industries (Table 1). The chemical industry accounts for 0.4 million te.

The starch molecule is a high molecular weight, highly branched and irregular structure. Native starch can be modified or chemically derivatised by esterification, etherification or cross-linking. Starch esters are used as adhesives for paper sacks and as binders in the production of gypsum and fibre boards. Starch acetates are used in sizing and film formation. There are also new applications for starch which have been proposed, particularly during theprocessing of synthetic polymers. For example, starch can be included (at 10-15%) in polyethylene for bag manufacture where it increases permeability to water vapour and in polyethylene bottles, where it gives increased stiffness and might aid biodegradability. These could be large volume applications, but there are disadvantages such as reduced mechanical strength. There are also alternatives to starch in its traditional uses such as synthetic sizing agents now used in the textile industry.

Table 1. Industrial uses of starch and products

Paper industry	Sizing Paper coating Adhesives
Textile industry	Sizing Finishing Textile printing
Chemical industry	Methyl glucoside Adhesives Protective Colloids Fillers Resin
Biotechnology	Enzymes Antibiotics Organic acids Amino acids Ethanol Other fermentation products

Table 2. Comparison of global biomass production

	Tonnes dry weight
Annual global biomass production	1.2×10^{11}
Utilizable wood	1.3×10^{10}
World starch production	1.1×10^{9}
World sugar production	1.2×10^{8}
World crude oil consumption	3.0×10^{9}
Lactose waste in whey	2.0×10^{6}

From U. Faust, M. Prave & M. Schlingmann (1983). An integral approach to power alcohol. Process Biochem., 18 (3), 31-7.

There are problems with the use of starch in that it cannot be handled easily in aqueous solutions and it cannot be chemically substituted easily below its gelatinization temperature. There are numbers of applications though for its hydrolysis products, notably glucose. Glucose may be methylated to alpha-methylglucoside, which has a wide range of uses in varnishes, plasticizers, surface active agents, resins and polyurethane foam production. Glucose may also be hydrogenated to sorbitol which is used in ascorbic acid manufacture and in surfactants.

2. Sucrose

Sucrose is obtained from sugar cane and beet, plus molasses from these refining processes. The sucrose molecule has 8 hydroxyl groups which can be used to attach to other groups and modify properties. Sucrose, unlike glucose is 'non-reducing', it is more stable in certain uses than other sugars. This property has favoured its use in polyurethane foam manufacture, but its technical, performance is limited by its structure. In polyurethanes, arms are attached to the 8 hydroxyl groups to make a polyol which is polymerized, but there are so many groups that the products are rigid. Current demand for sucrose polyurethanes in Europe is 9000 te pa which is probably the largest single use in the chemical industry, but new chemistry is needed to reduce the cross-linking to make more flexible products. Sucrose is also used to make surfactants by attaching fatty acid side-chains to one or two hydroxyl groups. These are principally used as emulsifiers in food and cosmetics.

3. Cellulose and lignin

Cellulose, lignocellulose and lignin are the largest source of biomass (Table 2), found in wood (which comprises 10% of global biomass) and leaves, straw, stems, etc. which comprise the bulk of the remainder. Wood is used to produce dissolving pulp, a form of pure cellulose. The European production is approximately 1.5 million te. Wood can be used to make a number of additional products such as cellulose esters (such as acetates), resins, turpentine and kraft lignin. It can also be used to manufacture a wide range of chemicals such as methanol, phenols, benzene, xylose and many others, but most are cheaper from an oil feedstock. Cellulosics may also be used to produce fermentation feedstocks, but the pretreatment costs are uneconomic. In general cellulosics have a difficult hydrolysis, transport, drying and storage. Also once products such as glucose are extracted, a residue of hemi-cellulose and lignin remains. Improvements in technology such as mechanical harvesting, cheap hydrolysis and improved by-product utilization are required before they are preferable to cereal starches and sugar.

4. Other agricultural feedstocks

The production of vegetable oils has been rising at an annual rate of 4-5% in recent years. Of the total world production of fats and oils of 70 million te pa, 20% is now soybean oil, 12% palm, 9% rapeseed and 9% sunflower. The remainder is animal fat such as tallow, butter, lard, etc.

Most oil and fat useage is in food (80%), but approximately 8 million te is used in chemical manufacture such as fatty alcohols, glycerol and fatty acid methyl esters. Surfactants are the most important application, but there are also uses in polymer manufacture and some esters are used in synthetic lubricants, particularly where biodegradability is important such as in outboard motors. Vegetable oils have potential for cheaper manufacture and they are less oxidised than carohydrates so that higher yields, particularly in biotechnological processes, may be achieved but it is not yet clear where bulk applications will be found.

Protein-containing feedstocks are also being produced at lower costs, notably soy. There are possibilities in nitrogen sources for biotechnological processes, but again big industrial applications are not yet on the horizon.

Raw materials for biotechnological processes

At present there is substantial use of agricultural products, mostly carbohydrates, as feedstocks for biotechnological processes (Table 3). The most important are sucrose and molasses used to make citric acid, monosodium glutamate and lysine; glucose used to produce lactic acid, xanthan and some amino acids, plus either substrate used for ethanol, enzyme and antibiotic manufacture. It is important to remember that in biotechnology these feedstocks are frequently interconvertible. For example lysine can be produced from molasses, but if colour removal is a problem, then sucrose or glucose can be used. Manufacturers may use all 3 to maintain their independence and thus there will always be a common pricing structure.

The production of many of these commodities is growing, so there is an increasing demand for raw materials, although in some cases this might not be quite as high as anticipated because of increased conversion efficiencies. For instance, enzyme production has been growing at an annual rate of 4-5% for several years and is predicted to increase at a higher rate in the future. Citric acid production too is now increasing. Even so, in most industrial countries the volume of carbohydrates used for biotechnological processes is small compared to the main uses in food and animal feed. Some countries, notably the U.S.A. and Brazil have introduced legislation encouraging the use of agricultural products for the production of fuel alcohol. This is the only present use which can significantly alter world demand for carbohydrates, yet at the same time it is uneconomic while oil prices are low. The price of grain for ethanol production in Europe needs to be reduced substantially to be competitive with petroleum. Similarly, the production of single cell protein on a large scale is uneconomic in the West, although specialist products such as Mycoprotein may be successful.

Table 3. Approximate estimates of feedstock requirements for major biotechnological products

Product	Annual Production (te)	Feedstock* Consumption (te)	Feedstock as proportion of of cost
Ethanol	8 million	16-17 million	40-60
Yeast	500,000	1 million	30
Citric acid	350,000	450,000	15
Lactic acid	20,000	22,000	15
MSG	250,000	400,000	15
Lysine	40,000	100,000	15
Xanthan	14,000	17,000	10
Antibiotics	-	over 200,000	-
Enzymes	-	over 200,000	-

* Carbohydrate (sucrose or glucose) - molasses is on average 50% metabolizable sugar.

Ranged in approximate order of price: ethanol is the cheapest, antibiotics and enzymes the most expensive.

In general, before large scale biotechnology for cheap, bulk products becomes economically viable, improvements are needed in fermentation rates, product recovery from dilute solutions, increases in concentrations, by-product utility, possibly more non-aseptic processes and others. There are enabling technologies which are being developed: genetic engineering can make new products, improve the rates of fermentations and improve the use of new raw materials. Other new advances in reactor design, continuous processes, solvent extraction and others are on the horizon. None, however, will permit the operation of new large scale processes in the near future. One possibility is the development of bulk biopolymers such as ICI's polybetahydroxybutyrate. Even these products are very sensitive to raw material costs. It is estimated that acarbohydrate feedstock must be £150/te or less for many applications and £100/te to compete with petroleum.

It can be predicted that biotechnology holds the greatest promise for the industrial use of agricultural raw materials, although it will be most successful initially in the manufacture of high value products and speciality chemicals. These will represent welcome new markets for agricultural feedstocks, but they will probably not make big impacts on present markets in the near future, unless there is a dramatic increase in the price of oil. For the mid and longer term the future may lie in developing big integrated plants which make a number of products and utilise by-product streams - in a way analogous to oil refineries.