Industrial Markets

For

Starch

Radek Messias de Bragança and Paul Fowler

The BioComposites Centre, University of Wales, Bangor, Gwynedd, LL57 2UW

3 June 2004

Contents

1.0. BACKGROUND TO STUDY

The present report updates industrial starch market information for non-food uses reported to the HGCA in 1996, with a particular focus on the UK. It includes current market analysis, opportunities for UK produced starches both as direct substitutes for currently imported starches and as components of products arising from the development of new markets.

In this report, data used were obtained from companies, industry bodies and trade associations, and from official statistics (in the UK/ or in Europe); when discrepancies were found (between data obtained from official bodies and companies) the authors used those data deemed most accurate (on the basis of, e.g., concurrency of data supplied by the majority of industry players).

As indicated in the report, the main policies that need to be addressed to either reduce starch imports or increase UK production revolve around:

1- maize imports
2- potato starch production
3- bio-fuel production
4- biotechnology industry
5- bio-material (including packaging) markets

In particular, scope for the direct substitution of imported (maize, potato) starches with UK-produced wheat (and potato starch arising as a result of potato processing) is evaluated in terms of technical performance and economic viability.

2.0. EXECUTIVE SUMMARY

1. Starches obtained from maize, wheat and potato are the main sources of starch used in the UK.

2. There is an overlap between the uses of maize and wheat starches. Maize and wheat starches can be interchanged in a range of industrial applications. Because wheat is locally produced and the economics of wheat starch production are better than those of maize starch production, upgrading maize starch plants to process wheat will have a major beneficial effect not only on the balance of payments but also on the economy as a whole.

3. Due to the physicochemical characteristics of potato starch, its end use markets are different from those for wheat/maize starch. The volume of potato starch imported into the UK is sufficient to justify the construction of a potato starch plant in the UK, on the basis that import figures are higher than the capacity of most existing potato starch processing plants.

4. Potato starch manufacturing in Europe is subject to production quotas and a policy of refunds to farmers. Despite being one of the major potato producers, the UK has presently no quota for potato starch production. However, a preliminary economic analysis shows that production without refund may be feasible in the UK if a plant manufactures both native and modified potato starches as do other plants in Europe.

5. In the UK, the food sector is the major end user of starch. It is estimated that 88% of starch is used for food, while only 12% is used industrially. These figures contrast markedly with EU figures as a whole where 55% of all starch is used for food and the remaining 45% for non-food uses.

6. The paper and paper board industry is the major non-food end-user of both potato and wheat/maize starches. However only 30% of the paper consumed in the UK is locally produced. This suggests that a more detailed study on the competitivity of the

UK-paper sector is needed to obtain data on how much more UK-produced starch can be incorporated into UK-produced paper.

7. Production of bio-fuels should be a major target as a new large scale use of wheat/potato starch. For a better assessment of the costs to the Treasury (subsidies) and environmental impact, it is recommended to undertake a pilot/demonstration study for the introduction of a bio-alcohol derived octane booster into a UK city.

8. Use of potato starch as a water co-flocculant is being promoted in some countries of continental Europe, on the basis that polyacrylamide, the most cost-effective co-flocculant, may not be safe. As this cannot presently be proved, polyacrylamide restriction policy is cautionary. Therefore, an environmental/health study of the use of polyacrylamide is justified. The eventual volume of potato starch that could substitute the polyacrylamide used in the UK would justify construction of a starch-processing plant.

9. There is an imbalance in the proportion of starch used to manufacture organic chemicals in the UK when compared with other European countries. Some organic chemicals, manufactured using starch as the main raw material, and identified in this study, are imported into the UK (and into Europe) in large quantities. Wheat starch can be produced at a very low cost in the UK. Furthermore, chemical processing know-how is high in the UK. There is, therefore, a justification for:

(a) Developing local technology to manufacture intermediates for the pharmaceutical industry (e.g., β-lactams and statins) that could be used by a range of local companies to allow the production (and potential export) of incorporated starch as high-value products.

(b) Developing know-how that could be used to locally manufacture amino acids, vitamins and colorants that are currently imported into Europe and into the UK in particular.

(c) Developing a technological platform that can use small molecules derived from starch fermentation (e.g., itaconic acid) as building blocks for organic chemistry.

10. Starch can be used in the manufacture of biomaterials. This includes chemically modified starch polymers and polylactic acid for use in the biodegradable packaging sector. This sector, which is presently very small in the UK, could contribute positively to waste management and landfill targets. A political framework to facilitate market development would include: supportive fiscal policies on starch based biomaterials, such as reduced VAT based on biodegradability credits, preferential public procurement and financial assistance to industries willing to adapt to the use of locally produced starch based raw-materials. Other starch based biomaterials that are presently being investigated, or yet to be introduced into the market in the UK, include pharmaceutical vehicles, medical implants, hydrogel dressings and bio-fillers. The UK's world-leading pharmaceutical sector could spearhead the development of starch-based materials into a range of (bio)medical applications.

11. Starch (mainly potato starch) is used as an oil-drilling fluid. Most petroleum producing countries do not produce starch but rely on imports. Due to the strong position of the UK in the world petroleum sector, this application and potentially large markets in the middle east could form the basis of a sustainable export market for potato starch based products.

12. Information on technology recently developed (in others countries) on cement starch additives and composites suggest that these applications may be developed and lead to a high volume starch use market.

13. Companies involved in starch manufacture in the UK have all declared a non-GMO policy. Until public discussion on the subject is settled and therefore the safety, ethics, and performance of GMOs are resolved, it is likely that GM plants are not going to be used in the UK starch processing sector.

3.0. MARKET ANALYSIS

3.1. Raw materials

The most commonly used sources of starch in the UK are cereal crops (mainly maize [*Zeamays* L.] and wheat [*Triticum* spp.]), but roots and tubers (such as potato [*Solanum* spp.] and cassava [*Manihot esculenta* Crantz]) are also used.

Maize kernels contain approximately 60% starch, 11% fibres, 8% protein and 4% oil, with the remainder being water and mineral salts. Wheat kernels are made up of 52% starch, 9% fibres, 12% protein and 23% bran. Potatoes contain around 20% starch, 2% fibres and 1% protein. Cassava contains around 32% starch, 1% fibres and 1% protein.

Starch from different sources may vary with regard to several characteristics. These include the shape and size of starch granules, and the composition of starch granules (relative concentrations of amylose and amylopectin, phosphorus and lipid content). Maize and wheat starches are similar in many respects, they have similar amylose: amylopectin ratios, approximating to 27:73. Potato starch has a lower amylose: amylopectin content (22:78) and a higher level of bound phosphorus, which allows its use in more specific applications.

This report is not concerned with a detailed analysis of starch granule structure and physicochemical characteristics. The reader is directed to the many excellent texts on the subject.

3.1.1. An overview of world starch production

Table 1 indicates world-wide starch production and the major sources of material.

Product	Quantity (10^6 t) in 2003		
	USA	Europe	Rest of the world
Maize starch	29.2	4	10.9
Wheat starch	0.5	3	1.1
Potato starch	0.1	1.9	0.8
Other starches	–	0.1	2.5
Total	29.8	9	15.3

Table 1. World starch production. Sources: Directorate General Agriculture[1], European Commission, US Department of Agriculture

In 2003, the European Union produced approximately 9 million tonnes of starch. The USA is the largest producer of starch in the world, at approximately 30 million tonnes a year. In the USA, maize is almost the sole raw material (only 2% of its production is derived from wheat and potatoes). Of the total world starch production, including Europe, about 82% is derived from maize, this is followed by wheat (around 6%), and the root crops, potatoes (6%) and cassava (6%).

It must be noted that there is an uncertainty about actual production quantities. For example, the main parameters used by the European Commission to calculate values are based on country quotas and refunds to the starch sector. Undoubtedly, some production occurs outside the quotas and under-recording of the actual starch output within the framework of the quotas themselves is reported to occur.[2] Non-quota production of starch also occurs by recovery from the effluent of edible potato processing (e.g., manufacture of crisps, chips, potato flakes). In the UK, estimates obtained during the course of this study suggest that the output of such non-quota potato starch is around 14,000 tonnes. Non-quota production occurs also from non-declared sales of potato to starch processors. During the 1998–1999 potato campaign, an inquiry by UCLAF-OLAF revealed that potatoes produced in the Netherlands were supplied to Germany in contravention of the quota system.[2] Under-recording occurred by virtue of the payment scale that was applied to individual deliveries of starch potatoes to processing factories, which was based on old process efficiencies. Overall volumes of potato starch produced in Europe from this source are estimated at 100,000–150,000 tonnes per year.

3.1.2. UK starch raw materials

3.1.2.1. WHEAT AND MAIZE

Maize and wheat are the main sources of industrial starches in UK (*Table 2*).

Starch supply/uses	1993 (1000's tonnes)	2002 (1000's tonnes)
Domestic production of which:	750	900
(imported maize)	560	531
(local wheat)	190	369

Table 2. A comparison of UK starch production in 1993 and 2002. Source: Entwistle, SAC

No maize is grown in the UK for starch production: it is all imported from southern France. In 2002, 1,424,522 tonnes of maize were imported of which 60% (849,600 tonnes) was used for maize starch production. In comparison, the UK produced 14,300,000 tonnes of wheat (2003) of which 4.5% (approx. 670,000 tonnes) was used for wheat starch production.

The data in *Table 2* show that domestic starch production has increased at an annualised rate of 4%. However, that growth is attributable almost entirely to wheat starch. Use of maize starch has reached a ceiling. The amount of maize starch remains at roughly the same volume and is thus declining in relative terms.

3.1.2.2. BARLEY AND OATS

Besides wheat, barley and oats are the two other significant cereal crops produced in the UK, corresponding to 27% and 3% respectively of the total UK cereal production, with the production of rye, triticale and maize being almost nil. Starch from barley is produced in Finland, whilst starch from oats is produced in Sweden. Both are easier to process than wheat as they do not require gluten separation. However, despite being cheaper to process, the absence of a valuable co-product (corresponding to gluten in wheat) renders both barley and oat starch processing less attractive. Nevertheless, oat starch has a relatively small granule size, with a narrower granule size distribution than maize or wheat, which may present an opportunity for a niche application in the cosmetics or bio-material sectors. Import data show that, despite being available in the European market, no use for oat starch has been developed in the UK. Triticale and rye starch do not have singular technical properties that cannot be matched by wheat starch.

3.1.2.3. POTATO

Farmers in mainland Europe, Japan and China, grow potatoes for starch production. However, there is no such potato starch production in the UK. The UK is a major potato producer accounting for 14.5% of the European Union production. It is worth noting that the UK potato sector needs new outlets for its production: in the last two years, as a result of oversupply, planting areas have reduced by 11%.[a]

The UK potato processing industry (crisp, chip, potato flake manufacturers) produces a range of by-products. These vary as a function of the specific process but include

[a] Value corresponding to 2001–2002 and 2002–2003 campaigns.

peels, skin slivers, white starch, grey starch (gelatinised starch containing peel and soil) and mash (from potato flake processing). The amount of starch recoverable from the by-products is estimated to be in the region of 10,000–18,000 tonnes per year. However the use of waste peel, skin and mash in starch processing would preclude its present use in animal feed.

The potato varieties currently grown in the UK are very specific and are grown for particular qualities such as skin finish, colour and taste, and are not equal to the ones grown for starch production in Europe (not sold as edible). The latter have a dry matter content of approximately 26%, higher than their ware congeners, the dry matter content of which varies between 18–22%. Nevertheless, ware potatoes can be used in starch production but productivity of the starch plant would be correspondingly lower.

Currently, 8%[3] of the total UK ware crop (equating to 530,000 tonnes[b]) falls outside size specifications which are important criteria for the processing market, and therefore do not enter the commercial chain. The cost to the industry of this wastage is in the region of £26.5 million per year.

Potential use of these potatoes encompasses a discussion on a specific market for UK-produced potato starch, a review of the economic feasibility of establishment of a potato starch processing plant, and other legal and macro-economic constraints. These questions are reviewed in *Section 4.1.1.*

3.1.3. The competitiveness of wheat and maize as raw material sources of starch

The increase of the market share of wheat processing in the UK mirrors the pattern experienced in the mainland European starch sector and is a new trend. The production of starch from wheat is cheaper than from maize despite its low technical yield compared with maize. The production of 1 tonne of starch requires 2 tonnes of wheat, but only 1.6 tonnes of maize. Nevertheless, the quantitative disadvantage (of wheat) is offset by its cost competitiveness. *Figure 1* plots the net costs per tonne of starch derived from wheat and maize after deduction of the value of co-products (e.g., wheat gluten, maize zein) obtained as a result of cereal processing. The figures are presented from data acquired between 1996 and 2003.

[b] Value corresponding to the 2002–2003 campaign.

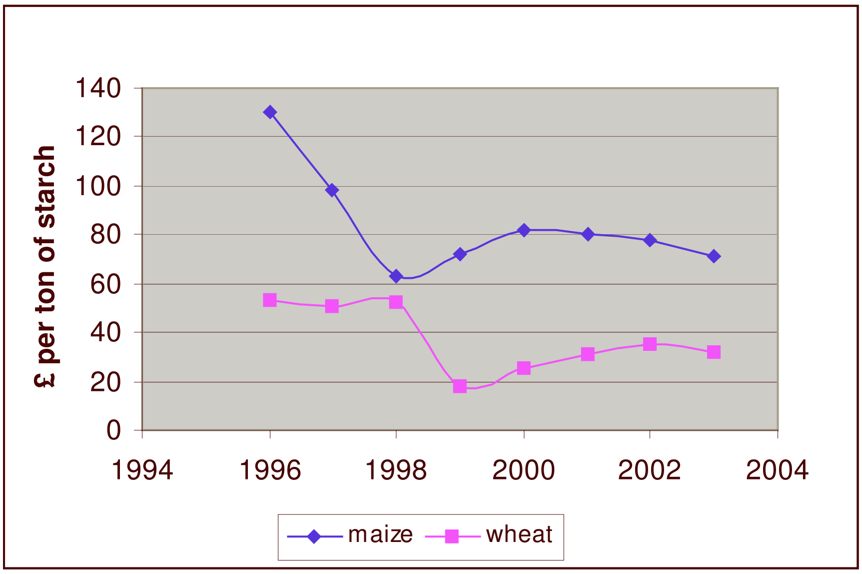

Figure 1. Net costs of wheat and maize as starch materials in the UK

These data were provided by HGCA/UK customs for the respective periods. The net cost was computed from wholesale prices of the relevant cereal material minus the price of the relevant co-products.

Therefore, the wheat versus maize advantage can be summarised as being due to:

(a) The price of the wheat raw material, which in the UK is generally lower than the price of maize. Wheat yield per hectare in the EU in general and in the UK in particular is very high, while in the rest of the world, and in the USA in particular, the opposite is true: maize offers a lower price and a higher yield by hectare. Due to structural overproduction of cereals in Europe, this price trend is expected to continue in the near future.

(b) The second factor in favour of wheat is the value of its co-products. Wheat starch entails production of wheat gluten, a valuable co-product sold to the bakery industry. This market is expected to grow at a rate of 6–7% per year, while the main co-products generated by maize starch production (maize zein, maize germ and maize oil) are raw materials for animal feed. These market values are determined by the market prices of feed proteins and are, therefore, less valuable.

In order to minimise raw material and, therefore, starch imports with consequent beneficial (to UK) maximisation of local production of raw materials and starch, two options are available:

(a) Introduce maize as a starch crop in the UK.

(b) Upgrade existing (ageing) maize processing units to wheat starch units.

Maize is presently grown as a silage crop in the south of the UK but it usually requires a dry climate and yields are low. Preliminary investigations have revealed that present varieties of starch-producing maize are non-optimised for cultivation in the UK climate. Therefore, the second alternative appears to be the most likely one, at least in the short term.

At the current levels of starch production from maize, total substitution of the imported maize would imply an increase of wheat area production of 177,000 hectares (*Table 3*). This also would lead to a corresponding rise in gluten production. which is presently imported as bakery additive in the EU and in the UK in particular.

Starch requirement (tonnes)	Wheat requirements (tonnes)	New area requirement (ha)
531,000	1,060,000	177,000

Table 3. Area requirements if wheat is to substitute maize in local starch production

3.1.4. The UK market characterised as a function of starting materials

In 2002, the UK market consumed approximately 1,200,000 tonnes of starch per year, with a rate of growth of about 3% per year, similar to that in the rest of Europe. This growth is attributable almost entirely to wheat starch production. Use of potato starch has reached a ceiling. The amount of potato starch used remains at roughly the same volume as in 1993 and is thus declining in relative terms. *Table 4* summarises the position of the UK market as it stood in 1993 and 2002.

Starch supply/uses	1993 (1000's tonnes)	2002 (1000's tonnes)
Domestic production	750	900
of which:		
(imported maize)	560	531
(local wheat)	190	369
Imports of unmodified starch,	133.6	142[a]
of which:		
Maize	34.8	39.2
Wheat	17.2	24.7
Potato	79.2	78.1
Imports of modified starch	87	185[a]
Total supply	886.7	1225
Utilisation		
In food industry	667.4 (75 %)[b]	1095
of which:		
Maize	471.5	652
Wheat	179.4	418
Potato	14.3	25
In non-food industry	216.2 (25 %)	129
of which:		
Maize	123.3	49
Wheat	27.8	51
Potato	65	29

Table 4. A comparison of UK starch production and use in 1993 and 2002

a) values provided by the UK customs; *b*) was estimated on basis of data obtained for refunds

3.1.5. Starch import dependency

The UK starch market is heavily dependent on imports, of both raw materials and (some) processed starch. See the data summarised in *Table 4* and illustrated in *Figure 2*.

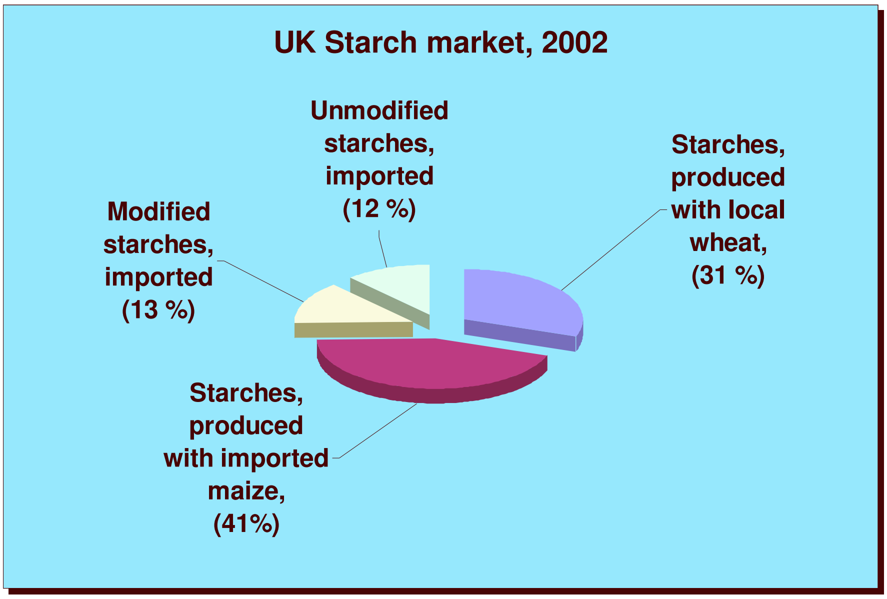

Figure 2. Imported inputs for the starch industries in the UK

In 2002, around 24% of the UK starch market was satisfied through imports (mainly from France and Belgium) of native or modified starches; while the remaining requirement was produced in five principal sites within the UK (See *Section 3.2.2.*). 37% of all maize imported is used for the production of starch. It is processed in two plants at Tilbury and Manchester.

Due to the expansion and conversion to wheat starch processing of two old factories, the relative importance of locally produced maize starch has decreased in the last ten years, but it is worth noting that the 530,000 tonnes of maize starch produced correspond to 890,000 tonnes of maize raw material (56% of all maize imported in the UK).

3.1.6. Possible perturbations due to CAP, EU extension and GM

3.1.6.1. CAP

Building on the 1992 reforms, Agenda 2000 continues the move away from price support to direct payment, thereby supporting people rather than products. This is a further step in the direction of a more decoupled support. As in the previous round of reform, payments are decoupled from price and volume output and are tied to production limiting programmes. In the arable crops sector, under set-aside arrangements, 10% of the land is taken out of production, but can be used for non-food production. For the cereals and potato sector, this represents a major challenge to develop new non-food industrial applications for starches.

The price cut for cereals is to ensure that the price for cereals, including potatoes, is more in line with world prices. The productivity of UK wheat farmers (6–7 tonne per hectare versus 2–3 tonne per hectare for most of the rest of the world) presents a competitive advantage in the globalised world. Priority must now be the development of new markets and a range of new opportunities are reported in *Section 3.3* of this report.

Price cut policies implicit in the CAP may also result in refunds for both export and production being discontinued in the long term. This would be a major simplification for business and authorities alike, since the highly complex monitoring would also cease.

A more detailed analysis of the implications of the CAP for potato producers is provided in *Section 4.1.1.1.*

3.1.6.2. EU EXTENSION

The impact of the recent enlargement of the European Union on starch production and its consumption is reasonably clear. Taken overall, production of starch and derivatives by the new countries of the enlarged EU is quite limited, and these countries are not self sufficient in these products. Poland for example, the largest potato producer of the new members, is a net importer of starch (roughly 60 % self sufficient). Overall, demand is set to grow in the face of relatively diminished overall production.

3.1.6.3 GMO AS RAW MATERIALS FOR STARCH PRODUCTION

GMOs are not well accepted in the EU. All the UK starch producing companies express a non-GM policy. However, at least two major European potato starch producers have a declared interest in GM potato plants. Avebe, from the Netherlands has patented two species of genetically modified potato,[c] and more recently Sweden has approved the trial introduction of GM potatoes for starch production. On the basis that Lyckeby Starkelsen, a Swedish potato starch company, has also bought plants in Eastern Europe and is about to become a major player in the starch European market, it is possible that starch from GM potatoes may enter the UK market in due course. GM varieties offer a range of advantages. In particular, GM potatoes produce high

[c] However the company has not been allowed by the Dutch government to produce them industrially.

amylose starch, and may to be introduced for use in the packaging sector where high amylose starches may confer desired film-forming properties. The issue of GM raw material sources of starches may be (naturally) circumvented by the use of peas as an alternative source of non-GM high amylose starch. Pea starch is presently produced on industrial scale in Canada, and is reported to be a source of starch with 45–70% amylose content.

3.1.7. Conclusions regarding UK starch raw materials

Wheat and potato are the two commercially important UK-grown crop sources of starch with wheat currently being the overwhelmingly more significant; beside these two, imported maize is the most important source. Wheat and maize starches have similar applications, and the economics of production suggest that wheat provides higher returns than maize as gluten, a co-product of wheat starch production, is a raw material for bakery use. However, the co-products of maize starch production are sold principally into the animal feed market, which implies that their prices, determined in relation to protein feed, are much lower.

Potato is not at present used as a starch raw material in the UK, although this country is one of the main European potato producers. A small amount of potato starch is available as a derivative of the potato processing industry. A part of local ware crop (equating to 530,000 tonnes) is presently not used by the food industry, and could eventually be available for starch manufacturing. High amylose potato starch may be produced by conventional breeding techniques and may be a technical alternative to GM potatoes developed by European starch producers.

3.2. UK industrial structure

3.2.1. Starch processing

Commercial starch is industrially produced from agricultural commodities through the wet milling process. The final products from a wet mill, however, include not only unprocessed (also called native) starch, but also a range of starch derivatives. These are either esters and ethers, or products from starch hydrolysis and subsequent processing by controlled bio-degradation (fermentation). In addition, starch milling produces a range of co-products, which include gluten and feed ingredients.

Figure 3 shows these processes in a diagrammatic form.

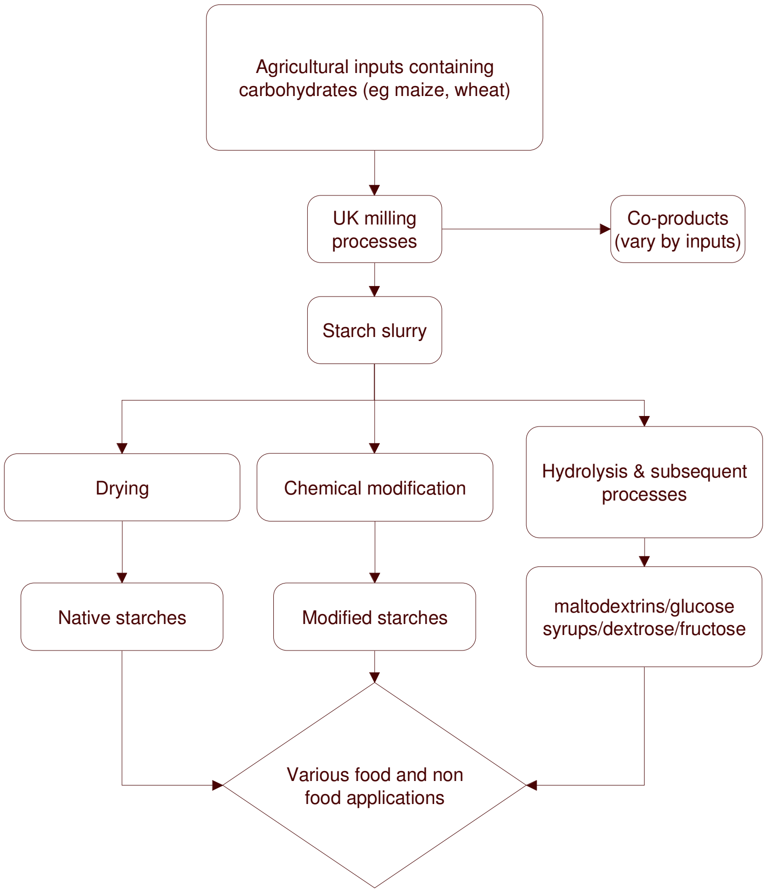

Figure 3. Production of starches and starch derivatives

3.2.2. Main UK industrial operators

In order to understand the industrial structure underpinning the starch sector in the UK, descriptions are presented of the four starch/starch derivatives' producers in the country. Additionally, a world starch producer, that operates in the UK as a wheat milling processor is also described.

3.2.2.1. AMYLUM UK (a subsidiary of Tate and Lyle) is based at Greenwich. Although it originally used maize as its source of raw material, its plant was upgraded and converted to wheat starch production in 1992. The company has an estimated starch market share of 26%. Home-grown wheat is used as raw material. Amylum UK has recently invested in a major new plant at Nesle, in north west France.

3.2.2.2. ADM (ARCHER DANIELS MIDLAND) is one of the world's largest agribusiness companies. For the business year ending 2002, it had declared sales of $14 billion generating a profit of $266 million. ADM's major business is the handling, distribution and processing of oilseeds and grains, including the production from them of specialist processed products, including amino, lactic and citric acids, animal feeds and vegetarian foods. It is focused on a smaller number of commodities than Cargill, and its emphasis is on adding value by further processing. Its sales in 2002 comprised 56% oilseed products, 15% maize products, 11% wheat and other milled products and 18% other products. It has recently bought six wheat milling plants in the UK.

3.2.2.3. CARGIL/CERESTAR is an American company that operates internationally as a marketer, processor and distributor of agricultural, food, financial and industrial products and services. On 31 May 2003 the company reported global profits after tax of $379 million, on a turnover of $50 billion and gross assets of $27 billion. In the UK, Cargill is involved in grain and cotton merchandising, as a financial products provider, in poultry products (the Sun Valley Foods products) and the production of starch and derivatives. Starch is produced at two plants located at Tilbury and Manchester. Both plants use maize as raw material imported from the south-west of France. Cargill's Tilbury plant was acquired in 1978 and upgraded in 1979. Cargill's Manchester plant was acquired in 2002, built in the 1950s but was upgraded in 1989. The company has an estimated starch market share of 59%, and now trades starch/starch products under the name of its subsidiary Cerestar.

3.2.2.4. GRANT is a Scotch whisky producer. It produces starch and glucose from wheat in its plant at Girvan in Ayrshire. Its plant was built in 1992 and subsequently expanded in 1999, serving its own consumption and a number of major companies in the area. The company has an estimated starch market share of 10%.

3.2.2.5. ROQUETTE FRERE is a privately owned French company. It is one of the largest producers of starch and derivatives in the world, being the largest producer of polyols, and with a reported consolidated turnover of $1.8 billion. With six starch-producing plants in the EU, including a large factory at Lestrem near Lille, it started supplying starch derivatives from its French plants in the 1960s. In 2000, it purchased the former ABR plant at Corby in the UK. This plant, which uses locally produced wheat, is being expanded. In the UK, the company has an estimated starch market share of 10%.

3.2.3. Is the UK starch market part of a regional market?

The location of the five UK based starch plants is shown in *Figure 4*.

1-Grant, 2,4 Cargill/Cerestar, 3 Roquette, 5 Amylum

Figure 4. Location of starch producing plants in the UK

The first industrial processes to produce starch were based on maize, and therefore the older UK plants still use these technologies. As already discussed (*Section 3.1.3*), wheat starch production is economically more feasible than maize in the UK, and is the starting material of choice for new build plants. The older plants are located in ports to reduce transport costs of imported maize. As seen in *Figure 4*, plants 2 and 4 (properties of Cargill/Cerestar), located near the coast, at Manchester and Tilbury, are maize starch processing facilities, plant 5 (today a property of Amylum) was originally a maize starch processing unit but has been upgraded to use wheat, while the other (more modern) plants (today property of Roquette, and of Grant) were built to process wheat.

It is important to establish whether the UK starch market is a cluster of local markets, a national market, a regional market or a global world market. There are 75 starch plants operating in Europe, plants from the four companies operating in the UK are presented in *Figure 5*. It is worth noting the localisation of a number of plants in Belgium, France and the Netherlands that can easily supply the UK. Freight costs for starch across the Channel have been reported to be around 5% of the price of the native starch transported.

Figure 5. Europe-wide distribution of starch plants with operators based in the UK

3.2.3.1. VERY LITTLE IMPORTS OUTSIDE THE EU

Import data show that very little starch is imported from outside the EU, but that there is a major trade flux between EU countries as shown in *Figure 6*.

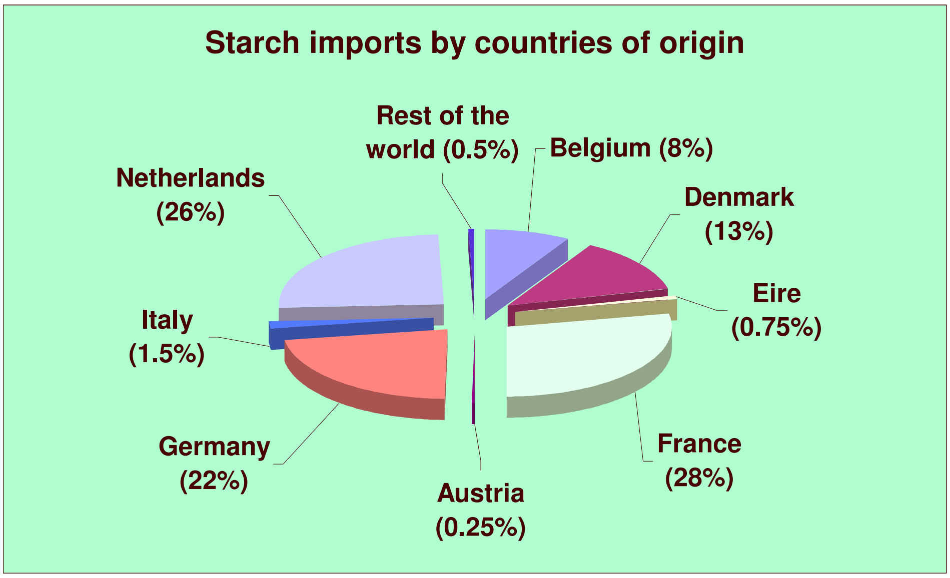

Figure 6. UK starch import by countries of origin

Roquette has supplied UK-based customers with starch/starch derivatives sourced from its continental plants for many years. In the paper industry, a number of starch users have reported that they plan their importation of starch over a one month period, indicating that there is no just in time delivery that would imply that the supplier should be located close by, and therefore supplies can be obtained from Europe.

One user indicated that it could use cassava starch (physicochemical properties are adequate) but that the suppliers, Thai companies, do not provide technical assistance for their products, and therefore they were disinclined to use them. Several paper companies noted that they could have bought cheaper maize starch from the US, but prohibitive customs duties do not allow them to do it.

3.2.3.2. POUND/EURO EXCHANGE RATE AS IMPORT- EXPORT DRIVING FACTOR

UK starch imports are mainly from Europe and a significant issue is the extent to which Pound/Euro exchange rates have driven imports. The trend over the last twelve years is shown in *Figure 7*. Between the beginning of 1996 and the end of 2001, the pound gained around 40 per cent when measured against the euro.

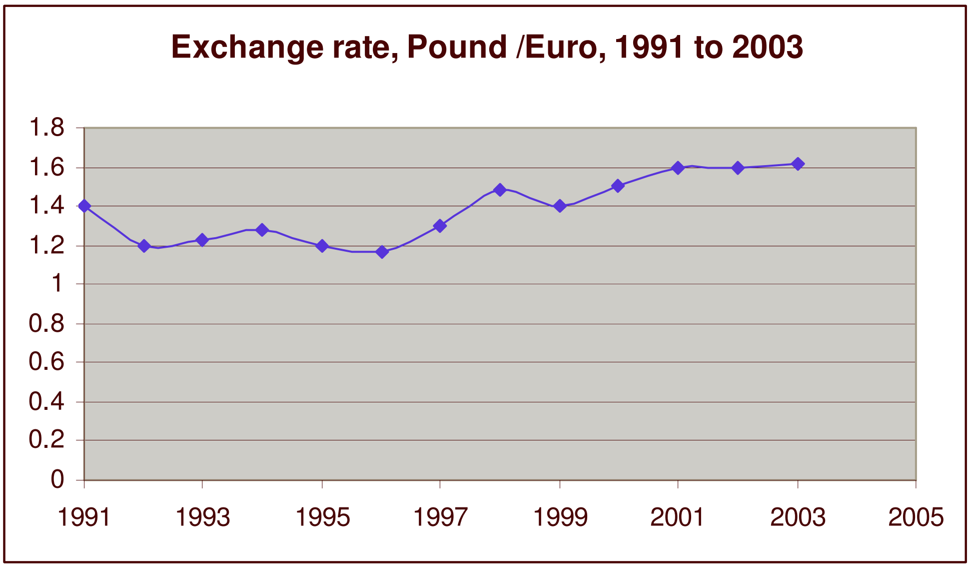

Figure 7. Exchange rate, Pound/Euro, 1991–2003

However, the data available suggests that exchange rate fluctuations have not been a core driver of the overall trend in either imports or exports. Indeed, *Figure 8* shows that imports have grown steadily from 1991 to 2001, whereas sterling fell relatively steadily from 1991 to 1996, then rose from 1996 until 2000. This pattern supports the proposition that, in the long term, exchange rate movements have not been a dominant driver of import activity.

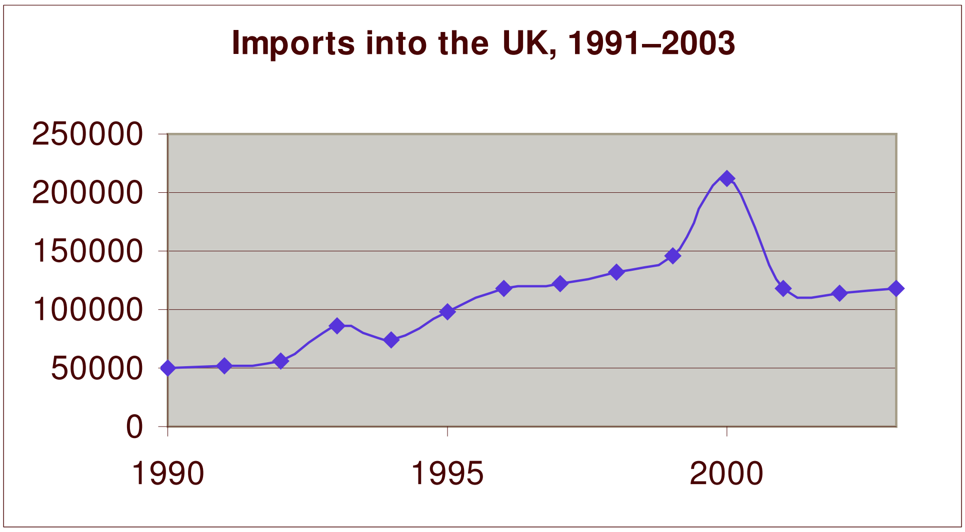

Figure 8. Starch imports into the UK, 1991–2003

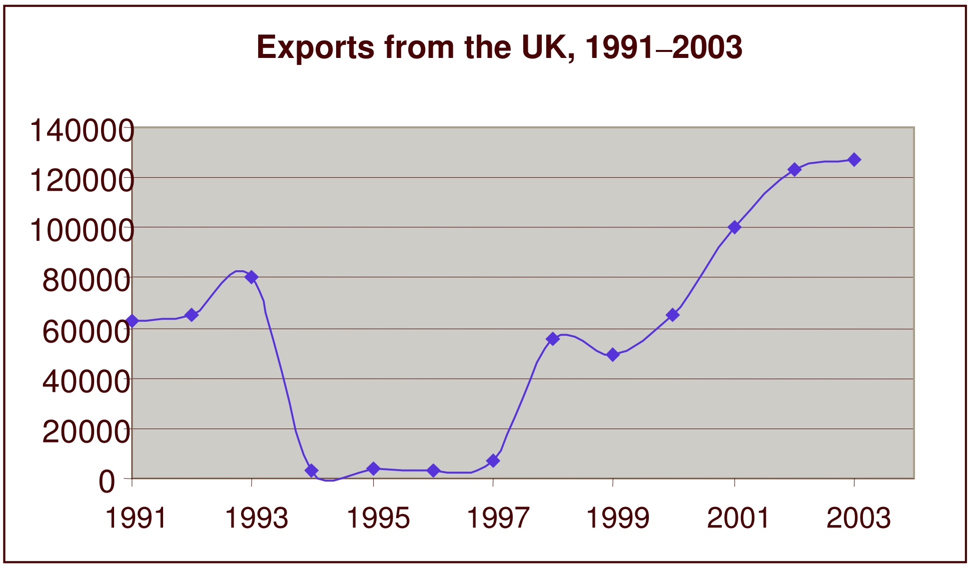

Figure 9. Starch exports from the UK, 1991–2003

In the same period starch exports (*Figure 9*) increased more than tenfold from a negligible level to more than 120,000 tonnes. Such an increase in exports in the face of such an increase in sterling is inconsistent with exchange rates being a major driver of trade in starch between the UK and the rest of Europe.

3.2.3.3. PLANT SCALE FACTORS

It should be noted that net balance of import-export activity indicates that imports are predominant. As the cost of raw materials is similar in the UK and mainland Europe (cost of agricultural inputs for starch production is determined by CAP), and there is little technological difference between plants and the cost of manpower is a relatively small item in the cost structure, the economy of scale of the starch milling operations is overriding in determining the ex-factory price of starch. The fact that the production scale is determinant in the price of the products is also consistent with high capital/ low manpower costs characteristic of wheat/corn starch plants as shown in the *Appendix*. The capacity of the plants of major starch operators is higher in Belgium (Bergen-op-Zoom for Cargill-Cerestar) and in France (Lestrem for Roquette and Nesle for Amylum), than for the corresponding plants in the UK. It is observed that a large fraction of imports are accounted for by the major multinationals involved in the starch business. If operations in the UK could be consolidated these imports would decrease.

3.2.3.4. TRANSPORT COSTS AND JUST IN TIME DELIVERY

Transport comprises a significant proportion of starch costs (around 10–15% according to some sources) and therefore there are advantages in having a plant near major consumers. This advantage is expected to partially compensate for the smaller size scale UK operations.

Data collected from freight companies indicate that the land transport cost for starch and its main derivatives, on a pound per tonne per kilometre basis ranges from £0.07 to £0.08. In broad terms, the cost of crossing the English Channel is of the order of £8–16 per tonne depending on whether a full load comprises the return leg. In a first analysis, therefore, a Channel crossing equates to a land transport equivalent distance in the range of 106–212 kilometres depending on backhaul opportunities. Noting that backhaul is common, 106 km provides a clear estimate of the additional travelling distance advantage available to processors/suppliers of locally (UK) produced starch.

Thus, the competitive advantage for local plants may be in the range of £25–66 per tonne of starch, being higher for plants located further from the English Channel. Assuming an average market cost for starch of £330 per tonne this would correspond to 8–20%.

In the case of potato starch, the cost of transport to some zones in the UK can in some cases outweigh the value of refund to the (mainland European) farmer.

Furthermore, some consumers have also indicated their requirements for just in time delivery that favours short distance suppliers, whilst other companies, with plants in both the UK and continental Europe, have indicated that they operate centralised European purchasing of their starch/starch derivative requirements. The extent to which one approach is favoured over the other was not, however, quantified within the scope of this report.

3.2.3.5. IS THE UK STARCH MARKET PART OF A REGIONAL MARKET? CONCLUSIONS

The geographic market for starch and its derivatives should be regarded as Europe-wide. The key factors supporting this assertion are:

(a) substantial trade flows exist between the UK and continental Europe;

(b) there is an absence of specific UK demand characteristics;

(c) costs are comparable in terms of position/technology of UK versus continental producers;

(d) there is an absence of customs barriers across the English Channel and the North Sea.

However, plants located distant from the English Channel will have cost advantages when supplying local markets.

3.3. Starch uses

3.3.1. Starch consumption: a world overview

In the US, the two main non-food uses of starch are in the bio-fuel sector and as fructose derivatives. The bio-fuel sector in Europe is still confined to pilot projects, while starch-based production for the fructose market is limited to a quota of about 300,000 tonnes, less than 2.5% of the consumption of sugar in the EU.

In Europe as a whole, starch is used for food and non-food applications as indicated in *Table 5*.

Sales	Quantity (10^6 tonnes)
Food	3.5
Non-food	2.7
Subtotal internal market	6.2
Export	1.3
Total	7.5

Table 5. Sales of starch and derivatives produced in the EU, 1998. Source: DGA, EU

Comparison of *Tables 4 and 5* shows that the consumption of starches for non-food uses relative to food uses is much higher in the European Union as a whole than in the specific example of the UK.

3.3.2. Starch consumption: UK overview

The non-food, end-use applications of starch in the UK according to accepted European Union analyses (i.e., paper and board sectors, organic chemicals, etherified and esterified [modified] starches, pharmaceuticals and others) is presented in *Table 6*. However, our analysis reveals this treatment by DGA to be possibly misleading as modified starch may also be used in a range of end-use activities classified as paper, pharmaceuticals or others. The tendency is therefore to quantify modified starches twice: simply as modified starches but then again as components entering the paper, pharmaceuticals and other markets. We have adjusted the

European analysis on the basis of discussions with starch stakeholders to take account of possible double counting and present proportional data for the EU in *Figure 10* compared with our own analysis for the UK in *Figure 11*. Indications from the starch industry suggest that in the case of the UK, etherified/esterified starch is used by the paper industry/food industry in a ratio 50:50, very similar to the 45:55 ratio suggested in Europe as a whole.

Sales	Quantity (10^6 tonnes)
Paper and board	0.9
Esterified and etherified starch [modified]	0.9
Organic chemicals	0.5
Pharmaceuticals	0.1
Others (enzymes, plastic, glues, others chemicals)	0.3
Non-food total	2.7

Table 6. Sales of starch in the EU market, non-food sector. Source: DGA, EU

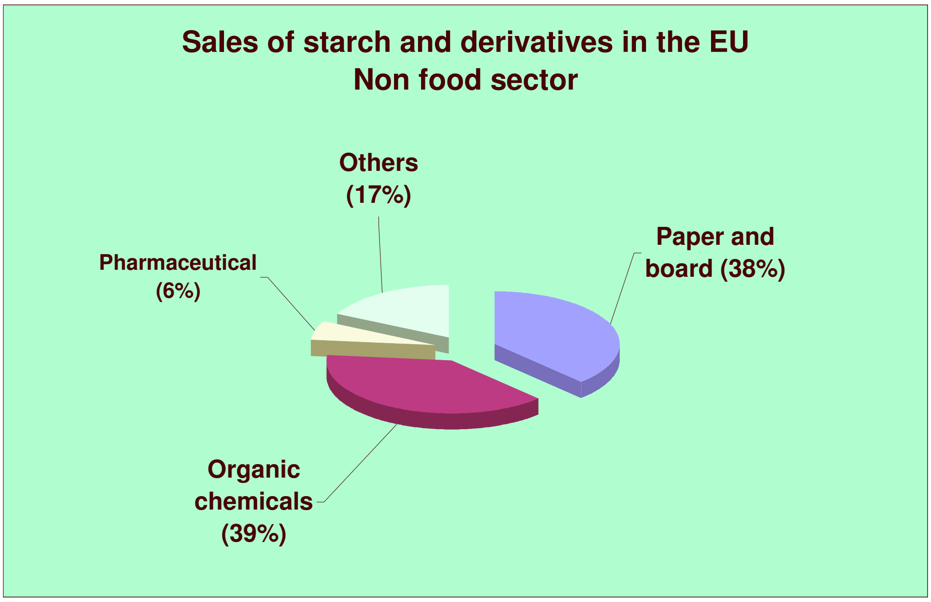

Figure 10. Proportional sales of starch and derivatives in the various non-food sectors within the EU

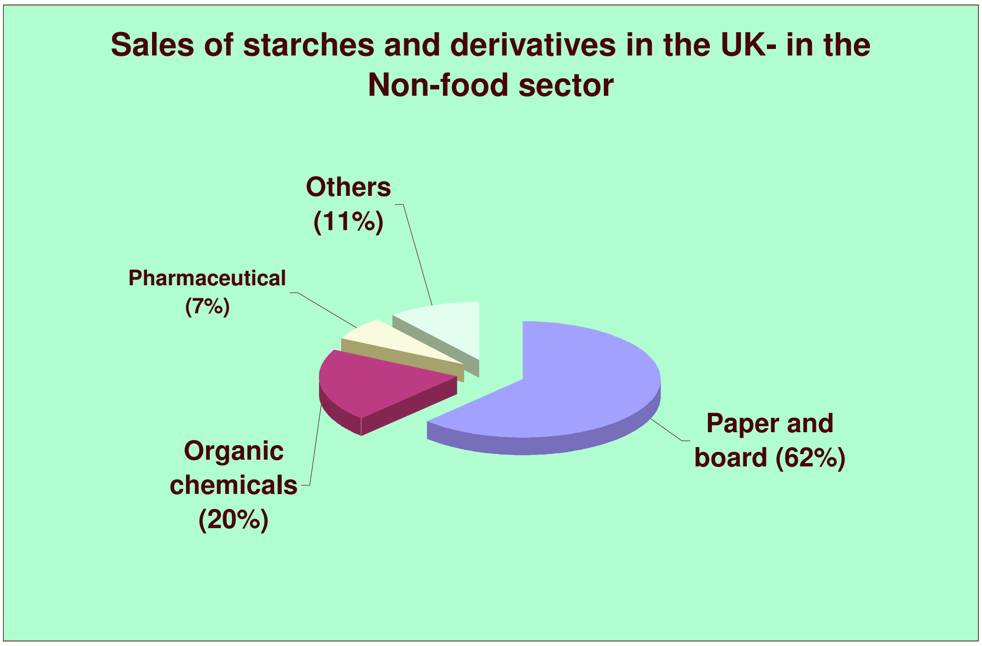

Figure 11. Proportional sales of starch and derivatives in the various non-food sectors within the UK

Comparison of *Figures 10* and *11* reveals that non-food starch consumption is more concentrated in the paper and board sector in the UK than in the EU as a whole, and that proportionally the EU as a whole is servicing the higher value organic and other sectors to a greater extent than is the UK. An analysis of each sector follows with a discussion of the data.

3.3.3. Paper making industry

As shown in *Figure 11*, the paper and board sector is presently the main consumer of starch and its derivatives in the non-food sector in the UK. Starches are used to improve the strength of paper, and as a component of coating formulations. In corrugated board manufacture, starch is used as an adhesive, bonding the layers of board together.

In 2003, the paper and board industry accounted for fully 62% of the non-food industrial use of starch in the UK.

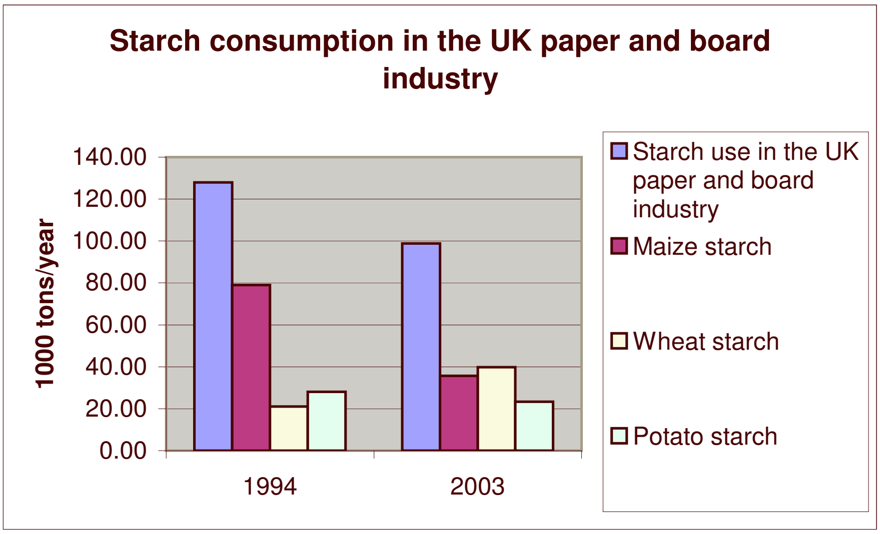

Figure 12. Consumption of starch by the UK paper and board industry. Sources: Batchelor et al, 1995, The Confederation of the Paper Industries, 2004

The data expressed in *Figure 12* indicate that the overall consumption of starch products in the paper and board industry is decreasing. Different factors are contributing to this trend:

1. improved manufacturing technology, which

(a) implies the use of modified, tailor-made starches (for example cationic starches used in the wet-end) with improved performance over native starches, but correspondingly reduced global consumption of starches;

(b) leads to the increased use of non-starch-based paper additives. These are synthetic organic polymers (polyacrylamide, polyimides, polyethylene oxide) used as retention aids in the wet-end and as dry strength additives. A range of competing products such as carboxymethyl cellulose, polyvinyl alcohol, methyl cellulose, wax emulsions as sizing agents, as well as cheaper acrylics and polyvinyl acetate have emerged as new coating agents to displace the traditional starch-based materials.

2. re-focused paper industry manufacturing paper grades with low starch incorporation. The UK paper industry is producing less coated paper grades (involving high starch consumption) than ten years ago.

3. a downturn of the paper industry, in the UK and Europe in general. Both the number of UK paper mills and the overall capacity have been decreasing in recent years. The latter factor is due to the internal dynamics of the paper industry and is not covered in this study.

3.3.4. Organic chemicals by starch biochemical processing

All starch derivatives are organic chemicals. Discussion in this section refers to organic chemicals obtained by biochemical processing, defined as the biological or microbiological conversion of the feedstock to the desired and more valuable product, based on degradation or synthesis.

3.3.4.1. PRESENT UK PRODUCTION OF ORGANIC CHEMICALS BY STARCH BIOCHEMICAL PROCESSING

The major bulk industrial chemicals produced by bio-processing world-wide and imported into the UK are presented in *Table 7*.

	World market estimates (1999) (10^3 tonnes/year)	UK import (10^3 tonnes/year)	Market price[a] (US $/ tonnes)
Lysine	350	20	2200
Lactic acid	70	6	2100
Ascorbic acid	60	2.7	1000
Glutamic acid	40	8	1700
Aspartame	15	n/a	40000
β-lactams	178	*b*	*b*

Table 7. Bulk industrial bio-chemicals: world-wide estimates, UK import and market prices
a) strong price fluctuations; *b*) price is a function of the class of the antibiotic

Commercial amino acids (e.g., L-lysine or L-threonine) are produced from starch based bio-processes. The carbon source (starch) is the major item of variable cost and this explains the fact that important world starch producers (Cargill, ADM) also produce amino acids. In China, potato starch is used as a carbon source for amino acid production. The nitrogen source varies from inorganic pure ammonia through to complex organic components such as maize steep liquor (itself a by-product of lactic acid bio-processing). The world market for amino and organic acids is reported to be around 2 million tonnes per year with a growth rate of 10% and higher.[4] Demand for amino acids in pharmaceutical products for intravenous and enteral nutrition is 15,000 tonnes,[5] the balance being used as a feed additive and flavour enhancer, with the exception of phenylalanine which is used in the production of aspartame, the well-known, low caloric sweetener. The world demand for phenylalanine in 2002 is estimated at 14,000 tonnes.[6] The most important amino acid commercially obtained by fermentation, lysine, is currently imported in the UK (20,000 tonnes per year, costing approximately £1,400 per tonne). A portion of Europe's lysine needs is met by imports.

Lactic acid, besides being a target as an organic building block, is an important organic acid with a range of applications mainly in the polymer industry (see *Section 3.3.5*).

A potential important application of lactic acid is in the production of esters, which could substitute a range of (toxic) solvents (halogenated, and in some cases methyl ethyl ketone)[d] used in cleaning, paint and ink formulations, and that can be an intermediate in the production of acrylic acid (via catalytic dehydration). It has been claimed that lactate-based solvents could replace 80% of the presently used conventional petroleum based solvents.[7] An American chemical company, Vertec Biosolvents has developed a range of soybean oil-ethyl lactate blends targeting markets of a range of solvents under environmental scrutiny (methyl ethyl ketone and *N*-methyl-2-pyrrolidone).[7] However, these end uses have been limited due to its present high cost. The current market price of ethyl lactate is, on a volume basis, seven times the price of methylene chloride, one of the solvents that it may technically substitute. It is expected that the ethyl lactate price will fall when new technologies are developed and large scale production (associated with others lactic acid derivatives) is introduced (see S*ection 3.3.5.5.3*).

Two important starch-derived organic chemicals produced world-wide are citric acid and ethanol. However in the UK, citric acid, the market size of which is 35,000 tonnes per year,[e] is produced mainly using molasses as raw material. Ethanol, for non-food applications (as a solvent) is mainly produced synthetically by BP Chemicals. UK imports of citric acid/ethanol are not significant. However, xanthan gum, a microbial polysaccharide used as a food additive and in a number of industrial applications (as a thickener and stabilizer in cosmetic, pharmaceutical and food industry) is produced in the UK using dextrose as the fermentation medium. UK annual production consumes approximately 400 tonnes dextrose.

The most important starch biochemical derivative used in the UK is sorbitol, a non-cariogenic sugar used in the manufacture of toothpaste. 24,000 tonnes are annually imported into the UK (mainly from France), worth £8m per year.

---

[d] Ethyl lactate can remove silicone oils, grease, machine coolants, and substitute glycol ethers used in semi-conductor industry.

[e] The producer occasionally uses other fermentation media. Because citric acid is also used as a biocide, sales of citric acid increased during the foot and mouth epidemic and some quantities of dextrose were also been used as well as molasses as a fermentation medium.

Higher value, low volume derivatives are exemplified by astaxanthin. Astaxanthin is a naturally occurring carotenoid.[f] When salmon are raised in aquaculture they are fed this carotenoid (or selected precursors) in order to attain their characteristic colour. An aquaculture company has indicated that astaxanthin is the most expensive ingredient in the industry. The global market for astaxanthin has been estimated to be worth $200 million.[8] It has been traditionally produced by chemical synthesis, but consumer pressure regarding chemical food additives has stimulated research and ADM has responded with a new astaxanthin biochemical process, reported to be a cash cow for the company. These results suggest that other economically valuable carotenoids (e.g., beta-carotene, lycopene, cantaxanthin, zeaxanthin and lutein) may be produced using similar industrial fermentation routes.

3.3.4.2. ORGANIC CHEMICALS FOR THE PHARMACEUTICAL INDUSTRY

Ascorbic acid, vitamins B11, and B1, β-lactams, and statins[g] are the most important organic chemicals used in the pharmaceutical industry that are obtained by fermentation from starch hydrolysates. However, ascorbic acid is currently imported into both the UK and mainland Europe from Far East manufacturers.

β-Lactams comprise a market worth over $8 billion split amongst cephalosporins ($4.8 billion, 33%), penicillins ($2.1 billion, 14.6%) carbapenems ($603 million, 4.2%) and other β-lactam derivatives ($605 million, 4.3%). No data is available on sales' volumes of companies manufacturing statins and lactams in the UK, but it has been reported that the starting material for the synthesis of carbapenem and other penems is produced by two companies, Kanegafuchi and Takasago, based in Japan. That is to say, UK-based companies are not using starch or glucose in biotechnological processes but are importing organic derivatives from overseas.

Similarly, no data is publicly available in respect of statin sales in the UK. It is believed, however, that Bayer, Novartis, Merck, and Parke Davis undertake their processing outside of the UK.

Speciality grades of pyrogen-free products are derived from starch such as D-glucose, D-fructose, D-mannitol and L-sorbitol for injectable solutions. Sorbitol and erythritol are produced as non-cariogenic sugar substitutes; and drip-feed drug delivery systems

---

[f] Produced by algae, marine bacteria and fungi. In the food chain astaxanthin accumulates in animals such as salmon, and certain birds imparting a vivid pink colour to their flesh, carapace or plumage.

[g] Inhibit cholesterol synthesis.

are significant substances supplied by starch producing companies to this sector. Starches are also used as excipients in the production of tablets, acting as binders and diluents. Etherified starches are used in the UK as plasma substitute, to expand and maintain blood volume in shock arising from conditions such as burns or septicaemia. The total UK market for these uses has been estimated to account for 10,300 tonnes of equivalent native starches.

Beta-cyclodextrins are promising starch derivatives that are being investigated for the formulation of high-value, polar active ingredients. These are high value/low volume applications. Cyclodextrins are presently imported. Starches/modified starches/glycol/ salted water systems are also used in large scale protein separation. No figures are publicly available in respect of the volume of starches used for these specific purposes.

3.3.4.3. ORGANIC CHEMICALS USED AS BUILDING BLOCKS FOR COMPLEX ORGANIC CHEMICAL SYNTHESIS

Most complex molecules prepared by organic chemistry are obtained from small starting molecules, like ethylene, which have so-called functional groups that can be modified or used to form bonds and therefore allow the synthesis of complex molecules. A range of such so-called building blocks can be obtained from starch fermentation processes. To reduce their present high cost, research aimed at processing technology improvements (in micro-biological strain and process optimisation, with particular emphasis in down stream processing, namely product separation and purification) is presently being investigated.[9] The most important targets derived from starch are:

(a) Itaconic acid, a five carbon unsaturated dicarboxylic acid derivative. As indicated later (*Section 3.3.5*), small acids are used in the production of biodegradable plastics. As a building block, itaconic acid has two different functionalities, that can undergo different reactions. The two carboxylic groups can be selectively derivatized by enzymatic chemistry which indicates a large possible range of end uses. Pyrethroids are possible commercial molecules to be synthesised from itaconic acid. In the material science field, methylmethacrylate polymers, and acrylic pressure sensitive adhesives may be obtained from itaconic acid.

(b) Succinic acid. This molecule is targeted as an attractive bulk intermediate under the alternative feedstocks programme of the US Department of Energy.[10] It has been considered as a feedstock for 1,4-butanediol which could subsequently be converted into adipic acid and adiponitrile, caprolactam and finally nylon fibre. Applied Carbochemicals Inc. and Tate and Lyle and the Michigan Biotechnology Institute are developing improved micro-organisms for cost-effective production and separations to establish succinic acid as a competitive alternative to the presently available feedstocks of adipic acid and nylon. It is also expected that the starch based succinic acid may allow cost-competitive production of tetrahydrofuran (a solvent and key ingredient of adhesives and magnetic tapes) and butyrolactone (also a solvent, and intermediate in the manufacture of pyrrolidone-based agrochemicals and pharmaceuticals).

3.3.4.4. ENZYMES

A range of enzymes is presently produced for uses in textile, baking, brewing, juice, flavour and as catalysts for bio-transformations. The total UK dextrose market for these applications in the UK has been estimated to require 125 tonnes of equivalent native starches.

3.3.5. Bioplastics

3.3.5.1. GENERAL OVERVIEW

In the past five years, a broad range of biodegradable plastics (bioplastics) has been commercialised by global suppliers. Demand for bioplastics is said to be fastest growing polymer sector, though from a relatively small base.

A study published by Agricultural-Industrial Research of the European Commission estimated (in 1998), the potential European bioplastic market to amount 1.1 million tonnes (*Table* 8) with the potential to create 20,000 new jobs.[11]

Possible applications	Tonnes /year
Compostable trash bags	380,000
Disposable products, packaging materials	180,000
Hard packaging	150,000
Bottles	130,000
Fast food packaging	120,000
Agricultural foils	70,000
Diapers and hygiene	60,000
Pharmaceutical packaging	50,000
Foil can binders	5,000
Total	1,145,000

Table 8. European market for bioplastics, estimated in a report by the Agricultural-Industrial Research EC Commission[11]

These values appear exceptionally high in comparison with current actual consumption of bioplastics. For example, Novamont, a major company in the starch biodegradables sector, has estimated the European market amounts to 30–40,000 tonnes /year.[12] However manufacturing trends for all biodegradable plastics, shown in *Figure 13* support exponential growth and the AIR estimates appear realistic.

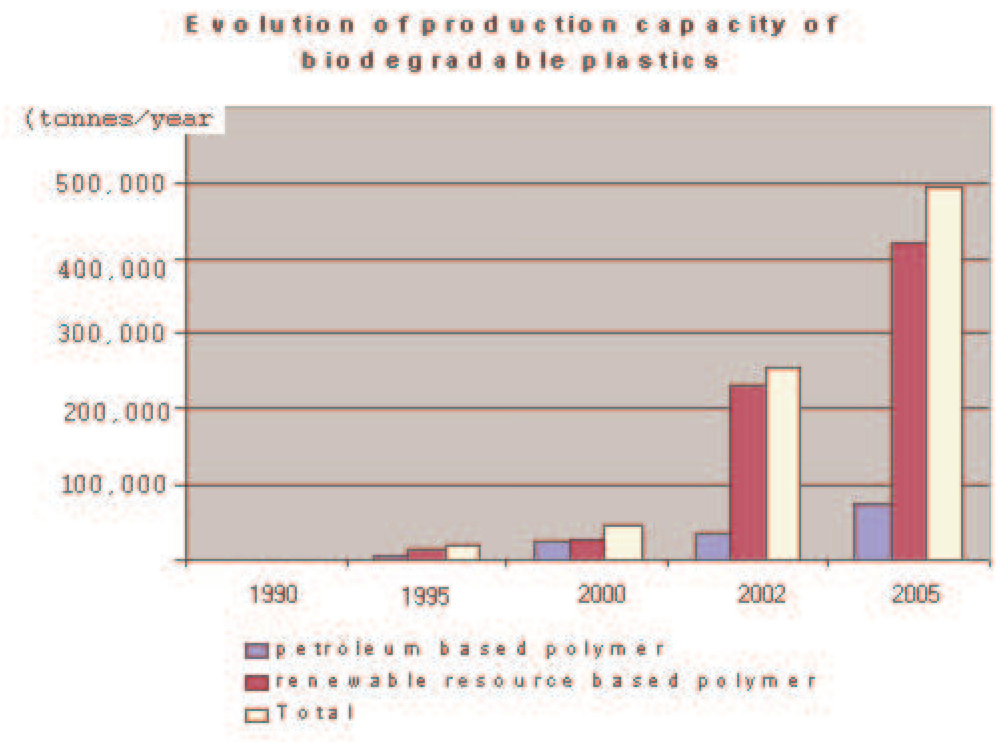

Figure 13. Worldwide capacity of production of biodegrable plastics[13]

Indeed, worldwide capacity was estimated to be 250,000 of tonnes in 2002. Two companies, Cargill Dow (manufacturing polylactic acid), and BASF (manufacturing Ecoflex, an aliphatic aromatic polyester) have already announced expansion of their production capacity, so another half million tonnes are expected within two to four years.[13]

On the basis that a European market of 1.1 million tonnes for all biodegradable polymers is a possible scenario in the next decade, it is plausible that, if correct macroeconomic policies are in place, the UK could supply 15% (165,000 tonnes/ year) of that demand.

3.3.5.2. WHAT ARE BIOPLASTIC MATERIALS?

Bioplastics are plastics able to (a) perform as traditional plastics when in use, (b) have reduced environmental impact in terms of energy consumption and green-house effect in specific applications, and (c) possibly, but not necessarily, completely biodegrade within a composting cycle. Composting is estimated to be cheaper than recycling for a range of short-lived materials (for example, bin bags, cemetery bags), and food contaminated plastics (fast food catering materials).

The possible origin of different biodegradable plastics is presented in *Figure 14*.

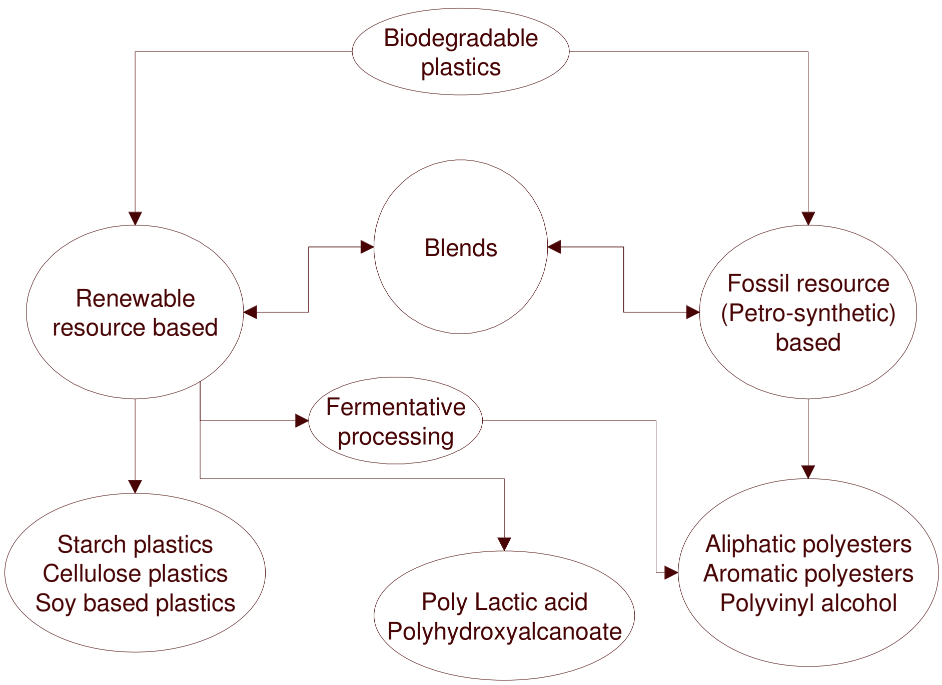

Figure 14. Sources of biodegradable plastics

Biodegradable materials can be either renewable or petrochemical derived. Commercial grades of renewables-based, biodegradable plastics include materials manufactured by Novamont (MaterBi grades), Biotec (Bioplast) and Rodenburg (Solanyl) all of which are starch-based materials. Furthermore, Mazzucchelli (Bioceta) manufactures cellulose acetate, whilst Cargill Dow (NatureWorks) and Mistui (Laceda) supply polylactic acid. Important petrochemical-based biodegradable materials are Dupont's Biomax, Eastman's Eastar Bio and BASF's Ecoflex, Japan's Showa Highpolymer (polybutylene succinate) and Korea's SK Chemicals' (polybutyrate adipate terephthalate). It should be noted that petrochemical-based biodegradable materials can also be produced using acids or diols from starch fermentative processes. This strategy is proposed by Dupont in its manufacture of 1,3-propanediol from starch to produce aliphatic polyesters. Additionally, biodegradable aliphatic co-polyesters produced by bacterial fermentation are expected to be launched in the next few years by two suppliers: Biopol PHBV (polyhydroxy butyrate/valerate), being developed by Metabolix, and Nodax PHB (polyhydroxy butyrate), manufactured by Procter and Gamble.

3.3.5.3. MARKET FOR BIOPLASTICS

Once formulated, biodegradable plastics fall into two broad categories,: one is highly amorphous, imparting flexibility and clarity comparable to a conventional LDPE (low density polyethylene) co-polymer, whilst the second group is semicrystalline, and more rigid, with properties similar to PET (polyethylene terephthalate), PP (polypropylene), or PS (polystyrene). Bioplastics can be used alone or as blends to make synergistic use of the mechanical properties of each polymer. A classic example is the mixture of PCL (polycaprolactone, an aliphatic polyester) and starch. PCL has a high tensile strength but is very brittle, whilst starch has a high elongation at break.[18,19,20] In combination, the two polymers extend the use of the blend beyond the individual capabilities.

Traditional plastics, such as polypropylene, polyethylene, and polyesters are developed to maturity following sustained research and development programmes coupled with substantial financial investment over the past 80 years. However, renewable materials, which have yet to undergo such intensive investment and research and development, remain in their infancy and further work is required to make them suitable as matrix polymers for consumers applications. Currently, they feature performance limitations and high cost, the two factors that are major barriers for their widespread acceptance as substitutes for traditional polymers. However a range of consumer applications is being developed for commercialisation, and an overview is presented in *Table 9*.

Segment	Examples
Packaging	Loose fill, film, hollow bodies, bottles, trays, nets, sacks, bags
Fast food catering	Crockery, cutlery, straws, beakers
Fibres textiles	Clothing, technical textiles, fabrics
Toys	Craft materials, bricks and blocks, golf tees
Convenience	Organic waste sacks, personal hygiene products (nappy film, cotton buds)
Horticulture	Plant pots, peat sacks, seed tapes
Agriculture	Mulch films, tying yarns
Medicine	Implants, gloves
Others	Functional supports, mounting technology

Table 9. Reported end-uses of bioplastics, as indicated by present day manufacturers

The ultimate cost, and thus eventual market share, of the different products obtainable from these polymers, is not only a function of the costs of the raw materials, but also a function of the processing techniques (starch based polymers have slower production rates in plastic film equipment) and mechanical properties of the resulting polymers. For example, if a polymer has a high mechanical strength, then a thinner bag may be produced than one prepared from weaker material and therefore less polymer can be used to manufacture the bag.

The UK market price (UK Customs, 2003) for a range of polymers shows the most expensive polymers to be five times more expensive than the cheapest. Thus, unprocessed PE costs £0.50–0.60 per kilo, PS and PET £0.60–0.70 per kilo and nylon £1.55–2.50 per kilo.

In the biodegradable plastics market, aliphatic polyesters (in the main PLA, the present main competitor of starch thermoplastics) sell for £1.50–2.50 per kilo. Starch itself is very cheap (£0.33 per kilo), but starch-based biopolymers such as Mater Bi (from Novamont) are more expensive (£2.40–3.40 per kilo.

The market price of a range of plastic sacks manufactured from a range of different polymers are reported in *Table 10*.

Product/manufacturer	Material	Price per 1000 (£)	Weight (g)
Ecoflex biosacks by Visqueen/BPI	Polyester	180	na
Kornas Paper sacks	Paper	145	212
Steward fibre	Jute	250	178
EPI	Polyolefin	135	40
Wentus Kunstshoff	Maize starch	247	94
Environmental Polymers	Polyvinyl alcohol	316	70
Symphony International	Polyethene	71.65	52
Otto	Maize starch	400	na
BACO[a]	Potato starch	138	90

Table 10. Price of different bioplastic bags from April–May 2001 compared with PE[21]
a) presently imported from East Asia

It is clear that PE-based bags are cheaper than (imported) starch based bags at present. However, the use of starch based materials could provide savings over the whole life cycle because they could allow the production of compost that can be sold, and therefore reduce the amount of money that the household may pay to its local authority for waste management.[21]

3.3.5.4. STARCH-BASED BIOPLASTICS

Initial interest in using starch in the plastics sector stemmed from its cost and propensity to biodegrade. Starch was therefore used as a filler or co-extruded with synthetic plastics to afford materials that would disintegrate at the end of a product's life. However due to poor interfacial adhesion these blends had poor mechanical properties, and the maximum tolerable amount of starch present usually did not exceed 5–6% by weight. In an approach to solve these problems, compatibilisers were introduced into the blends that would bind to both starch and the synthetic polymer to provide a single phase. However, the disadvantage of this technique was that the extent of biodegradability was governed by the presence of the non-biodegradable component of the blend. The current approach is the production of plastic materials based almost entirely on starch or other biodegradable materials in which the non-biodegradable element is entirely precluded.

Starch-based plastics presently commercially available on the large scale (on a worldwide basis) are foams (for the loose fill foam market), films (for agriculture, such mulch films, shopping plastics bags), mouldable products (pots, cutlery, fast food packaging). These sectors are reviewed individually in the following sections.

3.3.5.4.1. STARCH BASED FOAMS

A significant advance in the last 10 years has been the rapid growth of the starch-based packaging loose-fill foam market. Traditionally, expanded polystyrene (EPS) has been the sole foam packaging material. Two environmental concerns have been raised in respect of EPS: its visibility and indestructibility when discarded in landfill[h] and the release of blowing agent, a chlorofluorocarbon, during processing, which is detrimental to the earth's ozone layer. [22,23] Environmental factors therefore mitigate against the use of EPS in favour of starch-based materials and indeed technically, starch-based materials are considered superior for packing electronic/electric devices as they have better static electricity isolation properties.

In the US, it is reported that around 25% of EPS use has been replaced by starch-based foam, and this rate is steadily increasing as the quality of starch-based materials is improved.

In the UK, wheat-based foam[i] has been introduced by Green Light Products, which after five years of operation is reported to have gained 20% of the loose fill market. There still remains a major opportunity for further market penetration by starch-based products. The EPS market in the UK remains significant with 14,000 tonnes being manufactured locally and a further 44,000 tonnes being imported, fulfilling applications such as electrical goods packaging (42%), fish boxes (24%), horticultural purposes (14%), and as loose fill packaging (20%).

Other starch-based foam materials can be produced. Research commissioned by the USDA has led to the development of starch-based compressed micro foams which are claimed to be effective slow-release agents for a variety of volatile compounds, and could be used for dispensing agricultural chemicals, lessening the environmental impact associated with their use.

---

[h] EPS degrades extremely slowly and in the US comprises 7% of municipal waste by weight, and 18–20% by volume.

[i] Green Light Products directly processes wheat flour, and therefore is not using starch produced by one of the four local producers. This route has allowed the company to reduce its raw material costs, and be competitive against another starch-based foams producer, National Starch.

3.3.5.2.2. FILMS

Table 9 demonstrates the range of applications to which starch based films may be applied to agriculture (mulch films), the composting sector (bags and sacks wrapping)), laminated paper, and as food containers. Such markets are reported to be developed in Italy, Germany and Scandinavian countries.[24]

In the UK, DEFRA and DTI have supported a number of research projects to develop starch-based films for industrial uses. These projects are at various stages of completion. Applications are envisaged in the single-use, disposables markets outlined in *Figure 9*.

Non-starch based materials are produced by Eastman which supplies general-purpose and blown-film grades of Eastar Bio (polyester) from a 15,000 tonne per year plant in Hartlepool. The plant was a PET polymerization unit that was converted to biodegradable polyester production. The product is used in lawn-and-garden bags, agricultural films, netting, and paper coatings.

3.3.5.2.3. MOULDED PRODUCTS

Compounded thermoplastic-starch is mouldable in a similar way to traditional mouldable plastics like ABS, PS and LDPE.[25]

Starch-based mouldable products were first developed to serve niche markets where biodegradability was required, such as fast food serviceware (for example, cups, cutlery, plates), nursery pots, plant labels, and some less obvious products as dog chews and clay pigeons.

Commercially, the current most important sector is in the production of thermoformed products, for example, trays for fresh produce and meat, as well as disposable plates, bowls and cups. In these products, starch composites are foamed and formed with special equipment in a process comparable to making waffles.

A pilot programme to test acceptability of biodegradable packaging is currently underway with two supermarket chains, Tesco and Sainsbury. Data provided by the latter suggest that its own consumption of thermoformed trays could correspond to 8,000 tonnes of starch/year, suggesting the overall UK market could amount to 40,000 tonnes/year if the price were competitive with petrochemical-based alternatives. The present major supplier of thermoformed trays is a German-based company, Apack AG, but the major American company in the field, Earthshell Corp., has announced its intention to establish a manufacturing plant in Germany. Potatopak, a UK manufacturer (with a current production capacity utilising 12 tonnes of starch /year) is also participating in the scheme. All producers are using potato starch. Apack is using Eastman co-polyesters and PLA to laminate its starch-based tray to provide moisture and grease resistance to protect the substrate from premature degradation. The laminate also adds rigidity and printability. PLA is an inherently poor oxygen barrier, but use of a proprietary post-extrusion step reportedly extends shelf life by 50% to 6–9 days. The package is being tested for poultry in the U.S. It is expected that this sector will grow significantly in the next years.

3.3.5.4.4. OTHERS

New sectors are emerging, driven by improved technical performances afforded by starch-based materials versus traditional materials. These include hygiene products (diaper back sheet), and starch biofillers (functionalised derivatized nano-particles) for rubber reinforcement, with an industrial example from Goodyear already in the market as grip improver for tyres. Thus, biodegradability is becoming less the focus for starch-based materials as technical and performance advantages emerge that challenge the performance characteristics of the established petrochemical-derived polymers. Medical applications such as implants[j], dressings[k] are being investigated that will provide high value but low volume applications of starch.

3.3.5.5. PLA BASED BIOPLASTICS

3.3.5.5.1. GENERAL

The commercial interest in PLA is exemplified by the data provided in *Table 11*, which show worldwide operations related to PLA production. The majority of companies concerned chose not to report actual plant capacities.

[j] A UK based company is developing starch-apatite medical implants that are to be in the market in 2004.

[k] Dressings are designed to absorb wound exudate and thus control the state of hydration of a wound. Most are alginate based, but Merck is selling Aquaform® which is a modified starch based product. All are claimed to have superior properties but these were not verified as few comparative studies have been produced

Company name	Location	Main product	Capacity[a] (tonnes/yr)	Reference
Apack AG[b]	Germany	PLA-	*c*)	[26]
Boeringer Ingelheim	Germany	Biodegradable polymers	*c*)	[27]
Fortum Oyj	Finland	Lactic acid, PLA	*c*)	[28]
Galactic[d]	Belgium	**Lactic acid**, PLA, lactic esters	15,000	[26]
Hycail[e]	Netherlands	**PLA**	400	[29]
Purac	Netherlands	Lactic acid, **PLA**	80,000	[30]
Phusis	France	PLA	*c*)	-
Birmingham	USA	Biodegradable polymers	*c*)	[31]
Dow Cargill	USA	Lactic acid, **PLA**	140,000	[32]
Mistsui	Japan	**PLA**	500	[27]
Shimadzu Corp	Japan	**PLA**	>100	[27]

Table 11. Commercial operations related to PLA production
a) of production of the material highlighted in bold; *b*) under license from Fortum Oyj Finland; *c*) no figures available; *d*)Belgian company owned by beet sugar producer Sucrier; *e*) joint venture between the Dairy Farmers of America and the Dutch State University Groeningen

Cargill Dow with its PLA production facility in Blair, Nebraska is the world's largest bioplastic manufacturer. Any future starch-based bioplastic market is likely to shaped by the availability of PLA. PLA may be used to manufacture any of the starch-based products indicated in *Table 9*. PLA has recently been shown to be superior to HDPE for orange juice packaging, as vitamin C degradation is almost reduced to nil.[33] PLA/natural fibre composites show 50% better strength compared to similar PP/flax fibre composites which are today used in many automotive panels, and these composites could be processed in a similar way to PP composites.[34] PLA has better heat sealing properties than traditional materials (PS and PET), higher tensile values than PS but lower than PET, and oxygen/carbon dioxide barrier properties similar to PET. A recent study cast doubt on the use of PLA based fibres in the carpet industry because of its very low resistance to abrasion, but a major carpet manufacturer has indicated that it is considering the introduction of PLA fibre-based carpets, to appeal to environmentally conscious buyers.

The present cost of PLA falls between that of PET and nylon, indicating that if its performance properties are correct and verifiable it may occupy a share of the present market of these two polymers. The main commercial uses of PET and nylon are in food packaging, bottles, and in the textile industry.

3.3.5.5.2. PLA FROM WHEAT

US produced PLA is manufactured from maize, and because, as discussed previously, wheat starch is cheaper and more readily available in Europe, European based PLA industries are likely to be based on wheat. A preliminary economic analysis of a wheat-based lactic production process has been performed recently[35] and costs of PLA, evaluated using kinetic models for the saccharification and fermentation steps, are estimated to be approximately \$1.20/kg. This figure is 15% lower than the figure obtained from maize (\$1.40–1.55/kg[36]) and significantly lower than the present market cost of lactic acid (\$1.90/kg @ 88 % lactic acid).[37] Several ideas have been proposed to further reduce the cost of wheat-derived PLA by, for example, the recovery of wheat proteins, the use of fermentation residue as a fodder, and the recovery and recycling of sodium hydroxide.[35] The cost of the latter is reported to be the major operating cost, and a number of technical modifications have been proposed to this part of the process in recent years.[38] If such technology is to be introduced in the UK the potential use of local sources of co-nutrients (such as peas or rapeseed meal as nitrogen sources) for the lactic acid-producing bacteria should also be considered, not only to maximize local agricultural inputs for the process but also to scale down production costs.

3.3.5.5.3. STARCH VERSUS PLA

PLA-based polymers are expected to sell into the same markets as starch-based polymers and therefore the question of competition between these two materials is raised. On the one hand, there are no commercial pure starch-based thermoplastic polymers per se. Presently the most important starch bioplastics (from a commercial point of view) are blends and grafts between starch and caprolactone, or starch and vinyl acetate , as Novamont's MaterBi grades or Biotec's Bioplast grade. On the other hand, pure PLA is known to be very brittle,[39] has very low elongation at break and poor adhesion. These shortcomings are addressed by blending. Indeed, blends of starch and PLA may provide the future for biodegradable polymer materials.

Starch does not have mechanical properties matching PLA, but being cheaper, it is expected that a range of starch-PLA composites materials will appear in the market,[40] and modified starch has been shown to have plasticising properties suggesting a potential compatibility between these two materials. These composites are likely to be the direct competitors of present day starch composites. The outcome of this competition will be governed by price and the range of technical characteristics of the products, which are presently not known.

3.3.5.6. MACROECONOMIC FRAMEWORK

In order to become competitive with traditional plastics, starch-based materials must still undergo considerable development to not only improve processing techniques, but also to develop new uses in consumer applications.

A political framework to facilitate this should include:

(a) public-private funding for basic and applied research;

(b) development of the CAP allowing the possibility to process potato starch in the UK to produce new biomaterials;

(c) supportive fiscal policies on starch based biomaterials, such as reduced VAT based on biodegradability credits;

(d) preferential public procurement;

(e) financial assistance to industries willing to adapt to the use of locally produced starch based raw-materials;

(f) public awareness campaigns;

(g) the introduction of an UK eco-label.

3.3.6. Detergents and cosmetics

Rather surprisingly, there is no consumption of starch-based surfactants by the UK detergent industry. Alkylpolyglucosides, non-ionic starch-based surfactants, initially received huge interest in the scientific and technical communities, but presented low performance[l] against other natural and synthetic products. It appears that very little market penetration of alkylpolyglucosides has occurred. Their consumption in Europe is also very low.[m]

---

[l] APGs are low foam surfactants, and used therefore as co-surfactants. When produced they co-generate very dark secondary products and therefore are subject to costly purifications.

[m] See Comite Europeen des agents de surface et de leurs intermediaries organiques (CESIO).

Citric acid derivatives are widely used as sequestering agents and account for 6–7% of the detergent market with 30% (by weight) being used in some formulations. Citric acid (see *Section 3.3.4.1*) is derived from starch at many plants world-wide but the UK demand (35,000 tonnes per year) for citric acid is met in the main by fermentation of molasses.

Non-cariogenic sugars and starch based excipients are also used in the manufacture of toothpaste, and the most important of these sugars, sorbitol, is imported as seen in *Section 3.3.4.1*

3.3.7. Drilling industry

Starches have been traditionally used as drilling aids. Drilling fluids may be water or oil based, the aqueous versions being cheaper (3–4 times) but having, currently, poorer performance than oil-based systems. The aqueous systems are derived from gums, cellulose polymers and starches. Modified potato starch is reported to be the best starch component of drilling aids. Current UK production is small (in the range of 5,000 tonnes) as the North Sea market is very small. Indeed, a portion of this product might be exported to rich petroleum- and gas-producing countries having no local starch production. If potato starch is to be produced in the UK, and because of the importance of petroleum companies to the UK economy, research focused on improving potato starch-based drilling fluids may provide an opportunity to export certain new starch derivatives.

3.3.8. Paint and ink industry

A number of uses of starch derivatives as rheological control agents have been published as international patents by a number of paint manufacturers. The possible use of starch has been investigated as components of paints by ICI Paints. However, results showed that traditional, petroleum based products have superior properties. Currently, it seems that starch use in the UK paint industry is nil.

Nevertheless, an American company claims to have developed starch-based repulpable inks and coatings.[41] These starch-based additives are reported to perform as traditional products, but reduce the cost of paper recycling by minimising polymer residues from the adhesives and coatings arising from the re-use of old magazines. If the basic principle is true, and as the UK paper industry is a major paper recycler in Europe, this may provide a new outlet for starch/paper additives producers.

3.3.9. Textile industry

Because of the delocalisation of the textile industry to low-labour cost countries, and the performance of petrochemical competitors, the textile market is contracting in terms of starch requirements. The UK textile requirement for starch is estimated to be around 2,000 tonnes per year. Potato starch products are the most important ones in this sector. Starch products are mainly used for sizing and finishing. Indeed, 55% of UK-consumed textile sizes are based on starch and 45% are synthetic products. This proportion varies with the price of starch products which fluctuates according to potato harvesting conditions. Emerging synthetic polymers better meet the demands of high speed weaving machines which are used today. These synthetic polymers like polyacrylates and polyvinyl alcohol are not, or only under certain conditions, biodegradable. However, all European potato starch manufacturers claim to have developed biodegradable modified starches with a better affinity to cotton and synthetic yarn fibres which result in high sizing efficiency.

3.3.10. Water treatment industry

In the UK, synthetic organic polyelectrolytes, such as polyacrylamide[n,o], are currently used by the water treatment industry as flocculant aids, as they exhibit synergistic characteristics with very cheap inorganic flocculants (aluminium or iron salts) used in bulk in coagulation/flocculation processes. Native starches and their derivatives also act as flocculant aids, as the physical mechanisms underlying this application are similar to the ones that have made possible the use of potato starch in the paper industry.[p] In most cases, synthetics are claimed to perform better than starches (and derivatives) being needed in lower doses. But, the main technical advantage of starch derivatives over synthetic polyelectrolytes is a better shear stability. However, the inherent biodegradability of starch and starch derivatives[q] results in shorter shelf-lives

[n] Another commercial use of the same polyacrylamides is in sprinkler irrigation. Polyacrylamides give typically high drag reduction (around 30%), reduction in energy requirement (around 25% at 100 ppm) and increase in area of coverage.(around 2 % at 20 ppm of concentration) . There is no information of potato starch use in this field.

[o] Polyacrylamides are the most used polyelectrolytes in water treatment, however several other polymers have been proposed for such use: e.g., polyacrylic acid, poly(styrene sulphonic acid), poly(diallyl dimethyl ammonium chloride).

[p] In the wet end operation.

[q] In drinking water treatments, water is chlorinated at some point of the process after flocculation, and therefore there is no real problem of BOD increase when starch is used despite opposite claims.

(1–1.5 years) than for synthetics (5–7 years) and thus need to be suitably controlled as their flocculates lose stability and strength over time.

In a number of European countries (France, the Netherlands and Germany[r]) the use of synthetics has been discouraged (mainly in drinking water treatment) because acrylamide, the monomer used to manufacture the synthetic polyacrylamide, has been associated with cancer risk.[s] As a result, a number of potato starch-based flocculant aids have emerged on the market. A Swedish potato starch company indicates in its annual report that this is one of its main area of sales. India and China are the other two countries where starch derivatives are also reported being used.

The UK synthetic polyelectrolytes market has been estimated to consume 13,000 tonnes of material per year, with an annualised growth rate of 2–3%, covering the following areas: sewage sludge 5,000 tonnes, drinking water 2,000 tonnes, and industrial waste water 6,000 tonnes.

Based on commonly accepted efficiencies, the volume of potato starch required as a flocculant aid would be 4–6 times the volume of synthetic organic polyelectrolytes that would be replaced, corresponding to the standard production of a small potato processing plant.

The possible introduction of potato starch derivatives in the water treatment industry in the UK should be assessed on the basis of a more detailed investigation on the health/environmental/economics factors underlying the uses of polyacrylamide versus potato starch in this sector.

3.3.11. Batteries and electronic devices

New polyelectrolytic starch-based solutions (comprising 45–65% starch) have now been developed and are presently in the market. In 2003, sales were reported to be approximately 1,000 tonnes. Despite their superior properties, this market is expected to be low in the UK because battery production is being delocalised to low-labour cost countries.

---

[r] These are all potato starch producers.

[s] World Health Organisation standard for drinking water suggests a maximum of 1 ppm for acrylamide, 5 ppm is reported to be associated with an excess lifetime risk of 10^{-5}. Usual dosage of polyacrylamide is 1–10 ppm depending on the turbidity of the water and the amount of aluminium sulfate.

3.3.12. Starch based cement additives/lightweight concrete

In the US, the Department of Agriculture has promoted a study on the possible uses of maize starch in the manufacture of lightweight concrete additives. Data indicate that these aggregates should be very cheap, but would have a lower compressive stress than existing diatomite/perlite-based lightweight aggregates produced in the UK. It may be technically possible to improve these composite materials by modifying the starch with chemical groups with affinity for cement. In the US, Hercules is currently selling starch derivatives as cement plasticisers; in the UK, di-phosphate urea complexes and carboxymethylcellulose are currently used. No technical data are available to compare technical properties. The European market comprises 40,000 tonnes of lightweight concrete additives overall. Research in these areas may provide outlets for wheat starch products with mass market potential in the UK.

4.0. UK STARCH INDUSTRY DEVELOPMENT AND OPPORTUNITIES

4.1. New processing plants

Due to their specificity, the question of the introduction of new processing plants is discussed in two sections, one concerned with the establishment of a new unit for potato starch production, and the other focusing on the re-configuration of maize processing plants for wheat starch production.

4.1.1. Direct processing of potatoes for starch production

It is well-established that (a) the UK has large resources of potatoes that could provide feedstock for a potato starch processing unit, and (b) there is a substantial UK internal market for potato starch and its derivatives. The physicochemical properties of potato starch and its derivatives are sufficiently different from those of wheat to preclude potato starch substitution with wheat starch. As well as this internal market it is worth noting that there is (c) a potential export market for potato starch since there are only a small number of potato starch producing countries outside the EU. This conclusion is supported by the fact that the total EU potato starch export market share is high (over 50% of total starch production was exported in 2000) contrasting with the EU domestic starch market share (16.5% in 2000).

It is worth analysing the macroeconomic framework, and the pre-feasibility of a hypothetical small to medium size potato starch processing unit in the UK.

4.1.1.1. EUROPEAN UNION ECONOMIC FRAMEWORK

In the EU, production of potato starch is regulated by a system of refunds associated with a quota system. Quotas for potato starch production were allocated on historico-socio-economic grounds, with the intention of supporting established starch industries and their associated farmer-suppliers. At the time that this system was adopted, there was no starch production in the UK, and therefore no quota was allocated. However, this historic criterion has not always been applied, as reported previously by the European Court of Auditors,[2] since Spain has been allocated a potato starch quota (of 1,943 tonnes) which has never been used.[t]

The fact that quota attribution is not proportional to the European Union capacity to produce potatoes implies that there is no equity of treatment of UK farmers compared with their European counterparts. The discrepancy is illustrated in *Figure 14* which plots actual starch quota allocation against hypothetical quotas if those quotas were allocated proportional to the potato production of individual states of the European Union.

[t] Enquiries during the course of this study indicated that the 4 plants existing in the Iberian peninsula operate only with maize, it being unclear whether Spanish potato starch refunds have been used by other countries.

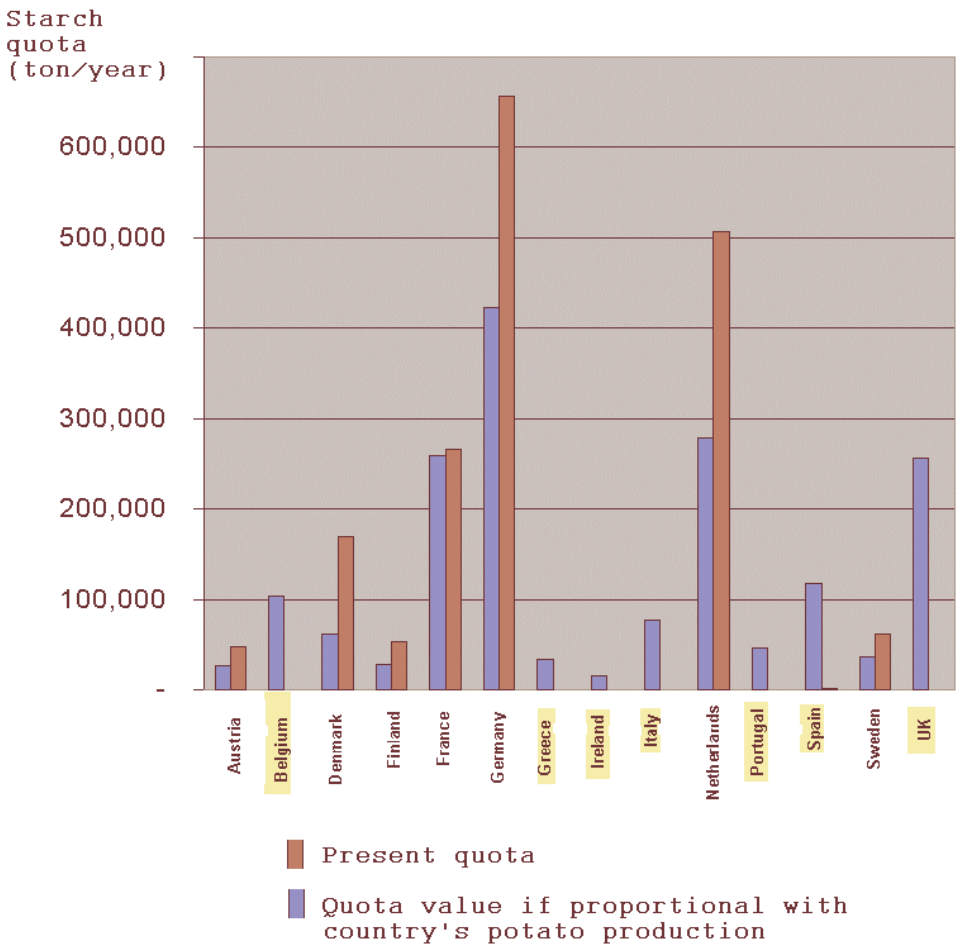

Figure 15. Potato quota and production in the UK. Source: British Potato Council, FAO, EU[42]

The quota system, and the associated refund policy is presently under review,[46] and the EU commission of Agriculture is to perform an analysis of the quota distribution in September 2004. The EU commission of agriculture[43,44] declared an interest in eliminating trade distortions, and expects, in the long term, to develop market-oriented agriculture in which market rules (and not cartel-like rules) would obviate any imbalance between supply and demand for any particular product, and so lead to the elimination of the quota system.

4.1.1.2. THE PROFITABILITY OF POTATO STARCH MANUFACTURING FOR EU FARMERS AND INDUSTRIES

The EU system is not only characterised by quota distribution, but also by the fact that potato farmers have a guaranteed minimum price (which corresponds to the maize price), and starch manufacturers are given support with the payment of a fixed premium.[45] The main arguments in favour of this support are: (a) to guarantee a minimum level of revenue to potato farmers, (b) to allow competition with cereals-based starch producers as (i) potatoes cannot be stored as cereals, and therefore production period is reduced (typically 7–8 months against 11 months for cereals), (ii) potato starch co-products have a reduced commercial value, and (iii) a high fraction of the production costs is related to the treatment of polluting effluents.

However, this system is not always applied in practice. An EU document reveals that in a German potato starch plant, a 4% tax is applied to all potato suppliers which are not partners of the starch plant while, in the Netherlands, payments to potato producers are deferred by a system of loan without interest.[u]

Indications of the high profitability of the starch production framework for EU farmers are provided by reports [2,46] of the willingness of some German farmers to pay an annual fee for starch potato delivery rights when such payments are absent from cereal or oilseed production costs. The average sum paid for these delivery rights in Germany has been over €300 per hectare (in 2001).[2] This represents three quarters of the sum of approximately €400 per hectare (€50 per tonne of starch at 8 tonnes of starch produced per hectare of potatoes planted and harvested) that growers received in the form of direct payments associated with planting one hectare of starch potatoes, rather than the area payments that they would receive from planting the same hectarage as cereals instead.[46]

Furthermore, it is worth noting that the Swedish company, Lyckeby Starkelsen, indicates in its latest annual report that, despite not knowing whether the potato quota system will be maintained in the medium term, and because potato starch production is profitable, it is planning to expand its starch processing activities and has bought potato processing plants in the Baltic states.[47]

4.1.1.3. NEW POTATO STARCH MANUFACTURING UNIT: CONCLUSIONS

Having established that the UK (internal) potato starch market could justify the establishment of more than one medium sized production plant, that excess potato starch (and modified potato starches) could also be exported, that existing UK potato production capacity could easily provide raw materials for these plants, and having

[u] That is, potato producers provide potatoes to the starch plant but are only paid after the starch is sold.

provided indications that in Europe potato starch production is very profitable, our two main recommendations are:

(1) As the predominant free market philosophy may lead to the total elimination of the quota system, the UK government should encourage the future establishment of a local potato starch processing and modification plant.

(2) In the mid term, if the EU quota system is to be retained, then the UK should aim to negotiate a potato starch quota proportional with its potato production capacity. In the event that a potato quota cannot be negotiated for the UK, then the possibility of starch production for non-food use and for export should be fully explored particularly in respect of the legal position, i.e., to avoid contravention of the quota system.

The *Appendix* provides supporting data of the margin that can be obtained by processing potatoes, suggesting that this could be feasible in the UK.

4.1.2. Conversion of maize-based processing plants to wheat-based units

The scope for a new entrant to the wheat starch processing sector by building a plant to serve the UK would be risky. This is particularly in view of the fact that the production of wheat-based starch is a large scale business that requires high capacity utilisation to break even. However, the conversion of maize-based processing plants to wheat-based plants is eminently feasible and indeed, is well underway in the UK as has been discussed in *Section 3.2.2*.

4.2. The bio-fuel industry

Ethanol, obtained as a fermentation product from starch may be used as a chemical solvent but also as a fuel additive or substitute.

As a fuel additive, typically 5–10% ethanol or its ether derivative, so-called ETBE (ethyl *tert*-butyl ether, comprising 47% ethanol and 53% isobutylene by mass), behave as anti-knock/octane boosters in spark ignition engines, and therefore can substitute other substances (e.g., lead, aromatic compounds, olefins, MTBE [methyl *tert*-butyl ether]).

Some anti-knock octane boosters (e.g., MTBE, MMT [methyl cyclopentadienyl manganese tricarbonyl]) are currently imported into the UK from outside the EU. In 2002, 960 tonnes were imported with costs per tonne ranging from £1,200–3,000. All these could be substituted with bio-ethanol derivatives. Indeed, technologies using ethanol produced from different agricultural sources (maize starch, sugar cane, wheat starch, sugar beet, cassava starch) are already in use in a number of countries.

As an important wheat producer, the French bio-ethanol experience is most relevant to this study. In France, the government is targeting the consumption of 5% of fuel from renewable energy by 2005. The French programme, based on experimental work on liquid bio-fuel in the early 1980s, was developed on a commercial basis when set-aside rules and tax incentives came into force in 1991 and has led to ethanol production from two feedstocks (1/3 sugar beet and 2/3 wheat). Alcohol production from sugar beet has been a long-standing activity in France, but technology has been developed to produce, on the industrial scale, wheat-derived alcohol and two industrial plants (using different technologies) have been built. ETBE, used presently on the large scale in France is reported to have less effect on global warming than MTBE (standard additive used in the UK) and contributes less to the depletion of natural resources and acidification of the atmosphere. With respect to air quality, exhaust gases are identical, except with regard to unburned hydrocarbon emissions (less with ETBE than MTBE) and aldehydes (less formaldehyde).

Research to improve yields of bio-ethanol, reduce energy and feedstock consumption, as well as to improve the value of the sub-products is underway. Due to improved technology and scale effects, in the 2004–2005 bio-ethanol production campaign, the production costs of alcohol are estimated to be reduced to within £0.10 (€0.15) per kilo of the current price (in France) of the methanol that it would replace in the manufacture of MTBE. This difference is purported to be compensated by the following advantages (a) lower contribution to the greenhouse effect, (b) retention of employment in rural areas, and (c) creation of jobs in the processing industry (1 job per 100,000 litres of ethanol), (d) reduction of country dependence on imported fuels, and (e) improvement of the national trade balance: France, like the UK, imports wheat gluten for bakery and cattle food which is the co-product in the ethanol process.

The energy paper published in the UK in February 2003 states this government's commitment to a low carbon economy. In June 2003, the EU directive on the promotion of the uses of biofuels for transport set indicative targets for the proportion of energy that should be sourced from fuels derived from renewable resources (2% road fuel by 2005, 5.75% by 2010).

Using data provided by ADEME and considering two possible scenarios of bio-fuel uses in the UK (5% and 10% substitution of present fuel consumption), an indication of the land area required for wheat production to ultimately derive ethanol is provided in *Table 12*.

Level of substitution[a] (%)	Estimated volumes of alcohol (1000 tonnes)	Estimated area of wheat[b] (1000 ha)
5[a]	270	253
5[c]	127	119
10[c]	254	238

Table 12. Land area requirements for bioethanol production
a) 23,000,000 tonnes of motor spirit reported to be consumed in 2002;[48]; *b*) considering that ETBE (with 47 % ethanol and 53 % isbutylene in mass) would be used as a bio-fuel; *c*) considering that solely ethanol would be used as octane booster

Two outstanding questions remain after reviewing the French study on bio-ethanol production:

(1) Is the production of bio-ethanol for fuel feasible in the UK context? It is necessary to establish that the calorific value of fuel derived from bio-ethanol from wheat is over and above the energy required to plant, harvest and process the wheat into fuel. The production of wheat for food and feed is very well-defined in the UK. However, its production for fuel will require different management, fertiliser and agrochemical inputs that will impact on the overall feasibility of production in the UK context. Thus, a full life cycle assessment and environmental impact is required on the pilot scale in a UK city to address the suitability of production for UK use.

(2) Current large scale production of bio-ethanol is carried out in Brazil, USA and France. All manufacturers produce material and supply the market with the benefit of governmental tax relief. It is reasonable to conclude that, in the first instance, tax relief would be a necessity in the UK. The Treasury has introduced a system of tax relief for bio-fuel use. A number of stakeholders have indicated that the level of relief is insufficient to stimulate a bio-fuel (bio-diesel) market in the UK. It is anticipated that a pilot study will provide independent data to underpin further discussions with the Treasury and inform the arguments of the stakeholders.

4.3. The bio-technology industry

The biotechnology industry could develop either in parallel with a bio-ethanol industry or entirely independently. This study has revealed that significant imports of fermentation-derived products enter the UK from China, Japan and other countries. These materials are derived from starches. Competing countries are supplying well-established (and growing) markets (e.g., L-lysine, ascorbic acid, β-lactams, statins). The industrial biotechnology sector in the UK appears to be fragmented and lagging behind European (e.g., Europabio) and US activities. The authors are encouraged by the DTI initiative to establish in the UK a so-called industrial biotechnology task force that will develop a road map for industrial biotechnology development in the UK over the short, medium and long terms.

The estimated new wheat area to provide starch for production of amino acid presently imported is presented in *Table 13*.

Import substitution (1000 tonnes of lysine/year)	Estimated volumes of wheat[d] (1000 tonnes)	Estimated area of wheat (1000 ha)
12.8*a*	27	10.3
0.105[b]	0.2	0.08
1.3[c]	2.8	1.04

Table 13. Estimated area requirements for the production of lysine presently imported
a) total UK import substitution; *b*) only UK extra EU import substitution; *c*) total EU lysine import substitution; *d*) assuming a theoretical yield of 0.70 (kg/kg glucose), taken from[49]

4.4. The materials' science industry

Biopolymers are to play a major role in the future. Production of wheat-based poly lactic acid looks to be a promising new outlet for wheat when corn based technology is suitably adapted and other legal and financial incentives are in place.

Modified starch based polymers can be produced as complementary to PLA polymers, and support for existing UK producers in the field must be provided mainly in the area of moulding products, where strong concurrency from Germany is expected.

A potential 15% market share for European market of bioplastics (as estimated by the EC Commission) expressed as a function of additional wheat area to be cultivated is provided in *Table 14.*

Market share[a] (%)	Estimated volumes of starch[b] (1000 tonnes)	Estimated area of wheat (1000 ha)
15	128	72
20	171	96

Table 14. Area requirements for wheat to bioplastic production
a) for a potential European market of 1,145,000 tonnes; *b*) assuming the polymer contains 75% starch

For the development of this sector we suggest two parallel strategies (aimed to develop synergies with others UK industrial sectors).

(a) to develop the pre-existing platform of investigation of biodegradable packaging/ waste management, involving starch based packaging industry, supermarket chains, and waste management institutions and aimed to the research and development of starch and PLA based polymers. Special attention must be given to the macroeconomic environment as outlined in *Section 3.3.5.4.*

(b) to develop a R&D platform between the pharmaceutical industry, starch/PLA producers and other interested sectors aimed to develop/improve and introduce to the market starch/starch derivatives (PLA, and others) based polymers as drug packagings, release carriers, plasma substitutes, medical implants. On the basis of the strong position of the UK pharmaceutical industry in the international market, any breakthrough provided by this research may provide an international market for starch derivatives.

5.0. REFERENCES

[1] H. Baere, Directorate General Agriculture, European Commission , rue de la Loi 130, B-1040 Bruxelles, Belgium.
[2] European Court of Auditors, Special Report 8/2001.
[3] British Potato Council, *Crop Wastage Survey*, 1998.
[4] T. Herman, *J. Biotechnology*, **2003**, *104*, 155.
[5] I. Kusumoto, *J.Nutri.,* **2001**, *131*, 2552.
[6] A. Budzinski, *Chemische* Rundsau, **2001**, *6*, 10.
[7] Anon., *Chem. Marketing Rep.*, **2002**, *8*, 2.
[8] E. A. Jonhson and W. A. Shroeder, *Advances in biochemical engineering/biotechnology*, Springler, Berlin, **1996**, *13*, 119.
[9] D. Wilke, *FEMS Microb. Rev.,* **1995**, *16*, 89.
[10] L. B. Scilling, *FEMS Microb.Rev.,* **1995**, *16*, 101.
[11] J. Lorcks, *Polymer Degradation and Stability*, **1998**, *59*.
[12] C. Bastioli, *Polymer Degradation and* Stability, **1998**, *59*, 263.
[13] H. Kab, *Kunststoffe*, **2002**, *92*, 34.
[14] G. Scott, and D. M. Wiles, *Biomacromolecules,* **2001**, *2*, 615.
[15] P. R. Gruber, D. Glassner, and E. Vink, *Polymer. Mater. Eng.*, **2002**, *86*, 337.
[16] T. U. Gerngross and S. C. Slater, *Scientific American*, **2000**, *August***,** 37.
[17] A. K. Mohanty, M. Misra, and L. T. Drzal, *Polymer. Mater. Sci. Eng.*, **2002**, *86*, 341.
[18] L. J. Chang, *J. Polym .Env.*, **2000**, *8*, 33,37
[19] H. Tanaka, I. Utsue, H. Tanaka and Y. Okumura, *U.S. Patent*, **1998**, 5,714,601.
[20] H. Tanaka, *US Patent*, **2003**, 6,617,449.
[21] G. Davis, *Material Characterisation*, **2003**, **51**, 147.
[22] G. M. Glen, and J Hsu, *Industrial Crops and Products*, **1997**, *7*, 37.
[23] A. M. Thayer, *Chem.Eng. News*, **1990**, *June 25*, 7.
[24] C. Bastioli, *Industrial uses of wheat*, **2000**, Cambridge, ACTIN.
[25] Q. Fang, I. Milford and A. Hanna, *Industrial Crops and Products*, 2001, *13*, 219.
[26] A. Sodegard and M. Stolt, *Prog. Polym .Sci.,* **2002**, *27*, 1123.
[27] J.-C. Bogaert, and P. Coszach, *Macromol. Symp*., **2000**, **153**, 287.
[28] G. M. Bolhman and Y. Yoshida, *CEH Marketing Research Report*, **2000**, SRI International.
[29] M. Ohrlander, and R. Palmgren, *J. Polym. Sci., Part A: Polym. Chem.,* **1999**, *37*, 1659.
[30] http:// www.purac.nl
[31] http://birminghampolymers.com
[32] http://www.cdpoly.com
[33] V. K. Haugaard, B. Danielsen and G. Bertelsen, *Eur. Food Res. Technol.,* **2003**, *216*, 233.
[34] K. Oksman and M. Shrifvars, *Composites Sciences and Technology*, **2003**, *63*, 1317.
[35] C. Akenberg, *Modelling and optimisation of integrated biotechnical processes*, PhD thesis, **2000**, Lund University, Sweden.
[36] J. Millis, *Proceedings of the symposium on Bioremediation and Bioprocessing, 205th National Meeting. American Chemical Society, Denver, CO,***2003**, 297.
[37] Anon., *Chem. Mark. Rep.*, **2003,** 12.

[38] H. Li, R. Mustacchi and S. A. Jackman, *Tetrahedron*, **2004**, *60*, 655.
[39] O. Martin and L. Averous, *Polymer*, **2001**, *42*, 6209.
[40] L. J. Chang, *Journal of Polymers and the Environment*, **2000**, *8*, 33.
[41] S. Bloembergen; I. J. McLennan and R. Narayan, *US Patent*, 5,872,199.
[42] Council Regulation (EC) No 962/2002 OF 27 May 2002
[43] K. Fishler, *On the objectives of CAP, Official Journal of the European Union,* 2003, C192E/221.
[44] http://europa.eu.int/commm/agriculture/publi/fact/cereals/index en.htm.
[45] European Union, Council Reg. 1722/93.
[46] LMC, *Evaluation of the Community Policy for Starch and Starch Products*, **2002**.
[47] Lyckeby Starkelsen, *Annual Report*, **2003**.
[48] Energy Production and consumption in the UK, at www.dti.gov.uk
[49] R. Landucci, B. Goodman and C. Wyman, *Appl. Biochem. Biotechnol.*, **1994**, *45-46*, 677.

Appendix

Data provided to analyse the economics of potato and wheat/maize starch production were provided by the International Starch Institute Denmark/ and ILO-Netherlands, Equipment costing is accurate to ±25 %. In the last ten years, main developments have been: a) reduction in milling energy (in wheat/corn starch processing); b) improved technology to separate protein fractions in wheat starch production; and c) improvement in the treatment of residual water (in the case of potato starch production).

Potato starch economics

Mass balance

1.0 tonne of potato (@ 18 % starch content)	0.212 tonnes starch @ 20 % moisture [a)] 0.140 tonnes of pulp @ 86 % moisture [a)]

a) Processing losses reduce yields by up to 2%

	tonnes	Price (£/ton) (ex-factory)	Value (£/t)
-Output			303
-starch	1	300	300
-pulp	0.66	4.55	3
-Input			265
-Potato	4.72	37 a)	175
-Processing costs b)			47
-Annual capital cost c)			43
-Output - Input			38

a) delivered at the factory

b) labour, energy, and maintenance @ £ 10/ tonne of potato (ISC estimates)

c) plant capacity of 35 000 tonnes p.a. starch/ 165 200 tones p.a. potatoes

capital cost £12 million (ISC estimates) charged at 12.5% over 8 years

Wheat starch economics

Mass balance

"1.000 tonne of wheat	0.089 tonnes gluten @ 8 % moisture [a)] 0.469 tonnes of A-starch @ 12 % moisture 0.093 tonnes of B-starch @ 8 % moisture 0.240 tonnes dry feed @ 12 % moisture 0.333 tonnes of bran [a)]

a) Processing losses reduce yields by up to 2%

	tonnes	Price (£/ton) (ex-factory)	Value (£/t)
-Output			397
-Wheat A starch	1.0	210	210
-Wheat B starch	0.198	90	18
-Dry feed	0.512	30	15.4
-Gluten	0.192	800	153.6
-Input			284
-Wheat	2.132	95 d)	202.5
-Processing costs e)			16.5
-Annual capital cost f)			65
-Output – Input			113

d) delivered at the factory

e) labour, energy, and maintenance @ £ 12.5/ tonne of wheat (ISC estimates)

f) plant capacity of 46 000 tonnes p.a. starch/ 100 000 tonnes p.a. wheat
capital cost £ 24 m (ISC estimates) charged @ 12.5 % over 8 years

We note that the starch business is characterized by high fixed costs and high raw materials costs relative to total cost, and consequently the higher the capacity utilization rates, the higher the profitability of the manufacturing plant, assuming that prices remain at the same level. Low capacity utilization rates may result in plants making a loss or just breaking even.

The wheat milling industry faces shrinking demand and industry overcapacity. In the US, demand has declined in the last two years, two of the identified factors reducing consumption are the Atkins diet and extended shelf-life breads. These factors suggest that wheat price would undergo reduction in the near future.

Maize starch economics

Mass balance

"1.000 tonne of maize	0.625 tonnes of A-starch @ 12 % moisture 0.195 tonnes of maize feed 0.195 tonnes of gluten meal 0.036 tonnes maize germ 0.024 tonnes of maize oil [a)]

a) Processing losses reduce yields by up to 2%

	tonnes	Price (£/ton) (ex-factory)	Value (£/t)
-Output			325
-maize starch	1.0	270	270
-maize feed	0.312	70	22
-maize gluten	0.070	200	14
-Germ	0.050	80	4
-maize oil	0.038	400	15
-Input			298
-maize	2.132	100	213
-Processing costs b)			20
-Annual capital cost c)			65
-Output – Input			27

g) delivered at the factory

h) labour, energy, and maintenance @ £12.5/ tonne of wheat (ISC estimates)

i) plant capacity of 46,000 tonnes p.a. starch

capital cost £24 million (ISC estimates) charged @ 12.5% over 8 years