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Caribbean Technology Policy Studies Project-II

THE THREAT AND THE PROMISE:

(An Assessment of the Impact of Technological Developments in the High Fructose Corn Syrup and Sucro-Chemicals Industries)

by

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Preface

This study of the impact of technological developments in the high fructose corn syrup and sucro-chemicals industries has been conducted as part of the second phase of the Caribbean Technology Policy Studies Project - a comprehensive joint project of the University of Guyana, University of the West Indies, and the International Development Research Centre (Ottawa). The description given here is to be taken as more than simply formal, for the research work underlining this study has been at all stages executed within the stated framework of the project. As a consequence the full significance of what is being attempted here can only be appreciated in the overall context of the principal foci of the project, namely an examination of the issues of indigeneous technological capability; search evaluation and bargaining; science and technology policy planning; and size, scale and technological transformation of the Caribbean. Within these overarching foci, the study is located in the specific area of the technological impact assessment studies undertaken by the project in the area of science and technology policy planning. In this area of the project's concerns the objective is to evaluate from the perspective of the concerns of the Caribbean region, certain fundamental technological transformations which have been occurring on a world scale with a view towards developing a technological planning capability to cope with these developments. The choice of topics within this subset has not been random, great care and attention were directed towards the topics chosen for study in this area of the project and the method of approach.

Having said all this it is important that the reader immediately understands that this is therefore not a study of the world's sugar industry in general (or more accurately sweetener industry), or that of the Caribbean in particular. The study treats with the sugar (sweetener) industry from two angles, namely the development of the high fructose corn syrup industry (HFCS), known in Europe as the isoglucose industry, on the basis of recent technological innovations and the threat which this poses to the world's traditional sweetener industry in general and the Caribbean's in particular, and the opportunities being created by recent technological advances in the field of sucro-chemicals. It is from this conceptual approach that the title of the study has been derived, namely 'the threat and the promose'. It should be appreciated even at this early stage that this is not just the simple aggregation of two different studies of the same industry or the study of two entirely different industries. The interface between technological developments and their applications in the HFCS and sucro-chemical industry is a matter of central concern to us. In fact, because the same transnationals (TNCs) are frequently involved in traditional sugar, other sweeteners, HFCS <u>and</u> sucro-chemicals it would suggest that any attempt to isolate the two areas of the study, or treat them merely additively, would be very unwise. Indeed it was recognition of this interface which propelled the study from its early stages of conceptualisation of being concerned with sucro-chemical technological development alone, into the form it has taken here.

The leading edge in the development and application of new technology in the case of the HFCS industry is the United States of America and to a lesser extent Japan, the European Community, Canada, and certain territories in South-East Asia and Latin America. The study will naturally focus on these territories, but our predominant concern will be with the USA where eleven firms and some seventeen plants constitute the overwhelming bulk of the world's resources currently committed to HFCS production. In the case of the sucro-chemicals, the leading edge of technological innovations is located in a United Kingdom based TNC, Tate and Lyle Ltd. Here considerable focus will naturally fall on this enterprise.

In pursuit of this study a number of sub-themes of some general significance are briefly touched upon from time to time, the principal ones being:

innovation and response in a mature industry;

the industrialization of a traditional tropical staple;

the uniqueness of the circumstances created by competition between developed and underdeveloped regions in producing a widely consumed commodity;

renewable versus finite resources in industrial development;

land use for food versus manufacturing output;

the role of government policy in the development of technology and its application; and so on.

Concern over possible diversion from the main thrust of the study has in some instances limited our intervention on these issues to a few hints. In conclusion it should be noted that relatively little accessible work has been done on the HFCS industry, and far less on the sucro-chemicals industry. Thus the study has as one of its major aims, contributing to the enlargement of the informational pool and increasing its accessibility and availability to the Caribbean. Without such an enlargement, systematic monitoring which as we shall argue is an extremely critical science and technology planning function, will not be possible. Part I of the study deals with HFCS (the threat) and Part II sucro-chemicals (the promise).

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Part I: THE THREAT

Chapter 1: SALIENT CHARACTERISTICS OF THE WORLD SWEETENER INDUSTRY

Section (i): Sugar in the Caribbean

The labels 'plantation economy', 'sugar exporting economy', 'King Sugar' etc.,which have been used frequently to describe the English-speaking Caribbean economies, are ample testimony to the importance which sugar has played in the historical development of the region. The sugar industry is a direct product of colonial conquest and settlement of the region, with cane sugar cultivation and processing always being export oriented and confined within the region to the production of 'raw sugar' which is the sucrose stage of approximately 95% purity. The cultivation of the sugar-cane plant has been almost single-mindedly focussed on the production of sucrose, with the limited utilization of by-products, e.g. bagasse as fuel, molasses for direct export or as animal feed, and the production of alcohols, mainly rum. Whatever resources have been allocated to local research and development have been concentrated in the areas of sugar cane varieties, its cultivation practices, equipment repair and maintenance of the sugar processing factories, and construction, earth moving and other problems dictated by the specific topography of the areas where sugar is produced. As a result, sugar has been very instrumental in the creation of a particular dynamic of material production which characterizes the region. That is generally we produce what we do not consume, and consume what we do not effectively produce, thereby denying a real, that is physical resource imperative, or social, that is demand dictated imperative, for the development of an indigenous technological capability.

After centuries of dominating Caribbean economic and social life, the development of the region's sugar industry peaked in the 1960's. By then, social and political transformations in the region, in particular the nationalist movement towards independence, the rise of trade unionism and increased land pressures leading to a greater assertiveness of the peasantry in demanding land and other resources, had created new priorities in the focus of development. These newer priorities called for a greater role of the state in development, and an increased emphasis on import-substituting activities behind domestic protective barriers. In turn this called for the manufacturing oriented TNCs to play major roles in the region's economy. Out of these complex processes there has resulted a general decline in the importance of sugar in the region's economy.

While just over two decades ago, in the early 1960's the region was producing approximately 1.2 million tonnes of sugar, with exports ranging from 80% to 90% of this total output, currently the region is producing approximately 0.8 million tonnes of sugar, that is about two-thirds of the 1960 output and exporting about 80% of this amount. In all the major territories production has fallen. In Barbados in 1981 output was approximately 95,000 tonnes of sugar compared with output levels of 160,000 tonnes reached in the early 1960's. This was the lowest output level attained since 1948. For 1982 the prognosis is also not good and as the Prime Minister remarked in his statement to Parliament on July 13, 1982: "I have to report to the House and Nation that 1982 has been as catastrophic a year for the sugar industry as was 1981. In 1981 the problems were those of a late start of the crop and unreasonable weather .... in 1982 the problems appear to be those of morale in the widest sense." In Guyana, output in 1981 was just over 300,000 tonnes compared with over 380,000 tonnes attained in the 1960's. In Trinidad-Tobago

1981 output was 93,000 tonnes as compared with levels of output of over 230,000 tonnes of sugar produced in the 1960's. This output level was also the lowest since the end of World War II. In Jamaica, 1981 output was 208,000 metric tonnes as compared with output levels of over 480,000 tonnes in the 1960's.

The decline in sugar production reflects the overall decline in agricultural output and productivity in the region. Thus comparative data on value added in the agricultural sector and per capita food production for the larger territories of the region as shown in Tables 1 and 2 indicate the extent of the decline over the past decade.

As the data show in Guyana for six of the ten years the index of per capita food production was less than 100 (base period production 1969-71); in Jamaica this was so for eight of the ten years; and in Trinidad-Tobago this was the case for every year during the past decade. Similarly, the value added data show substantial declines in the contribution of the agricultural sector to GDP, most notably in Barbados and to a lesser extent Trinidad-Tobago. In the latter case oil has tended to dominate the economy and the agricultural sector's contribution to GDP in the decade 1961-70, that is even before the oil boom, was just over five per cent.

The years following the tremendous boom in world sugar prices of 1973-74, have witnessed crucial developments in the region's sugar industry. The collapse of the unsustainable sugar prices of the 1973-74 period has merged with the ending of the protected marketing arrangements of the Commonwealth Sugar Agreement (CSA) after a quarter of a century, and the establishment of the far less favourable Lome Convention's sugar protocol of the EEC/ACP countries. Unlike the CSA, the Lome sugar convention is not based on a cost plus mechanism.

Table 1:
Indices of Per Capita Food Production, 1971-1980 (1969-71 = 100)

Country	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Guyana	102	90	89	100	100	94	99	104	92	88
Jamaica	102	100	98	96	93	92	89	92	90	90
Trinidad-Tobago	91	97	88	90	95	96	95	90	87	79

Source: As quoted in the 1980-81 Annual Report of the Inter-American Development Bank, p 21.

Table 2
Percentage Contribution of Agricultural Sector to GDP, by country, 1960-80

Country	1961-1970	1971-75	1976	1977	1978	1979	1980
Barbados	22.0	11.2	10.9	10.8	10.5	10.8	10.8
Guyana	22.2	18.5	16.2	16.4	18.4	17.7	18.6
Jamaica	9.8	7.6	7.9	8.6	9.5	9.0	8.6
Trinidad-Tobago	5.4	4.4	3.6	3.4	3.1	3.4	2.4

Source: 1980-81 Annual Report of the Inter-American Development Bank, p 16.

However, it is strongly linked to the internal subsidization of EEC beet sugar production, so much so that as we shall discuss more fully later since the signing of the Protocol the EEC has emerged as not only a major consumer and importer of sugar, but a major producer and exporter as well. The difficulties of the Lome protocol are well summed up in this statement of the Marketing Director of the Guyana Sugar Corporation:

> First of all, we have a quota in the EEC instead of the old CSA quota. Now I am not underestimating the vital importance of the EEC quota to us in Guyana. Our quota of 167,000 tons represents a guaranteed market for over half our export sugar, and the price currently is much above the world price. But somehow the sanctity of this quota has to be fought for day in, day out, in a way we never had to fight for the CSA quota. Sometimes one feels like a man running backwards and forwards along an endangered dam, patching and patching, as French beet farmers, bureaucrats in Brussels, and unsympathetic European pressure groups of all sorts, who do not know or hardly care about our circumstances, try to punch holes in the dam and let the whole structure wash away. The slightest shortfall can lead to immediate suspension of quota. Prices are imposed, not negotiated. You have the feeling that you are fighting a war that never ends, even though you thought the peace was made and signed and sealed in the Lome Sugar Protocol./1

In addition to the above considerations, two other points are of great importance to the present state of the region's sugar industry. One is the expiry of the US Sugar Act and the recent re-imposition of protection for US domestic sugar producers. This has resulted in the removal of the second and secondary pillar of protected marketing of the region's sugar. The other factor has been the tremendous boom in oil prices and the associated global inflation of prices.

Because of the above circumstances the region's sugar industry can truly be termed as being at a tremendously crucial stage. Despite the tendency for output to decline a significant part of the region's resources is still involved in sugar. In Barbados and Guyana, sugar earns about one-third of these countries foreign exchange. In Guyana, sugar is the largest single employer of wage labour. A point which is of great significance, however, is that the decline in the region's sugar output has been due more to declines in output per man-hour worked, yields of sugar cane per hectare, and the conversion efficiency of the factories (from sugar-cane to raw sugar), than the curtailment of acreages, and a reduction in total factory capacity. Thus for example in Guyana the rated capacity of the sugar industry is of the order of 500,000 tonnes per annum, compared to current output of 300,000 tonnes per annum. In other words the industry is only operating at about three-fifths of the level it can, with the present resources devoted to sugar. The declines in sugar output therefore understate the true loss in importance of sugar to the Caribbean region.

Much of the difficulties facing the region's sugar industry stem from uncertainty over the future directions of public policy. In all the territories the state has assumed a larger rôle in the industry's production, processing and marketing of sugar In the cases of Guyana and Trinidad-Tobago through 'nationalization' the governments 'own and control' the bulk of the resources of this sector. From all indication, however, the governments of the region are uncertain as to whether to pursue the expansion of sugar production or not. The strongest argument in favour of increased output is of course the existence of significant resources already committed to this industry and the momentum and pressures this naturally produce to ensure further growth and expansion. At the same time, however, the uncertainty of the marketing situation along with the social and political legacies of the industry in the region, combine to discourage any real vigour in the pursuit of this expansion. The result has been a benign neglect and a tendency to deal with the industry as an ailing part of the various national economies of the region. This has been encouraged by developments in the tourist industry (Barbados and Jamaica), bauxite-alumina (Guyana and Jamaica), oil (Trinidad-Tobago) and the growth of an import-substituting manufacturing sector in all the territories of the region.

Some recognition of the quandary the governemnts are reflected in the plethora of commissions, tribunals, committees of inquiry, etc. which have been established to examine the industry or certain aspects of it, and to make recommendations. Although not forcefully raised at any stage, one question which has emerged, is whether or not the single-minded use of the industry's resources to produce sucrose for consumption overseas is the best use of such a vast amount of the region's resources. This and other similar questions are to the forefront of our inquiry and in this sense, if no other, the study hopes to break new ground in the regional assessment of its resources devoted to sugar production.

Section (ii): Technology and End Use: The Concept of Sweetener

The traditional view of sugar, and the one which dominates the popular consciousness of the Caribbean is that it is an agent used to sweeten foods, beverages, etc. But sugar has other properties beside its sweetness which if not appreciated by the average household are clearly recognizable to that large section of its end users which make up the industrial market for sugar. Thus to take one example, sugar is not only sweet but it is also a food in itself, and as a food it is non-toxic although its consumption has been linked to dental caries, obesity, etc. The importance of these other characteristics of sugar are drawn out when sugar is placed in the wider context of its end uses. It is from this context that the concept of 'sweetener' is derived and it is in this context therefore that HFCS has also to be evaluated. But before we turn to examine this let us first take note of the major categories of sweetners which are produced.

There are two major categories of sweeteners, namely natural-caloric sweeteners and synthetic sweeteners. The former can be sub-divided into two further categories: the carbohydrate sweeteners which are most commonly used and are all calorie rich and in which sucrose dominates, and other exotic natural products with sweetening properties. The schema below indicates these categories with a few pertinent remarks where appropriate.

(A) NATURAL CALORIC SWEETENERS

Carbohydrate

1. Sucrose (mainly cane and sugar beet). As far as white sugar is concerned these two are indistinguishable but only cane sugar can be processed as brown sugar, domestic syrup or treacle. Treacle is a by-product of the industry with about 50% sugar and is used to prepare alcohol, citric acid, yeast, animaly feeds, etc.

2. Lactose (a disaccharide containing galactose and glucose obtained from cheese whey).

3. Polyhdric Alcohols (reaction of hydrogen on sugars and includes sorbitol prepared from dextrose, maltitol prepared from maltose, xylitol prepared from wood waste.) These are used mainly in soft ice-creams and are thought of as producing less tooth decay. Xylitol is suspected of being carcinogenic.

Other Exotic

1. Stevioside (extracted from the leaves of Steviare Baudiana).

2. Monallin (extracted from the serendipity berry).

3. Thaumatin (extracted from a West African berry).

4. Starch Hydrolysates
Glucose syrups derived from starch which contain dextrose (D-glucose) and other higher saccharides.

5. Fructose (a white crystalline reducing sugar which occurs naturally in fruit and flavours). Because it has a different metabolism to sucrose it has been accepted as a diabetic sugar.

6. HFCS or Isoglucose (to be studied in greater detail).

4. Glycoprotein (extracted from the red berry of West Africa).

5. Licorice

(B) SYNTHETIC SWEETENERS

1. Saccharin (isolated in 1379 and under suspicion of being carcinogenic).
2. Cyclamate (30-80 times sweeter than sucrose).
3. Aspartame (table sweetener under suspicion of being carcinogenic).
4. TGS (a chemical modification of sucrose, to be studied in detail later).

The heavy industrial uses of sugar has drawn greater and greater attention to the various properties or characteristics of available sweeteners. From discussions with persons in the industry it seems clear that whatever propaganda or advertisements may be put out on the properties of any particular sweetener, that sucrose is still the standard from which all other sweeteners are measured. The principal qualities of sucrose sweeteners which emerge are the following:

1. Good taste
2. Good bulking agent
3. Good dilutent and carrier
4. High and ready water solubility
5. Good preserving agent
6. Colourless
7. Chemically and microbiologically pure
8. Non-toxic
9. Nutritious and energy giving
10. Good digestibility
11. Rapid and total fermentability
12. Good storage ability
13. Good flavour
14. Its crystalline structure which makes it suitable for home uses.

There are disadvantages in sucrose which we shall examine later, but these refer primarily to its suitability as a chemical feedstock and not as a food. All competitive sweeteners therefore, have to measure up to the standards set by sucrose or they are unlikely to penetrate the sweetener market in a significant way. Thus for example, many of the high intensity sweeteners (e.g. saccharin) favoured because of their low calories, (apart from possible carcinogenic effects) have a taste which discourages their widespread use.

The product which we are studying here has an array of characteristics or properties which makes it a formidable competitor to sucrose. The principal properties of HFCS or isoglucose which have been identified are:

1. High sweetness
2. High fermentability
3. High humectancy
4. A water white colour which is readily blendable with other foods
5. A clean non-masking taste
6. A favourable viscosity when compared with other sugars and syrups as shown in Table 3 below.
7. Its osmotic pressure makes it a good conservator of food because there is a lower development of bacteria, yeast and fungi without special additives.
8. Increases moisture content of foods and lowers the freezing point which is important in some industries, e.g. ice-cream.
9. Its sweetness has a synergetic effect on the total sweetness of food so that a 50:50 solution of HFCS and sucrose has a higher sweetness than the addition of both products.
10. It enhances the flavour of food, particularly fruit.
11. It is non-toxic, readily digestible and nutritious.

Table 3

Viscosity of HFCS and Other Sweeteners

Product	Centipoises
HFCS (71% solids, 42% HFCS)	150 cP
Saccharose (71 Brix)	360 cP
Saccharose (66 Brix)	120 cP
Dextrose	130 cP
Invert Sugar (70%)	130-150 cP
Glucose Syrup (64 DE)	500 cP

Note: Viscosity measures the property of a fluid that resists the force tending to cause it to flow.

Source: R. Crott, 1981, p 25.

There are three major limitations of HFCS which inhibit both its industrial and household uses, and which because they are there pose a technological challenge which is presently being vigorously pursued. The first of these is that HFCS is a liquid sweetener. As Table 3 indicates it is comprised of 71% solids and 29% water. Its liquid state limits the uses to which it can be put when compared to crystalline sucrose. It also adds to transportation costs. While its liquid state generally inhibits its applications, this is not to deny that in certain manufacturing areas its liquid state may well constitute an advantage, or be immaterial to the producer. Thus in the dairying and soft drinks manufacturing sector its liquid state facilitates the use of automated liquid systems in factories. This factor as we shall see plays an important role in determining the character of the market penetration achieved by HFCS.

The second limitation is that HFCS has to be stored at 27 ^{o}-36^{o}c in order to prevent coloration and crystallization. This adds to the cost of its handling, particularly when taking into account the fact that it is a liquid. Again, like the previous limitation this does not mean that this property does not favour its use in certain industrial applications. Thus the fact that it is subject to colour changes when heated beyond certain temperatures helps in baked products where colour changes enhance the appearance and the appeal of the product.

The third limitation of HFCS is that it is not easily produced in a crystalline form. A crystalline form has been produced, but this is so high cost as not to be presently commercially viable, so that resources already committed to the industry and those planned for the next five years or so are premised on the production and use of liquid HFCS.

Before leaving this topic it would be useful to make a couple of observations on the low-calorie-high intensity sweeteners. First the stimulus for development of these sweeteners derives principally from concern about excessive calorie and particularly carbohydrate intake leading to obesity. Second, the major limitations of existing products are that they have tastes which are not readily acceptable as a substitute for sucrose; they do not interact well with other foods; they are possibly carcinogenic; and they are high cost to produce. As far as cost is concerned the industry's rule-of-thumb is that a high intensity sweetener has to be at least 50 times as sweet as sucrose to break even. Table 4 overleaf gives a broad indication of sweetness factors, calorie value/sweetness ratios, sweetness quality and relative cost per unit of sweetness.

TABLE 4

SELECTED COMPARISONS OF HIGH INTENSITY SWEETENERS

		Sweetness Factor	Calorie Value/ Sweetness	Sweetness Quality	Relative Cost per unit of Sweetness
	(Sucrose	1	4	Very good	300
	(HFCS	1+	4	Very good	280
	(Glucose	0.7	5.7	Good	300
A	(Fructose	1.2	3.3	Fruity	1000
	(Inverted Sugar	1	4	Very good	300
	(Sorbitol	0.5	8	Bland	12000
	(Xylitol	1.0	4	Bland	4200
	(Saccharin	300	0	Sweet/metallic/bitter	10
	(Cyclamate	30-120	0	Clean, sweet	70
B	(Aspartame	180	0	Sweet/slightly lingering	420
	(Acesulpham K	150	0	Sweet/chemical/bitter	-
	(Talin	3000	0	Sweet,lingering	350
	(TGS	600+	0	Like sucrose	-

Source: W. M. Nicol (1980) and R. Crott (1982).

Section (iii): The Global Sweetener Market

In recent years the picture of the global sweetener market has shown a broad pattern of declining per capita consumption of sweeteners in the developed countries and an increasing per capita consumption in the under-developed countries. The increase of consumption in the underdeveloped countries has been accompanied by strong efforts at self-sufficiency, so that their increased consumption is not fully reflected in increased world trade. The overall growth of world production/consumption of sweeteners has been about 2-2½% per annum since 1975, with a decrease over the period 1980-81 due to the partial recovery of prices in these years and a current surplus (mid-1982) leading to a collapse in prices. The general industry rule-of-thumb is that when per capita consumption is below 15 kg per annum the household consumer market for sugar dominates consumption and when it is above 50 kg per annum the industrial food processing sectors predominate. Between 15 kg and 50 kg per capita consumption of the balance progressively shifts in favour of the industrial market as consumption increases. Table 5 overleaf gives the global picture of the per capita consumption of sugar by continent. There it can be seen that 50 countries have a per capita consumption of less than 15 kg per annum, while only 14 have a per capita consumption in excess of 50 kg per annum. The bulk of the countries (87) fall within the range of 15 kg-50 kg per annum. Most of the Caribbean territories fall within this group, although quite high on the scale. Thus in Trinidad-Tobago and Guyana per capita consumption is currently of the order of 44-46 kg of domestic sugar alone! If sugar imported in foodstuffs is added the figure may well exceed 50 kg, thereby forming a major category of exception to this general rule. The reason for this is of course the high domestic availability of sugar combined with local sales at

TABLE 5

PER CAPITA SUGAR CONSUMPTION (Number of Countries by Continent)

	below 15kg	15kg-50kg	over 50kg
Europe	1	19	2
America	1	28	7
Asia & Oceania	19	19	4
Africa	29	21	1

Source: W. Nicol (1980).

controlled prices which have been introduced as a device aimed at reducing the cost-of-living burden of sugar consumption on the average household. In other words, domestically consumed sugar is subsidized and this subsidization encourages its relative 'over-consumption' in the region.

The world supply of centrifugal sugar averaged about 89 million tonnes for the years 1980-81, and while consumption averaged about the same, demand exceeded supply in 1980 and vice versa for 1981. The data in Table 6 indicate the demand/supply levels by regions. While the role of the traditional suppliers and demanders can clearly be seen as well as the regional balances between output and consumption which gives rise to trade in sugar, the emergence of W. Europe as a major sugar producing region with a large excess supply is probably the single most important characteristic of these data. In both 1980 and 1981 output of sugar exceeded demand in W. Europe thereby turning that region into a major sugar exporting region, even as it remains a critical element of the world's import market for sugar. The traditional imbalance between domestic output and demand while being reduced remains substantial in North America. For the years 1980-81 output averaged about one-half of consumption. This means that North America continues to be an important sugar importing region. The same is true for E. Europe where despite increases in output supply is about 70 per cent of consumption. The regions of Africa, Asia and Oceania are broadly in balance with the exception of Australia which remains a major sugar exporting country. The output levels for sugar in 1980-1981 indicated in Table 6 compare with a world output of HFCS of approximately 2.8 million tonnes in 1980 and 3.9 million tonnes in 1981. Of this amount the USA produced 2.0 million tonnes and 2.4 million tonnes in respective years.

Table 6

World Supply and Demand of Centrifugal Sugar, Raw Value (million tonnes) 1981

	Supply		Demand	
	1980	1981	1980	1981
Total Africa	5.96	6.42	6.71	6.90
Cuba	6.81	7.93	-	-
Total Central America	12.70	13.79	5.03	5.08
USA	5.31	5.63	9.33	9.07
Total North America	5.40	5.73	10.34	10.01
Brazil	8.27	8.73	6.26	5.87
Total South America	13.31	13.50	10.70	10.44
India	4.53	5.99	5.04	5.39
Total Asia and Oceania	18.57	21.86	22.14	22.69
Total E. Europe	11.97	12.05	17.71	17.67
EEC	13.55	15.48	10.97	10.59
Total W. Europe	16.67	19.05	15.07	14.74
World Total	84.60	92.40	87.71	87.54

Sources: ISO Statistical Bulletin, Landell Mills Commodity Bulletins.

Table 7 contains some projections to 1990 of world consumption of sweeteners by major categories. The data there suggest that by 1990, 81.3 per cent of sweetener consumption will be in the form of centrifugal sugar and 9.2 per cent will remain as non-centrifugal. Non-caloric sweetener consumption will be 1.3 per cent of the total and starch based sweeteners 8.2 per cent of the total, that is an amount of 11.6 million tonnes out of a total world consumption of sweeteners of 141.4 million tonnes in 1990. The nature of the sweetener industry and market is such that projections of output and consumption are invariably hazardous and it is not surprising how much in the past estimates have varied from actual performances. Consequently these projections for as far ahead as 1990, (as indeed all others in this study) should be handled with due caution.

While we are not concerned with a detailed analysis of the world's sugar market, certain features of it are important for forming the background to the assessment of both the HFCS industry and the sucro-chemical industry. The first of these is that international trade accounts for only 20-25 per cent of world sugar output. Of this 20-25 per cent only about one-tenth to one-sixth of it is traded on the 'open free market'. The remainder is marketed under special bilateral and regional marketing arrangements. Of the total sugar traded as much as 90 per cent is derived from cane.

Second, the world market for sugar is characterized by periods of over-supply and under-supply leading to wide fluctuations in the prices and quantities of traded sugar in the 'open free market'. Thus for 15 out of the last 26 crop years (1945-80) world production of centrifugal sugar has exceeded world demand. Stocks of sugar have fluctuated between one-fifth to over one-third of annual consumption. A time series of world sugar output and ending stocks as a

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percentage of consumption is shown in Table 8, while in Table 9 the movements in prices are revealed. Note the data in Table 9 are on a crop-year basis and the ending stocks are as of August in each year. All these highlight the high instability of sugar prices. In the years since 1950 five definite sugar cycles have been identified, all of them with the characteristic boom in prices followed by rapid declines. These five cycles are as follows: 1951-55; 1956-61; 1962-68; 1969-77; 1978-82.

Because so much of sugar is marketed by special agreements the role of political factors and government policy have been foremost in influencing price behaviour. In an effort to impose some order and harmony in these arrangements a seventh International Sugar Agreement was signed in 1977. Many problems, however, remain, the major one being the non-participation of the EEC, which as we have seen, has become under their domestic sugar support schemes a major producer, importer and now exporter of sugar. Indeed as we shall see more fully later the EEC's efforts to support the sugar beet industry of Europe is the major factor discouraging the expansion of HFCS production in Europe./2

Given the importance of political considerations in the operations of the world's sugar market the range of countries which presently trades in sugar compounds the difficulties of a common approach to an orderly international sugar regime. Presently significant sugar exporters now range from countries highly dependent on sugar in terms of foreign currency earnings and where most of the sugar produced is exported (Cuba, Dominican Republic, Guyana), through major producers which have a high internal consumption so that only a relatively small proportion of total output is exported (Brazil, India), to a third group of major producers and exporters for whom sugar plays a relatively minor role in their economies (EEC, Australia).

Table 8

World Sugar Production and Stocks/Consumption Ratio (million tonnes)

Crop Year Beginning September	Cane Sugar Output	Beet Sugar Output	Total	Ending Stocks as a % of Consumption
1972	44.8	30.1	75.1	22.14%
1973	48.0	32.0	80.0	21.62%
1974	50.0	28.5	78.5	24.51%
1975	49.9	31.7	81.7	26.52%
1976	53.5	32.8	86.3	30.28%
1977	57.5	35.0	92.5	34.57%
1978	56.5	34.6	91.1	34.15%
1979	50.9	33.5	84.4	26.37%
1980	54.5	32.4	87.0	24.10%
1981	61.3	35.0	96.3	28.96%

Source: USDA Economic Research Service, Sugar and Sweetener Outlook and Situation (various issues)

Table 9

Raw Sugar Spot Prices (US cents per lb)

Year	World Price
1972	7.43
1973	9.61
1974	29.99
1975	20.49
1976	11.58
1977	8.11
1978	7.82
1979	9.60
1980	29.02
1981	16.93
Jan., 1982	12.99
Feb., 1982	13.05
March, 1982	11.24
April, 1982	9.54

Notes to Chapter 1

1. I. McDonald (1979).

2. See, R. Crott (1981).

Chapter 2: INNOVATION IN A MATURE INDUSTRY: THE CASE OF HFCS

Section (i): The Development of HFCS Technology

The food industry has traditionally used micro-organisms derived from natural sources to produce products. Examples of these processes are the brewing of ale, beer, etc., the making of alcohol and the production of dairy foods. It was also known that starch could be converted into a sweetener by an acid process (hydrolysis) and this process was commercially utilized on the basis of potato starch in the US as early as 1850. In 1866 corn sugar or dextrose was being prouced in limited quantities in the US. These traditional uses of enzymes and yeasts were, however, limited in their applications. Thus in the case of the corn industry, wet millers knew as early as the 1800's the process for converting D-glucose (an aldose) to D-fructose (a ketose). This process is known as isomerization and explains why in Europe high fructose corn syrup goes by the trade name of isoglucose. The process then known consisted of treating glucose with an alkaline catalyst at a high Ph. The technology was limited in its applications because of two major circumstances associated with this process. One was that in the process of conversion excessive by-products were produced. These tended to cause dark colours and to develop off-flavours. This point underscores the significance of the properties other than sweetness which determines the use of sweeteners as referred to in the provious chapter. Unfortunately, while technically these undesired effects could have been removed, their removal was far too expensive to make the product economical. The other limitation was that the process was crude and really consisted of non-specific and uncontrollable reactions which made its industrial uses very limited.

In face of this circumstance research on sugar isomerization continued, but much of the research, however, was being done on the metabolism of carbohydrates in bacterial and animal cells and was concentrated on 5-carbon sugars (pentoses) instead of the 6-carbon sugars like D-glucose. By the 1950's, however, a significant discovery was made. It was found that free monosaccharides outside the cell would undergo ketolisomerization in the presence of a proper enzyme. The proper enzyme discovered was xylose isomerase. This discovery was however, not made within the sweetener industry or the food industry but by biological and medical scientists who were studying the role of sugars in the metabolism of the biological system. The significance of this work was not quickly appreciated by the corn wet milling industries until the publication by Hochster and Watson on xylose isomerase was 'accidentally' noted by Elder, a research director in CPC International./1

Further research however, continued and this was directed towards finding a glucose isomerase which could convert glucose to fructose through the necessary re-arrangement of the molocular structure of glucose. The main difference of the two sugars is that while glucose has 6 carbons, xylose has 5. Laboratory research by Marshall and Kooi revealed that the enzyme prepared from Pseudomonas Hydolphilia which was described in the literature as a specific sylose isomerase also functioned as a glucose isomerase in the conversion of D-glucose to D-fructose. This discovery was of particular moment because D-fructose is much sweeter than D-glucose. However, limitations on its application in industrial processes existed and the corn industry did not adopt the new scientific discovery, although a patent was taken out by the US firm CPC, on the Marshall and Kooi's process (US patent number 2,950,228, issued August 23, 1960).

Research in the general area continued in the 1960's, but the center of this research shifted to Japan. Here also the initial focus was biological, and much of the work was conducted in research institutes and not industry. It was only later that the commercial food orientation came to the forefront and industry began to take note. In 1965 the Japanese researcher J. Sato reported that filamentous bacteria, Streptomyces, produced glucose isomerase. Together with Tsumura, a Japanese patent (Number 17640 issued on October 7, 1966) was taken out on the Streptomyces (Actinonycis) species. At about the same time Y. Takasaki another Japanese researcher working at the Fermentation Research Institute of Japan published on the commercialization of this process. The article stressed the suitability of the process to the wet milling industry for the production of high fructose corn syrup. Again CPC bought out exclusive rights to utilize the enzyme for production. The US patent to Takasaki was given in 1971 (Patent number 3,616,221).

Despite these favourable developments the corn wet millers still thought the process too expensive. This reflects some of the ossification which develops in a mature industry. The main high cost factor was attributed to the cost of enzymes. At the time soluble enzymes were used in a batch reaction process and then discarded. A momentous breakthrough in the field of enzyme technology was, however, at hand, as a new technique of enzyme immobilization had been developed which could permit the indefinite use of enzymes in the process of isomerization. The possibility of the repeated re-use of enzymes would mean considerably lower costs of enzyme production.

However, it was not until 1967 that commercial US production of HFCS commenced. This was done on licence from Takasaki and the Japanese government. The first production contained 15 per cent fructose. This was later raised to 30 per cent and within a year to 42 per cent HFCS. The process used was the older batch system using a soluble glucose isomerase. The emerging technology of enzyme immobilization was not used. The 42 per cent HFCS produced in 1968 was the genuine first generation of HFCS sweeteners. By 1972, however, a continuous process using immobilized enzymes was introduced at Clinton Corn Processing Industry.

Ten years therefore elapsed between the discovery of the glucose isomerase and its significant commercial utilization. Two factors appeared to be key in the timing of its more general development in US industry. The first was the result of the legal action between CPC International and Standard Brands Inc. which resulted in the removal of basic patent coverage for the isomerization of glucose to fructose in 1975, and which cleared the way for its more general industrial use. The second factor was the tremendous boom in sugar prices of 1974 which at one stage peaked at 66 US cents per lb. This served as a big incentive for industrial users to switch to HFCS and much of the industry's present capacity was built on decisions made during this period, the industry being, as we shall see more fully later, very sensitive to the price of competitive sweeteners. The collapse of sugar prices after 1975 depressed the industry particularly as over-capacity became evident. However, by 1980-81 there was a partial recovery of prices accompanied by all round technological improvements which made the industry more and more competitive and its business outlook optimistic. While we shall discuss in detail these issues in Chapter 4, it is pertinent to note here that in the production of HFCS, by-product recovery (corn oil, corn feeds and corn meal) has ranged from 40-60 per cent of the per bushel corn cost. The prices of these products had also strengthened during the period 1980-81, leading to a favourable impact on the development of the industry.

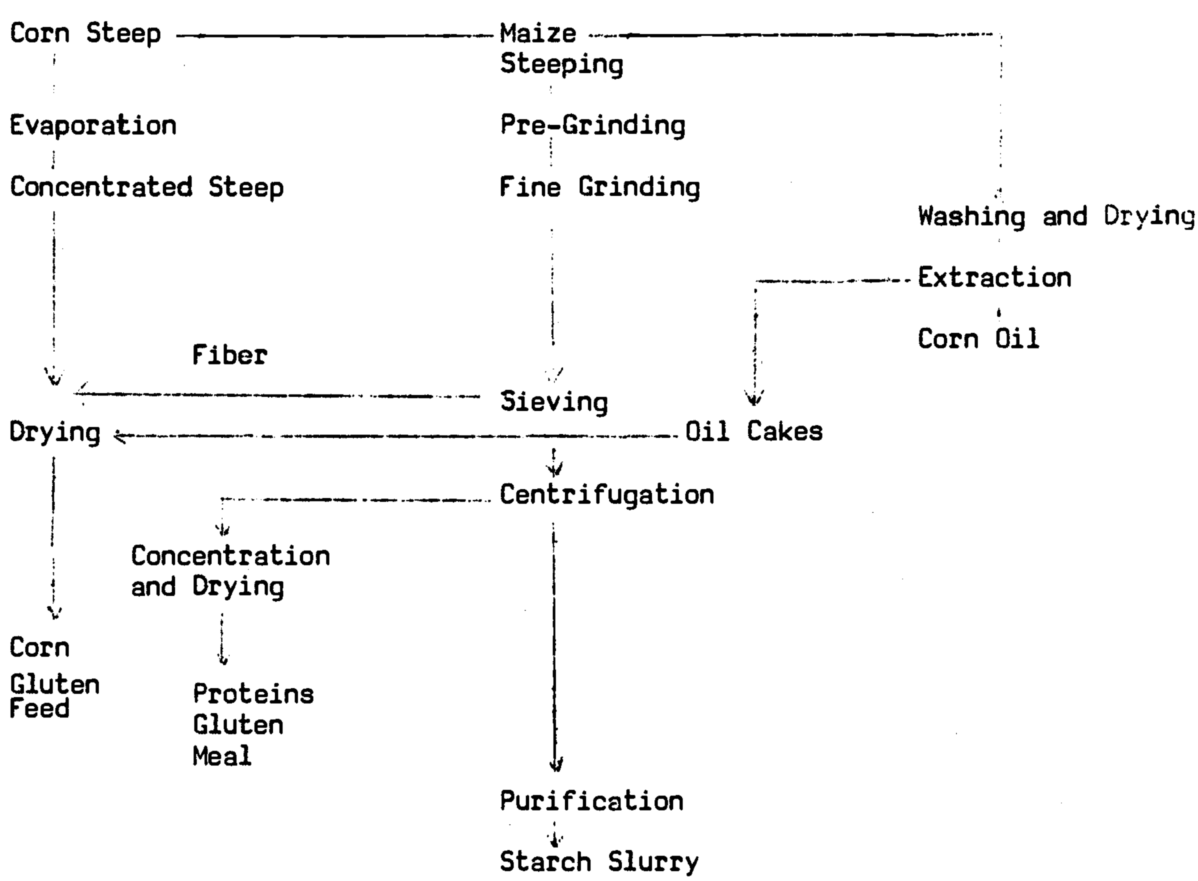
Enzymatic conversion of dextrose into fructose reaches equilibrium at

50 per cent conversion, that is a 50:50 liquid mixture of D-glucose and D-fructose, so that the HFCS produced at 42 per cent fructose was the commercially practical limit while having the same sweetness as liquid sugar. In the industry there has naturally been a strong incentive to improve on this conversion rate and as a result of a new fractionation technology which involves the chromotographic separation of fructose from dextrose by means of ion exchange resins, a 55 per cent variety HFCS was produced in 1978. This is now in widespread commercial production. With the new fractionation technology it is theoretically possible to produce up to 100 per cent fructose bearing syrup, but to date the 55 per cent, and to a far lesser extent a 90 per cent product are the only ones commercially produced. The 55 per cent product is 10 per cent sweeter than sucrose, while 90 per cent product is one to one and a half times as sweet as sucrose. It is largely used in health foods and other such speciality areas. The 55 per cent product is produced by blending the 90 per cent product with the 42 per cent product.

The breakthroughs in enzyme production have been of the greatest significance to the industry. In the USA this is one of the fastest growing 'new' technology industries. Currently there are more than a dozen different microbial producers of glucose isomerase, with six of these being commercially produced./2 There is also a wide variety of techniques used in the immobilizing of the enzymes and several types of reactors are used in the industry. These latter have been classified as batch, packed bed, continuous flow stirred and ultra-centrifugation membranes. The most commonly used is the packed bed./3

While the bottlenecks of enzyme production have been overcome and are still being improved on, the major remaining hurdle is the commercial crystallization of HFCS. If this is done on a cost effective basis it would become a direct competitor to table sugar. Cetus Corporation (a Californian based bio-engineering laboratory) has joined with Standard Oil Coy of California to develop a process for the crystallization of fructose. The technique used so far is to convert dextrose to fructose in a manner different to that currently used in the production of HFCS, but the process is so far not cost competitive with sugar in all its uses. This will be amplified on in the next section.

A schematic outline of the processes involved in the production of HFCS is shown below. In the first schema the production of dextrose syrup from corn which is the substrate for conversion to fructose is shown:



Source: R. Crott (1981), p 16.

Having obtained the substrate, starch slurry, the isoglucose process is as follows:

Starch Slurry

← Lime water

← α-amylase

Feed Tank (pH 6-7)

Liquefaction

← pH adjustment (acid)

← gluco-amylase

Saccharinification

Filtration

Carbon Treatment

Ion Exchange

Evaporation

← Mg SO4

← Base pH adjustment

Mixer

Heat Exchange

Isomerisation Reactor

← Acid pH adjustment

Mixer

Carbon Treatment

Ion Exchange

Evaporation

Heated Storage Tanks

<u>Source:</u> R. Crott, (1981) pp 17 and 18.

In the process overleaf, the starch slurry which has about one-third dry solids is liquefied by bacterial α-amylase and heated to about 80°c to 110°c. This process is a continuous one with the pH raised to 6-7. After a short cooling period (up to 60°c) the liquefied starch is saccharified by application of gluco-amylase and the adjustment of the pH to 4.0-4.5. The holding time here is 24-90 hours. The result is a saccharified starch of 94-96% dextrose, measured on a dry basis. This is then de-colourised with carbon and the calcium ions which were added for liquefaction are removed to prevent their de-activation of the isomerase enzyme. In some processes this de-ionizing step is omitted where the α-amylases used are appropriate. The refined dextrose is then concentrated (to about 40-45 per cent solids) and is placed in a mixer tank where various salts are added and the pH again adjusted to 7.0-8.5 depending on the type of enzyme used and the reactor type. At this stage it is the dextrose content of the substrate which determines the yield of the finished product. The only reaction of the glucose isomerase introduced after this stage is to convert dextrose to fructose. This is possible because the continuous process using immobilized glucose isomerase form a very minimal by-product as the contact time between enzyme and substrate is short.

After isomerization is completed and about one-half of the dextrose converted to fructose the solution is refined, the pH adjusted to 4.0-4.5 and the product concentrated to 71 per cent dry solids by evaporation. In the case of 55 per cent HFCS, dry solids constitute 77 per cent.

Further details on reactor design and enzyme usage are not necessary at this juncture, but the reader so interested can follow the summary given by Crott (1981). The important point to note is that as indicated earlier there is a mixture of reactor designs in use. The preference noted for the packed-bed type is because in this type of reactor the concentration of active glucose is higher and contact time between enzymes and substrate shorter. This helps to reduce the costs of HFCS production. Similarly the effectiveness of the enzymes depend on a number of parameters: contact time between substrate and enzyme, pH, temperature, oxygen, size of particles, purity of syrup, presence of metal ions, concentration of syrup, degree of mecrobial infection of the stream, etc. As Crott points out: "it is here that the 'craftsmanship' and experience of the user is of importance to select and control the best possible mix of the parameters". /4

Section (ii): Analytical Observations

A number of important analytical observations emerge from our brief survey of the development of HFCS technology. The first of these is the wide range of disciplines which have converged to make the innovation possible and later ensured its application to large scale production. There has been the traditional chemical interest in the role of micro-organisms in food production which has been transformed by the new developments in enzyme technology.

has also been the role of medical and biological research in the metabolism of sugars in the human body which was instrumental in the isolation of the enzyme and the understanding we now have of the process of isomerization. There has also been the work of those scientists who saw the commercial possibilities of what was a primarily scientific discovery and played an important role in moving the discovery from a scientific stage to the technological application stage.

The convergence of these various disciplines and the merging of basic scientific research and technological innovation has not however, been easy or straightforward. Long lags existed between the development of the basic isomerization process and its industrial application. This signals the crucial role of interdisciplinary awareness in successful technological development. In the literature on technical innovation there is presumed to be a substantial lag (usually 8-15 years) between the time technical innovation is generated and it is used as an innovation. This lage varies from product to product with chemical/pharmaceutical developments falling in the mid-range. In the case of HFCS, if 1952-53 is treated as the pivotal year for the breakthrough discovery (Casey 1976), then it took seven years of basic research and a further seven years of technology advancement and two years for industry to commercialize the results. A total of just over a decade and a half.

A second observation is that while government and private corporations have played a role in the development of HFCS, (the Japanese government through its Fermentation Institute and the many corn milling corporations in the US, Europe and Japan), much of the critical work was done in research institutions. This factor may have helped determine the lag in the application of these scientific advances in the corn starch industry, but an important point which emerges is that a crucial feature of S and T planning should certainly be the creative networking of what might appear at first sight to be independent and often unrelated institutions, enterprises and agencies.

A third observation is that the long established and 'mature' nature of the corn wet milling industry must certainly have hampered its flexibility and creativity in dealing with the technical changes outlined here. Several factors suggest that this was so. One is that while the starch inudstry had always supported enzyme research this has been confined to hydrolases or degradative types. The breakthrough inherent in the possibilities of a different class of enzymes which could rearrange the sugar molecule D-glucose was not appreciated by the industry until Elder's 'accidental' noting of the work of Hochster and Watson. Another factor is that even after this was appreciated it took more than a decade, up until 1965, for US corn wet millers to show interest in the discoveries. Whelan (1974) and Casey (1976) severely criticized the corn wet milling industries for these delays. Finally, even after enzymes were in use the industry was slow to adopt the immobilization techniques which were being developed. As Casey observes:

> "the failure of industrial carbohydrate technologists to recognize at an early date the technical adventages and economic impact of enzyme immobilization technology was a major oversight, which can be ascribed to poor knowledge exchange between scientific disciplines". /5

The immobilization of creativity and innovation associated with mature industries leads to long intervals in innovation, and these long intervals in turn further immobilizes these industries, creating an unhealthy spiral of technological conservatism.

A fourth important analytical observation is the truly international character of the development of HFCS technology. Early work in the US was followed by a period of concentrated development of research into isomerization in Japan supported by government and universities. The long list of publications emanating from Japan between the years 1961-69 is good testimony to the work done there. Later however, the major applications were made in the US. /6 The reason why the Japanese, noted for their quick spotting and implementation of a profitable technical breakthrough did not appear to seize the opportunities afforded by their own researchers in their breakthroughs in HFCS technology is that as far as the resource configuration of Japan goes, that country remains relatively indifferent to the pattern of development of sweetener technology. It has no large-scale sugar beet industry or corn production, and both the traditional production of sucrose and HFCS are highly raw material intensive. The leading role played in the development of the industry by US corporations therefore in large measure reflects the preponderant global role of US corn producers.

A fifth observation is that from the inception there were always three major technical hurdles which had to be overcome if HFCS was to be a commercial success, viz.

(i) to produce a better than 42 per cent product;

(ii) to produce and utilize enzymes efficiently;

(iii) to crystallize the final product.

The first of these technical hurdles was overcome by the development of fractionation technology, that is the separation of a mixture, usually of chemically related or otherwise similar components, into fractions of different properties. This technology has been applied to crystallization and distillization of mixtures making use of fractionating columns.

The second of the technical hurdles was overcome through the rapid development of the enzyme industry. Indeed the HFCS industry combines two industries, the corn wet millers and the enzymes producers. Some corn wet millers do of course, produce their own enzymes. The United States market for microbial enzymes is presently estimated at nearly $105 million, and the world market at approximately $210 million. Discussions with persons knowledgeable in the industry suggest that the rule-of-thumb is an annual growth of the industry of approximately 15 per cent. A figure of 14½ per cent was reported in Chemical Weekly./7

These enzymes are not only used in HFCS production but also in gasahol, waste treatment, blood tests, etc. When we examine sucro-chemicals in the next chapter we shall refer to this, as the fermentation processes are important to the production of sucro-chemicals. The expansion of R and D and production capacity in enzymes is reflected in a significant fall in the cost of enzymes in the production of HFCS. As we shall observe in Chapter 4, whereas in 1972 these accounted for 16 per cent of the total cost of HFCS, currently it is under 5 per cent. Presently as many as 100 organisms have been patented as isomerase producers even though as we indicated earlier only about six are widely used, with firms utilizing not only different organisms but different immobilization methods, as each has different properties. Despite all these gains the view is that 'most scientists believe another breakthrough may be required in enzyme genetics or in the discovery of more heat stable varieties before additional savings can be made.'/8 While this may be true for some industries, however, as far as HFCS is concerned the cost savings to be anticipated will only be marginal. It is important however not to dismiss the impact of progressive improvements of an incremental sort in enzyme technology and isomerizing conditions.

One firm, Cetus Corporation of the US has used a new route based on olefins conversion. The olefin, a halide ion and hydrogen peroxide are catalyzed by an enzyme to alkene halohydrin which another enzyme then converts to the oxide, releasing the oxide for re-cycling. A variety of oxides can be produced with only small modifications. The halide ion is inexpensive and re-cyclable. This process may be upgraded with recombinant-DNA techniques focusing on modifying the useful enzyme to produce more enzymes or the enzyme's genetic coding may be transplanted to a different organism more suited to industrial scaling upwards./9

With reference to the third bottleneck the following quote from the General Manager of the Sweeteners Division of Tate and Lyle is apt:

"If HFCS could be dried to a granular solid and stabilized economically, sucrose could be very seriously threatened. The technical problem is not easy, but the prize is substantial, so it must be assumed that considerable research is in progress in this area."/10

Discussions with persons in the industry have always elicited the view that this research is well advanced and that before very long the commercialization of a crystalline process would be forthcoming. If this were to eventualize the threat to sucrose would indeed be substantial, but even without it, as we shall observe in the following chapters the threat which already exists is formidable indeed.

The final observation which I would like to make, stems from the relation of corn to HFCS. As we have already hinted, and as we shall discuss in detail in Chapter 4, the production of HFCS yields important by-products which have a critical bearing on the economics of HFCS production. In addition to this, corn can be used to produce not only HFCS but an entirely different product, even though using the same fermentation process, namely, ethanol. In turn, this product can be used as either a chemical feedstock or as is more likely a gasolene extender. Already sugar cane has been used in this way, most notably in the Brazilian gasahol programme. This alternative use of corn is possible within more or less the same plant design and production processes. Indeed, the flexibility even extends into the yielding of the same by-products (corn oil, corn feed and corn meal) as in HFCS production. This flexibility of plant switching gives ethanol produced by corn a strategic competitive flexibility when compared to the use of sugar cane thereby increasing the threat to the stability of a sucrose industry based on cane sugar.

In the USA the view is that ethanol has the most 'immediate potential' of all the renewable resources to cope with the present energy crises. From this point of view as Nordlund has observed: "corn and grain sorghum [are] the most attractive feedstock in terms of availability and economics". /11 The US government has indeed afforded it limited encouragement as a fuel extender. Current US production is about 60 million gallons and it is projected that output of this product could range from 300-900 million gallons this year. Two US corn poodUcers had switched capacity to ethanol production in 1980 in face of 'over-capacity' in HFCS production, namely, Archer-Daniels-Midland in Cedar Rapids and CPC International in Pekin, Illinois. In conclusion it should be noted that the US consumes on average over 300 million gallons of gasolene annually. To replace 10 per cent of this would be equivalent to 2½ times the entire annual consumption of ethanol on a 95^{0} alcohol basis.

Notes to Chapter 2

1. This observation was made by Casey (1876) on the basis of a private communication to him (n.d.) from Elder. For Hochster and Watson's work see Journal of American Chemical Society, 75,3284 (1953) and Arch. Biochem. Biophys. 48,120 (1954). On the early history of the development of HFCS, see H. E. Bode (1967) and J. P. Casey, (1976).

2. See R. Crott, (1981).

3. ibid, p 19.

4. ibid, p 23.

5. Casey, (1976) p 30.

6. The list of Japanese publications include:

   N. Tsumura and T. Sato,Agri. Biol. Chem. 25,616,(1961).
   N. Tsumura and T. Sato, Agr. Biol. Chem. 25,620, (1961).
   K. Yamanaka, Agr. Biol. Chem. 27,265, (1963).
   K. Yamanaka, Agr. Biol. Chem. 27,271, (1963).
   Y. Takasaki and O. Tanabe, Nihhon Nogei Kogaku Kaishi, 36,1010,(1962).
   Y. Takasaki and O. Tanabe, Nihhon Nogei Kogaku Kaishi, 36,1013, (1962).
   M. Nakate and S. Yoshimura, Agr. Biol. Chem., 27,342, (1963).
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   N. Tsumura, M. Hagi, T. Sato, Agr. Biol. Chem. 31,902, (1967).
   Y. Takasaki, Y. Kosugi, A. Kanbayashi, Fermentation Advances, Academic Press, 561 (1969).

7. Chemical Weekly, June 4, 1980, pp 39-40.

8. D. E. Nordlund (1980) p 15.

9. Chemical Weekly, July 30, 1980, p 15, Chemical Engineering July 28, 1980, p 37-39. These references suggest that commercial application may occur by 1983-84.

10. W. M. Nicol, (1980), p 73.

11. D. C. Nordlund (1980) p 16.

Chapter 3: THE STRUCTURE OF THE HFCS INDUSTRY

Section (i): World Structure

High fructose corn syrup is commercially produced in significant quantities in the United States, Japan, Canada and the European Economic Community, with minor levels of output reached in a few countries of Asia and Latin America. These latter presently total about 56,000 tonnes. Total world output for 1980 is currently estimated at 2.8 million tonnes, while the 1981 estimate of production is given as 3.4 million tonnes. These totals are slightly above the estimates given earlier this year./1 Table 10 presents the data on global production of HFCS from the crop year 1974-75 to crop year 1979-80 along with projections of Earley to crop years 1984-85 and 1989-90. Before referring to the projections in this table we should note that whereas total world output in crop year 1974-75 was just over half a million tonnes of HFCS, by 1979-80 this had increased to approximately 2.5 million tonnes. Actual output for the calendar years 1980 and 1981 is as we have noted, 2.8 and 3.4 million tonnes respectively. From the inception the United States has been the overwhelmingly dominant producer of HFCS. In the crop year 1974-75 that country produced approximately 86 per cent of total world output and in the latter period 1979-80 despite increased output from other countries this was still as high as 81 per cent of world output. Between 1974-75 and 1979-80 output of 55 per cent HFCS had risen from a negligible amount to over 46 per cent of total world output of HFCS. In the United States, 55 per cent HFCS has displaced the first generation 42 per cent HFCS as the principal product of the industry accounting for over half of its output of HFCS in crop year 1979-80. World output of 90 per cent HFCS, however, remains negligible with only the US producing a small amount of

Table 10

WORLD HFCS PRODUCTION AND PROJECTIONS

	1974-75	1979-80	1984-85	1989-90
	1,000 mt, raw sugar equivalent			
United States	458	2,000	3,000	3,600
42%	431	910	1,100	1,225
55%	27	1,040	1,800	2,200
90%	-	50	100	175
Canada	-	75	210	275
42%	-	45	90	110
55%	-	30	110	130
90%	-	-	10	35
European Community	-	45	45	55
Japan	77	340	750	1,175
42%	77	270	500	725
55%	-	70	220	410
90%	-	-	30	40
Other Countries	-	-	30	40
Total	535	2,460	4,035	5,145
42%	508	1,270	1,765	2,155
55%	27	1,140	2,130	2,740
90%	-	50	140	250

Source : Earley (1980)

50,000 tonnes. As HFCS is produced from corn it is useful to note that estimates of the global output of all corn sweeteners in 1981 is approximately 8.2 million tonnes, with regular corn syrup accounting for 3.6 million tonnes, dextrose 1.2 million tonnes, and HFCS the remainder.

In the following sections we shall examine in some detail the structure of the industry in the major producing areas, its major markets and also make projections of future output. Here it would be useful to complete the global picture by noting in a very preliminary way the sort of magnitudes of total output being projected for the world. Table 11 which follows summarizes a few of the projections currently available and the dates they were made.

Table 11

Projections of World HFCS Production (million tonnes)

	1984-85	1989-90
Earley (1980)	4.0	5.1
Vuilleumier (1981)	5.6	-
GATT-Fly (1980)	4.0	-
Hegelberg and Ahlfeld (1981)	4.5	5.5
Koutras and Greditor (1981)	5.2	-
Thomas (1982)	5.4	-

Earley's projections are presented in some greater detail in Table 10. These also go as far as 1989-90. It is useful to note that according to his estimates, 55 per cent HFCS should account for 2.7 million tonnes or 53 per cent of total world output in 1990, with 42 per cent HFCS accounting for 2.1 million tonnes or 42 per cent of the total, and 90 per cent HFCS the remaining 5 per cent. My own estimates are based on current capacity and output levels together with announced capacity changes up to August 1982, and allowing for a lag of 2-3 years between announcement of planned changes in output and actual changes. The main advantage of my estimate over the others is its recency and the fact that they cover only a 2-3 year period ahead. The variation in estimates are considerable, from 4.0-5.6 million tonnes. The fact however that output recorded in 1981 was 3.4 million tonnes and that actual capacity in the US stands at 3.6 million tonnes up by one-third over the past year suggests that the higher estimates are easily the more reliable. A final point to observe in this preliminary look at global production and which is not self-evident from the tables is that almost all the world's output of HFCS is sold in the internal markets of the producing countries. International trade in HFCS products is negligible.

Section (ii): The United States Industry

The United States is the dominant country in the world's sweetener industry. It is a major producer of all the principal sweeteners: cane sugar, beet sugar, corn syrup, dextrose, non-caloric sweeteners as well as HFCS. It is also a major importer of sweeteners - particularly cane sugar from developing countries. As a consequence, developments within the United States have the profoundest significance for future developments on a world scale. As we have noted in Table 10 the United States is by far the world's largest producer of HFCS. The raw material base on which its output has been built up is the domestic availability of corn. The US is the world's largest producer of corn. Its present output of about 170 million tonnes represents about half of the world's output of corn, while exports of corn from the US alone accounts for 75 per cent of world trade in this commodity. More than three-quarters of the corn produced, however, has so far been used principally as animal feed to sustain the meat and dairy industries.

In Table 12 estimates of nutritive sweetener deliveries in the US are presented for the years 1975-81, along with projections to 1985. These data indicate that between 1975 and 1981 the consumption of sucrose has been fairly static; the consumption of dextrose, while relatively small, has been falling; the consumption of HFCS has grown dramatically, while marginal increases in the consumption of corn syrup have taken place. The result of these developments has been that overall corn sweetener deliveries have risen rapidly relative to cane and beet sugar deliveries. In 1975 corn sweetener deliveries were 24 per cent of total deliveries, and by 1980-81 these averaged over one-third of total deliveries. For the same period the overall growth in sweetener deliveries was just over 10 per cent.

If we turn to Table 13 before looking at the projections in Table 12 we can observe sweetener deliveries on a per capita basis. There the striking growth of HFCS consumption is readily observed. Whereas in 1975 per capita consumption of HFCS was 2.3 kg, by 1981 it was estimated at 10.5 kg, that is an increase by a factor of nearly 4½. The decline in the per capita consumption of dextrose and sucrose should also be noted in this table. Corn syrup deliveries have showed a small increase in per capita consumption, rising from 8.0 kg in 1975 to 8.3 kg in 1981. As a result total per capita corn sweeteners consumption has grown from 12.6 kg in 1975 to 20.4 kg in 1981. Total sweetener consumption meanwhile was 53.6 kg in 1975 and had risen by only six per cent to 56.7 kg in 1981

Turning to the projections in both Tables 12 and 13, we should first note the method of calculation used by the author. He assumes a 4 per cent annual decline in sucrose consumption over the period due to corn sweetener substitution.

Table 12

USA: ESTIMATED NUTRITIVE SWEETENER DELIVERIES (1975-85)

1000 metric tons dry

Year	Sucrose	Corn Syrup	HFCS	Dextrose	Total Corn (Col.3+4+5)	Total Sweetener (Col.2+6)	% Corn
1975	8,734	1,714	482	499	2,690	11,424	24
1976	9,235	1,728	715	499	2,942	12,177	24
1977	9,410	1,759	942	413	3,114	12,524	25
1978	9,232	1,796	1,221	385	3,402	12,634	27
1979	9,119	1,819	1,543	390	3,752	12,871	29
1980 (1)	8,545 (8,600)	1,882 (1,852)	1,905 (1,985)	398	4,185 (4,235)	12,730 (12,835)	33 (33)
1981 (1)	8,203 (8,375)	1,920 (1,909)	2,286 (2,409)	406 (364)	4,612 (4,682)	12,815 (13,057)	36 (35)
1982	7,875	1,958	2,743	414	5,115	12,990	39
1983	7,560	1,997	3,154	422	5,573	13,133	42
1984	7,258	2,037	3,628	431	6,096	13,354	46
1985	6,968	2,078	3,990	439	6,507	13,475	48

Note (1): The bracketed figures are revised estimates for 1980 and 1981 obtained from USDA publications.

Source: Vuilleumier (1981) and USDA, Sugar Market Statistics (various issues)

Table 13

USA: ESTIMATED NUTRITIVE SWEETENER DELIVERIES (PER CAPITA), 1975-85

kg dry

YEAR	SUCROSE	CORN SYRUP	HFCS	DEXTROSE	TOTAL CORN (Cols.3+4+5)	TOTAL SWEETENER (Cols.2+6)	% CORN
1975	41.0	8.0	2.3	2.3	12.6	53.6	24
1976	43.0	8.0	3.3	2.3	13.6	56.6	24
1977	43.5	8.1	4.3	1.9	14.3	57.8	25
1978	42.3	8.2	5.6	1.8	15.6	57.9	27
1979	41.4	8.3	7.0	1.8	17.1	58.5	29
1980	38.7	8.2	8.7	1.6	18.5	56.5	33
1981	36.5	8.3	10.5	1.6	20.4	56.7	36
1982	34.9	8.7	12.2	1.8	22.7	57.6	39
1983	33.3	8.8	13.9	1.8	24.5	57.8	42
1984	31.7	8.9	15.8	1.9	26.6	58.3	46
1985	30.2	9.0	17.3	1.9	28.2	58.4	48

Source: Vuilleumier (1981), and USDA, Sugar Statistics (various issues)

As far as corn syrup and dextrose are concerned he assumes a marginal, 0.2 per cent, annual rate of increase. HFCS growth rates are, however, substantial, with a 15 per cent increase projected for 1983-84, and 10 per cent increase projected in 1985. On this basis corn sweeteners would account fro 48 per cent of the total sweetener market in 1985, with HFCS alone accounting for 30 per cent of the market. Meanwhile sucrose consumption is expected to decline substantially, averaging only about one-half the sweetener market by 1985. While projections of sweetener deliveries and consumption are particularly hazardous, Vuilleumier's estimates have not been far out. Thus for example although the projections were made during the course of 1980, final figures for sucrose consumption for the years 1980 and 1981 respectively show 8.000 and 8.375 million tonnes as against projections of 8.545 and 8.203. The bracketed figures in Table 12 indicate the actual figures for the years 1980 and 1981 and there it can be seen that no serious discrepancies exist, except for a tendency to slightly underestimate HFCS output. The complex nature of the industry and its high degree of susceptibility to output variations based on price changes, weather, political and other circumstances are too well known for the difficulties of forecasting to be underestimated. Indeed at the time of writing (third quarter of 1982) prices are at a five-year low with a glut in world sugar supplies. In turn this has been exacerbated by the US decision to impose import restrictions, as well as this year's bumper crop projected for the EEC. It is already evident, therefore,that if these conditions prevail, 'over-capacity' may well emerge in the HFCS industry over the period 1982-85, converting the cautious projections of Tables 12 and 13 into unduly optimistic forecasts.

The data presented in Table 14 show the projected output of HFCS by product. These reflect the expectation that second generation HFCS, that is the 55 per cent variety, will become the major product of the HFCS industry, replacing the 42 per cent variety. As the data show whereas the 55 per cent product accounted for only 11 per cent of the total output of the industry in 1978 by 1985 this is projected to be as high as 59 per cent. Indeed Earley's estimates for 1989-90 presented earlier in Table 10 show the 55 per cent variety as representing 62 per cent of the two varieties by that year. However, it should be noted that totals given by Earley and Vuilleumier differ and that Earley also includes the 90 per cent variety HFCS in his projections, whereas Vuilleumier omits it, because he relegates it to the small specialty market.

Data on the industrial deliveries of HFCS and sugar by product categories are presented in Table 15. These data reveal a number of interesting points. First, the major sales of HFCS are clearly in the beverages, baking and canning industries. Of these major markets, the beverage industry's market is by far the largest - accounting for 57 per cent of all sales and 40 per cent of the total beverage's market for sweeteners. The decision by the Pepsi-Cola and Coca-Cola Companies to use HFCS in their products, subsequently followed by other beverage companies has been a decisive factor in the development of the HFCS market. Indeed when it is considered that Coca-Cola has only changed its formula thrice in its history, the far-reaching consequences of this decision cannot be easily over-estimated. Because of the importance of the beverages market, data are presented in Table 16 showing the current approved levels of soft drinks replacement in the US market. The smallest share of the market for HFCS is in the area of

Table 14

U.S.A. : ESTIMATED HFCS DELIVERIES BY PRODUCT:

1978, 1980, 1985. 1000 Metric tons dry

Product	HFCS		HFCS		HFCS	
Type	1978	%Total	1980	%Total	1985	%Total
42%	1,085	89	1,293	68	1,636	41
55%	136	11	612	32	2,354	59
	1,221	100	1,905	100	3,990	100

Source : Vuilleumier (1981)

Table 15

USA: INDUSTRIAL SUGAR AND HFCS DELIVERIES BY MARKET (1980-81)

1000 metric tons dry

	Sugar		HFCS		HFCS % OF SWEETENER MARKET	
	1980	1981 (Estimate)	1980	1981 (Estimate)	1980	1981 (Estimate)
Beverages	2,160	1,960	990	1,302	31	40
Baking	1,340	1,135	470	391	26	25
Canning	590	485	410	305	41	43
Dairy Products	450	432	180	176	29	29
Processed Foods	540	396	120	101	18	20
Confections	930	816	10	11	1	1
TOTAL INDUSTRIAL	6,010	5,144	2,180	2,286	36	31

Source : Vuilleumier (1981) and Smith (1982) confections. Here the failure to develop a crystalline product has been the decisive factor.

The data in Table 17 show the structure of the US sucrose market in 1979 and 1980. From these data it can be observed that less than 40 per cent of the sucrose is used for non-industrial purposes, with industrial uses ranging between 61-63 per cent of total sucrose. Since HFCS threatens the industrial market the structure of that market is particularly relevant to our inquiry. The data in this table show clearly that the major markets are firstly beverages, followed by baking and cereals, and confectionery. The market for canned foods, confectionery and dairy products, and miscellaneous foods follow next. This market structure for sucrose can be profitably compared with the possible theoretical penetration of HFCS into these markets. Table 18 presents two such estimates, one by Rivero (1980) and the other by Vuilleumier. While there are some differences revealed in the Table both estimates agree on the virtually complete switching over of the beverages industry into the use of HFCS products. Rivero projects a 100 per cent switch over and Vuilleumier a 90 per cent switch over. Rivero also sees a total substitution in the canned goods industry but Vuilleumier limits his estimate to 60 per cent. The next major market segments are dairy products and miscellaneous products with Rivero giving half of these to HFCS and Vuilleumier 30 and 40 per cent respectively. Both authors give baking and cereals a 25 per cent penetration. In both estimates the confectionery market is the least likely to be affected - reinforcing the importance of the technical hurdle of HFCS being a non-crystalline product. However, the projections vary significantly with Rivero giving an estimate of 20 per cent and Vuilleumier only 5 per cent.

Table 16 (cont'd)

*	A . E Staley Mfg. Co. Product Bulletin 4/29/80 and subsequent updates.
**	Lehman Bros. Kuhn Loab Inc. John C. Maxwell, March 1981, cases = 24 pack, 8 oz.
***	Excludes Fresca and Tab.
****	Pepsi-Cola approval is for fountain syrup only.
*****	Excludes Diet Rite Cola.

Source VUILLEMIER. (1981)

Table 17

USA: STRUCTURE OF SUCROSE MARKET

Industrial	Actual Use 1979	Actual Use 1980	Actual Use 1981
Beverage	22.9%	22.8%	20.1%
Canned Foods	8.1%	6.2%	5.3%
Ice Cream and dairy products	4.9%	4.7%	5.0%
Baking and cereals	11.2%	14.1%	14.2%
Miscellaneous processed foods	6.0%	5.7%	6.3%
Confectionary	8.2%	9.8%	10.7%
	61.3%	63.3%	61.5%
Non-industrial	38.7%	36.7%	38.5%
Total	100.0%	100.0%	100.0%

Source : USDA, "Sugar and Sweetener Report", GAO "Report to the Congress sugar and other sweeteners: An industry assessment"; and Barry & Gilbert (1981)

Table 18

USA ITCS - ESTIMATES OF LONG TERM THEORETICAL

PENETRATION BY MARKET

PRODUCT	RIVERO	VUILLEUMIER
Beverages	100%	90%
Canned foods	100%	60%
Dairy Products	50%	30%
Miscellaneous Processed Foods	50%	40%
Baking and Cereals	25%	25%
Confections	20%	5%

Source : Rivero (1980) and Vuilleumier (1981)

In Tables 19 and 20 estimates of HFCS deliveries by market are given in both absolute and percentage terms. In these estimates the predominance of the beverages market and the limited role of the confectionery market are once again highlighted. In Table 20, the actual figures for 1980 are given alongside Vuilleumier's estimate in order to note the actual variations. While these data indicate a support for the ranking of markets given by Vuilleumier, there are differences between the actual and estimated percentages, the most significant being in the case of beverages and canning.

Before leaving the issue of the market distribution of HFCS a few observations picked up from interviews and discussions with persons in the industry are worth noting. One of these is the point already made that the growth of the confectionery market for HFCS is limited by the failure to produce a crystalline fructose at a competitive price. The moisture affinity of the liquid product impairs its use in the confectionery industry although some producers of confectionery are using limited quantities of HFCS. In the market for baked goods it would appear from discussions that most of the growth so far has been by way of a substitution for dextrose, so that the growth of HFCS here affects principally the corn sweetener category. In the canned foods industry a major problem which exists is the browning of the product from use of HFCS and this has so far restricted its use. Finally, in the dairy industry, the growth of HFCS has met with the obstacle of its tendency to lower the freezing point of ice-cream. All these technical hurdles indicated here, can theoretically be overcome. The issue, however, is whether this can be done at a competitive price. Indications are that the industry is confident of soon being able to

Table 19

USA: ESTIMATED HFCS DELIVERIES BY MARKET

1980 - 1985 1000 metric tons dry

	1980	1981	1982	1983	1984	1985
Beverages	967	1,302	1,676	2,000	2,354	2,669
Baking	385	391	423	440	497	502
Canning	288	305	328	366	413	432
Dairy Products	168	176	187	198	204	211
Processed Foods	88	101	116	130	138	147
Confections	9	11	13	20	22	29
	1,905	2,286	2,743	3,154	3,628	3,990

Source : McKeany-Flavell Co., Inc. projections from "Sweetener Outlook", Donaldson, lufkin, and Jenrette, June 1980, with adjustments, as quoted in Vuilleumier (1981)

Table 20

USA: MARKET SHARES (HFCS)

Major Market for HFCS	HFCS ESTIMATED MARKET SHARE 1980	HFCS ESTIMATED MARKET SHARE 1985	ACTUAL 1980
Beverages - carbonated and non-carbonated	51.0%	67%	45%
Baking	20.0%	12%	22%
Canning	15.0%	11%	19%
Dairy Products	9.0%	5%	8%
Processed Foods including jams, preserves	4.5%	4%	6%
Confections	.5%	1%	0.5%

Source : U.S.D.A. and Vuilleumier (1981) overcome these obstacles and evidence of this is said to be given by the production capacity expansions already announced by the industry.

Finally the data in Table 21 show that within the US eleven firms, with 17 plants predominantly located in the Midwest are responsible for its output of HFCS. The largest of these is Archer Daniels Midland (with over one-quarter of total capacity) followed by A. E. Staley just under one-quarter and Clinton with 17 per cent of the capacity. These 3 firms alone, therefore, account for 68 per cent of the total market. Apart from Hubinga, which accounts for 9 per cent of the market, the other seven firms have capacities ranging from 1-3 per cent. A point of some significance which will be taken up later in the study is that the HFCS producing firms in the US also have major investments in cane and beet sugar along with maize, and food products such as soya-bean, flour, etc.

Summing up we may therefore note the following:

1) The US is the world's largest producer of HFCS with capacity projected to rise at a rapid rate over the next 5-10 years.

2) Most of the expanded output will be in the area of second generation HFCS, or the 55 per cent variety.

3) The major markets for HFCS will be beverages, followed by baking and canned goods; the smallest market will be confectionery.

4) The growth of market shares will depend on certain technological developments in crystallization, but already the theoretical possibility of penetrating the sucrose market is considerable.

5) The growth of HFCS occurs in the context of a static or declining growth in the overall sweetener market in the US.

6) The US firms in the industry have a highly oligopolistic structure. They are also multi-product firms, in particular producing significant quantities of other sweetener substitutes.

Table 21

USA: EXPANSION OF 42% AND 55% HFCS CAPACITY BY FIRMS

Dry Lbs/annum (x 10^6)

Company	Capacity 1980 (42%)	Capacity 1980 (55%)	Estimated Change, For - 1981 (42%)	1981 (55%)	1982 42%	1982 55%	1983 42%	1983 55%	Est. Capacity 1983 42%	1983 55%
American Maize Products	250	-	(75)1/	325	-	-	-	-	175	325
Amstar	250	-	-	-	-	200	-	-	250	200
Anheuser-Busch	75	-	-	-	-	-	-	-	75	-
Archer Daniels Midland	1,100	400	(100)	850	-	-	-	-	1,000	1,250
CPC International	310	-	235	-	245	100	-	-	790	100
Cargill	260	-	(50)	260	160	280	-	-	370	540
Clinton	670	300	(150)	135	-	-	-	-	520	435
Great Western	30	70	-	-	-	-	80	320	110	390
Hubinger	320	170	-	-	-	-	-	-	320	170
Holly Sugar	100	-	-	-	-	-	-	-	100	-
Staley (A.E.) Mfg.	770	620	-	570	-	-	-	460	770	1,650
Total	4,135	1,560	(140)	2,140	405	580	80	780	4,480	5,060
Cumulative Total	4,135	1,560	3,995	3,710	4,400	4,280	4,490	5,060	-	-
Estimated Demand	2,992	1,388	3,182	2,142	3,385	3,305	3,600	5,100	-	-
Excess Capacity (%) 2/	38	12	26	72	30	30	24	(1)	-	-

1/ Parentheses signify capacity converted to 55% HFCS.

2/ As percent of demand. Roughly 14% is required to allow for seasonal fluctuations.

Sources: Vuilleumier, S (1980); Barry R.D. & Gilbert A.Y. (1981); L. Smith (1982)

Section (iii): The Canadian Industry

The Canadian markets for sweeteners generally and HFCS in particular are far smaller than those of the United States. Thus in 1981 only 90,000 tonnes of HFCS was produced. Like the US the market for corn sweeteners has grown rapidly between 1975 and 1981, but in the latter year it accounted for 19.4 per cent of the total sweetener market as compared with over one-third in the US. Canada does not produce dextrose, and all of its requirements are imported from the USA. In Canada also more corn syrup was consumed than HFCS during 1981, but by the end of this year it is expected that the situation would be reversed. Data on a comparable basis to that used in presenting the US industry are shown in Tables 22 and 23. There it will be observed that Canadian production of HFCS only commenced in 1979. Like the US, per capita consumption of sucrose has been falling, from 43.5 kg per capita in 1975 to 39.9 kg per capita in 1981. However, the level of per capita sucrose consumption in Canada is slightly above that of the US, but in overall sweetener consumption the US is ahead.

The projections in these two tables show that Canadian HFCS output would reach 290,000 tonnes in 1985 or 23 per cent of total sweeteners consumption and 37 per cent of industrial sweeteners consumption. Sucrose consumption would fall from 81 per cent of total sweetener consumption in 1981 to 64 per cent by 1985. Like the US the projections are based on a 4 per cent annual decline in sucrose deliveries between 1980 and 1985, but corn syrup growth is projected here at 6 per cent annually over the same period. HFCS capacity has been projected on the basis of an annual increase of 50,000 tonnes to 1985.

Table 22

Canada: ESTIMATED NUTRITIVE SWEETENER CONSUMPTION (1975-85)

1000 metric tons dry

Year	Sucrose	Corn Syrup	HFCS	Dextrose	Total Corn	Total Sweetener	% Corn
1975	987	76	0	16	92	1,079	8.5
1976	901	84	0	17	101	1,002	10.0
1977	1,039	92	0	18	110	1,149	9.6
1978	1,027	100	0	19	119	1,146	10.4
1979	1,051	108	10	18	136	1,187	11.5
1980	1,000	118	42	19	179	1,179	15.0
1981	960	125	90	19	234	1,194	19.4
1982	922	132	140	20	292	1,214	24.0
1983	885	140	190	20	350	1,235	28.3
1984	850	148	240	21	409	1,259	32.5
1985	816	156	290	21	467	1,283	36.4

1975-80 sucrose figures F.O. Licht; Corn sweetener figures McKeany-Flavell estimates.

1980-85 sucrose figures assume a 4% annual decline due to corn sweetener penetration.

1980-85 corn syrup growth assumed 6% annually. Dextrose growth assumed 3% annually.

1980-85 HFCS figures assume a 50,000 ton annual increase due to capacity expansions.

As quoted in Vuilleumier (1981)

Table 23

Canada: ESTIMATED NUTRITIVE SWEETENER CONSUMPTION (Per Capita) 1975-85

kg dry

Year	Sucrose	Corn Syrup	HFCS	Dextrose	Total Corn	Total Sweetener	% Corn
1975	43.5	3.3	0	.7	4.0	47.5	8.5
1976	39.2	3.6	0	.7	4.3	43.5	10.0
1977	44.7	3.9	0	.7	4.6	49.3	9.6
1978	43.8	4.3	0	.7	5.0	48.0	10.4
1979	44.5	4.6	.4	.8	5.8	50.3	11.5
1980	41.9	4.9	1.7	.8	7.4	49.3	15.0
1981	39.9	5.1	3.7	.8	9.6	49.5	19.4
1982	38.0	5.4	5.8	.8	12.0	50.0	24.0
1983	36.1	5.7	7.7	.8	14.2	50.3	28.3
1984	34.4	6.0	9.7	.9	16.6	51.0	32.5
1985	32.7	6.2	11.6	.9	18.7	51.4	36.4

As quoted in Vuilleumier (1981)

The data in Table 24 indicate that the incremental growth of second generation HFCS between 1981 and 1985 will be greater than that of the 42 per cent variety. This is in keeping with what we have come to expect in this industry. The market shares of sugar consumption in Canada are shown in Table 25.

As one would expect the ranking is similar to that of the US, except that the positions of miscellaneous processed foods and canning are reversed. The figures quoted in this table are all estimates and too much reliance must not be placed on their accuracy even though overall they support the trends we would expect.

The long term penetration possibilities of HFCS for each of the major market segments in Canada is shown in Table 26. Generally these accord lower levels of penetration to HFCS in the Canadian market, as compared with those projected for the US market. The observed differences would seem principally to reflect the different levels of industrial development attained and differences in the degree of differentation of the sweetener markets in the two countries. However, the location of Canada's industrial heartland in close proximity to the US corn belt makes it impossible to fully separate the two markets.

In conclusion it should be noted that two companies control the Canadian market. One of these, Zymaize is a subsidiary of Tate and Lyle of London, England, and the other Canada Starch is a subsidiary of CPC International. As Canada is a net importer of sugar and corn it follows that the TNCs investments in Canadian HFCS are clearly based as much on Canada's integration and access to the US corn market as to Canadian corn producers.

Table 24

Canada: ESTIMATED HFCS PRODUCTION CAPACITIES

1000 metric tons dry

	1981		Additional Capacity Expected 1982		Additional Capacity Expected 1985	
	42%	55%	42%	55%	42%	55%
Canada Starch						
Cardinal	59		15	12		12
Port Colborne *			50	51	50	51
Zymaize Company						
London	90	23	—	23	—	34
TOTALS	149	23	65	86	50	97
CUMULATIVE TOTALS	149	23	214	109	264	206

* HFCS 42% and 55% production expected late 1982 with expansion potential to about 450 million 1lbs. Assumes 50% distribution between 42% and 55% production for 1982 and beyond.

Estimates from public sources and Agriculture Canada.

As quoted in Vuilleumier (1981)

Table 26

Japan: Estimated Per Capita Nutritive Sweetener Deliveries (1975-1985)

Products	Theoretical long-term penetration of HFCs
Beverage	70%
Baking	20%
Processed Foods	25%
Canning	40%
Dairy	20%
Confections	5%
Other	-

Source: Vuilleumier (1981)

Section (iv): The Japanese Industry

Because of its resource configuration Japan is both an importer of sugar and corn. There is no specific resource imperative leading to the development of HFCS production, even though as we have noted Japanese researchers have played a key role in the technological innovations in this product. As would be expected the Japanese market for sweeteners is large, totalling 3.7 million tonnes in 1981 or approximately 25-28 per cent of the US market. Because of its high level of industrialization, the demand for industrial sugar is high, accounting for approximately 60 per cent of total consumption. Like the USA, consumption of sucrose between 1975 and 1981 has not grown significantly. The expansion of HFCS consumption has, however, been reaching a total of 450,000 tonnes by 1981. Overall corn sweetener consumption has risen from 14 per cent of total sweetener consumption in 1975 to 24 per cent in 1981, with HFCS consumption rising from nil to more than half of the corn sweeteners used in this period.

Despite its high levels of industrialization per capita consumption of sucrose in Japan was only 23.7 kg in 1981 or 65 per cent of the US figure. Total per capita sweetener consumption was also only 31.0 kg during 1981 as compared with 57.3 kg in the USA, that is 54 per cent of the US total. Not surprisingly therefore, HFCS consumption per capita remains relatively small at 3.8 kg for 1981 as compared with the US total of 10.2 kg for 1981, that is 37 per cent of the US total. These data are shown in Tables 27 and 28 which also contain projections to 1985.

Table 27

Japan: ESTIMATED NUTRITIVE SWEETENER DELIVERIES (1975-85)

1000 metric tons dry

Year	Sucrose	Corn Syrup	NFCS 42%	NFCS 55%	Dextrose	Total Corn	Total Sweetener	% Corn
1975	2,725	316	-	-	120	436	3,161	14
1976	2,979	380	-	-	138	518	3,497	15
1977	3,159	353	162	-	146	661	3,820	17
1978	2,967	298	218	-	141	657	3,624	18
1979	3,130	304	251	-	144	699	3,829	18
1980	2,870	270	285	90	145	790	3,660	22
1981	2,795	270	150	300	140	860	3,655	24
1982	2,711	273	177	341	141	932	3,643	26
1983	2,630	276	208	388	142	1,014	3,644	28
1984	2,551	279	244	441	144	1,108	3,659	30
1985	2,475	282	285	503	145	1,215	3,690	33

Source: Vuilleumier (1981)

Table 28

1975-1985 ESTIMATED JAPANESE PER CAPITA NUTRITIVE SWEETENER DELIVERIES

kg dry

Year	Sucrose	Corn Syrup	HFCS	Dextrose	Total Corn	Total Sweetener	% Corn
1975	24.5	2.8	-	1.1	3.9	28.4	14
1976	26.5	3.4	-	1.2	4.6	31.1	15
1977	27.8	3.1	1.4	1.3	5.8	33.6	17
1978	25.9	2.6	1.9	1.2	5.7	31.6	18
1979	27.1	2.6	2.2	1.2	6.0	33.1	18
1980	24.6	2.3	3.2	1.2	6.7	31.3	22
1981	23.7	2.3	3.8	1.2	7.3	31.0	24
1982	22.8	2.3	4.4	1.2	7.9	30.7	26
1983	21.9	2.3	5.0	1.2	8.5	30.4	28
1984	21.1	2.3	5.7	1.2	9.2	30.3	30
1985	20.3	2.3	6.5	1.2	10.0	30.3	33

As quoted in Vuilleumier (1981)

The projections are based on the following assumptions:

1) a 3 per cent annual decline in sucrose consumption as compared with 4 per cent in the USA;

2) corn syrup and dextrose deliveries are projected on a one per cent annual growth over the period, as compared with 2 per cent for the USA;

3) HFCS is projected on an annual 15 per cent increase as compared with staggered US increases of 20 per cent over 1981-82; 15 per cent 1983-84; and 10 per cent for 1985.

In the projections for Japan Vuilleumier allocates HFCS in the ratio of 60:40 for the 55 per cent and 42 per cent varieties. On the basis of these projections the total corn sweetener market is expected to increase its share to 33 per cent of the total, with HFCS accounting for just under 20 per cent of the total.

Production capacity of HFCS by manufacturers and type of product is shown in Table 29. These data indicate a less oligopolistic market structure than in the USA. The largest firm has about 21 per cent of total capacity with the next largest having just about 20 per cent. The next two firms together account for about 17 per cent of capacity, making the 4 leading firms responsible for 58 per cent of production capacity. This can be compared with the 3 leading firms in the USA which account for 68 per cent of US capacity. The seven remaining firms in Japan have capacities which range from 8 per cent to 2 per cent of the total. The data in this table also reveal that the bulk of the present capacity is in 42 per cent HFCS, but increases in capacity will as with Canada and the US, favour the 55 per cent product.

In Table 30 the market distribution of HFCS in Japan is shown along with that of other corn sweeteners. In contrast to the USA, dairy products is the largest market segment in Japan, followed by beverages, canning, baking and the miscellaneous category 'others' which includes confectionery, other processed foods, etc. If we recall in the US the major market is beverages which presently account for over one-half of HFCS use. In Japan the ratio is only 28 per cent. In the US, dairy products are 9 per cent of HFCS produced, but in Japan this accounts for 33 per cent, that is the largest market share.

Section (v): The EEC Industry

Given its size and degree of industrialization one would have expected the growth of HFCS in W. Europe to be rapid. This is not the case, however, and the major reason for this is the policy of deliberate restriction of HFCS growth in the EEC. Because of the overriding role of EEC policy in relation to market forces it would be useful if we begin by briefly outlining this policy, for without an appreciation of it, the data presented in the subsequent tables would lose much of their force.

In 1967 in an effort to restore the competitive position of starch the EEC introduced measures to subsidize its production. While the intention was to restore the competitive position of starch vis-a-vis petro-chemical based products (e.g. paper), by 1974 this subsidy was extended to glucose producers which were producing this product from corn as well as wheat and potato starch. This subsidy was carried over into the 1975 regulation governing the common organisation of the community's cereal market. At

Table 30

Japan: MARKET SHARES FOR CORN SWEETENERS (1980)

A. CORN SYRUP	ESTIMATED MARKET SHARE
Confections	57%
Sorbitol	18%
Jams & Preserves	9%
Canning	2%
Others	14%
	100%

B. DEXTROSE	ESTIMATED MARKET SHARE
Confections	26%
Processed Foods	17%
Beverages	12%
Baking	10%
Canning	7%
Feed	7%
Others	21%
	100%

C. CORN SYRUP SOLIDS	ESTIMATED MARKET SHARE
Sake (wine)	50%
Ice Cream	40%
Others	10
	100%

D. HFCS	ESTIMATED MARKET SHARE
Dairy Products	33%
Beverages-carbonated and noncarbonated	28%
Canning	14%
Baking	13%
Others	12%
	100%

As quoted in Vuilleumier (1981)

about this time, however, the production of HFCS (called isoglucose in Europe) had commenced and it benefitted from the subsidy. In 1977 the policy was reversed. The subsidy for HFCS was abandonned as HFCS capacity expanded and several plans were announced by producers for further increases in output. If these developments went through they would have posed a severe threat to EEC beet production, which was at that very time being encouraged in Europe.

In the EEC beet sugar was subject to a production levy, linked among other things to the EEC-ACP Lomé Sugar Protocol. In order to maintain the competitive position of beet sugar, this levy was applied to HFCS. It was also further announced that HFCS producers would have to help bear the costs of exporting sugar surpluses from the Community. These policy measures were challenged in the European courts by the HFCS producers, who won a declaration in October 1978 that the levy as it was then applied was invalid.

Following on this decision the EEC Commission proposed a production quota system similar to the one in use for sugar. Basically HFCS output was categorized into three parts, namely, a basic or A quota calculated on previous production, a B quota equal to 27.5 per cent of the A quota on which a levy is raised, and a C quota which has to be exported outside of the Community, without any financial assistance from the Community. After being challenged these arrangements were declared invalid by the European courts on procedural grounds. They were amended and subsequently reintroduced by the Community - surprisingly with retroactive effect. This regime lasted until 1980. In 1981 a new common regulation for sugar <u>and</u> HFCS was introduced for the following five-year period. Basically this regulation limits EEC production of HFCS to a ceiling of 200,000 tonnes for the period.

The pressures existing within the EEC to limit HFCS production do not only arise from beet producers whom it is already clear the Community wishes to support in preference to both HFCS producers and imported cane sugar, but the ACP grouping of cane sugar countries also, who are anxious to preserve their market position. Here there is a definite convergence of interest with the EEC's domestic beet sugar producers in the struggle to preserve markets against HFCS competition. Because of this, it would be fair to conclude that far less than in usual circumstances, will market forces shape the future of the EEC's production of HFCS.

Examining the EEC's HFCS industry we are immediately struck by the fact that the EEC is a net importer of corn. It produces only about 60 per cent of its domestic requirements. The EEC, however, has a large, complex and highly differentiated industrial market in which the demand for liquid sugar is quite substantial. The data in Table 31 show the EEC sweetener consumption for the sugar year 1980-81. There it can be observed that total sweetener consumption was over 11 million tonnes as compared with 12.7 million tonnes in the USA. The consumption of cane and beet sugar was 9.8 million tonnes, that is a larger quantity than in the USA (8.2 million tonnes). This reflects both the support for beet sugar in the Community and its commitments under the Lome Convention. Corn sweetener contribution to total sweeteners used amounted to 11.6 per cent, as compared with the US figure of 35 per cent, Japan: 24 per cent and Canada: 19 per cent. The Community's HFCS production in 1981 totalled only 176,000 tonnes or 14 per cent of all corn sweeteners used or 1.6 per cent of total sweetener consumption. This makes HFCS production in Europe the least developed of the major Western industrial regions. As the data in the table indicate, in the European Community, the major producers of HFCS are

Table 31

EEC: ESTIMATED NUTRITIVE SWEETENER CONSUMPTION (1980-81)

1000 metric tons dry

Country	Sugar	Corn Syrup	HFCS	Dextrose	Total Corn	Total Sweetener	% Corn
Belgium	355	32	11	19	62	417	14.9
Denmark	240	14	1	8	23	263	8.7
France	2,030	80	26	45	151	2,181	6.9
Germany	2,150	135	55	70	260	2,410	10.8
Ireland	165	28	0	15	43	208	20.7
Italy	1,775	65	18	35	118	1,893	6.2
Netherlands	660	80	30	43	153	813	18.8
United Kingdom	2,380	380	35	55	470	2,850	16.5
TOTAL	9,755	814	176	290	1,280	11,035	11.6

Source: Vuilleumier (1981)

W. Germany, the UK, France and the Netherlands, but the totals produced (the highest being 55,000 tonnes in W. Germany) are relatively small.

The same data are presented in Table 32 on a per capita basis. There it can be observed that the highest use of HFCS is in the Netherlands where the figure is only 2.1 kg per annum. Sweetener consumption in Europe is very high, ranging from 61.1 kg in Ireland to 33.1 kg in Italy. Four countries, Denmark, Netherlands, UK and Ireland exceed an annual consumption of 50 kg; and apart from Italy, W. Germany (39.4 kg per annum) is the only country with an annual consumption under 40 kg per annum.

Finally in Table 33 we present data on the allocation of HFCS quotas in 1980-81, and the production capacities of various EEC firms. These data show a total production capacity of 265,000 tonnes, as against actual output of 178,000 tonnes. The largest capacity resides in Belguim, followed by the UK and France. Because of the distribution of capacity, there is intra-EEC trade in HFCS but, no extra-regional exports and hence no C quotas. In this regard, taken as a group, the EEC industry conforms to the picture of an industry developing on the basis of satisfying its internal markets first.

Given the role of EEC policy in shaping of HFCS production it would be meaningless to make projections based on the usual elasticities population growth rates, past output, etc. The real issue is what EEC policy will be, as already for the next five years basic output is fixed at 200,000 tonnes. While the beet farmers' lobby is clearly dominant at the moment, powerful interests are shaping up against it. Thus the UK group of EEC consumers, in a submission to a Select Committee of the House of Lords on the European Communities (EEC Sugar Policy) made the following submissions:

Table 37

EEC: ESTIMATED NUTRITIVE SWEETENER CONSUMPTION (per capita 1980-81

kg dry

Country	Sugar	Corn Syrup	HFCS	Dextrose	Total Corn	Total Sweetener	% Corn
Belgium	36.1	3.3	1.1	1.9	6.3	42.4	14.9
Denmark	46.8	2.7	.2	1.6	4.5	51.3	8.7
France	37.9	1.5	.5	.8	2.8	40.7	6.9
Germany	35.2	2.2	.9	1.1	4.2	39.4	10.7
Ireland	48.5	8.2	0	4.4	12.6	61.1	20.6
Italy	31.1	1.1	.3	.6	2.0	33.1	6.0
Netherlands	46.9	5.7	2.1	3.0	10.8	57.7	18.7
United Kingdom	42.7	6.8	.6	1.0	8.4	51.1	16.4

Source: Vuilleumier (1981)

Table 33

EEC: ESTIMATED HFCS 42% (ISOGLUCOSE) QUOTAS, PRODUCTION, AND CAPACITIES

metric tons dry

Country	Basic "A" Quota	"B" Quota	Total Quota	Production	Capacity
Belgium					
Amylum/Analst	56,667	15,583	72,250	72,255	80,000
Denmark	-	-	-	-	-
France					
Roquette Freres/Lille	15,887	4,369	20,256	20,022	35,000
West Germany					
Maizena/Hamburg	28,000	7,700	35,700	32,174	55,000
Ireland	-	-	-	-	-
Italy					
FRAGO/Milano	10,706	2,944	13,650	10,109	20,000
SPAD/Spinola	5,963	1,612	7,475	6,618	10,000
Netherlands					
DZB	7,426	2,042	9,486	9,000	20,000
United Kingdom					
Tunnel Ref. Ltd./London	21,696	5,967	27,663	27,483	45,000
TOTAL	146,245	40,217	186,462	177,661	265,000

Source: Crott (1981)

"Isoglucose: CEGG is opposed to the application of the system of quotas and levies to isoglucose. We consider that the product is being taxed and penalized simply because it competes with sugar."/2

To the same Commission the UK Group of Industrial Users of Sugar included the following statement in their memorandum:

"The UK industrial sugar-using associations cannot support the Commission's proposals for the 1980-85 sugar regime. Their views may be summarized as follows .... they are unjust to the isoglucose industry."/3

The Select Committee in its own conclusions observed:
"The reason for the Commission's proposal to incorporate isoglucose and sugar in one composite regime is not given. Were the proposal to mean that some flexibility existed for isoglucose and sugar to compete with each other, rather than isoglucose production being strictly limited by its production quotas, then the proposal could be viewed as the development of a Community sweetener policy. Unfortunately this is not the case. If anything, the proposal is slightly more restrictive as the total of isoglucose production quotas has been lowered by 8,000 tonnes (4.5 per cent). The proposal appears to be mainly a tidying-up operation by the Commission, whereas the Committee would welcome the evolution of a genuine sweetener policy which gave consumers unrestricted access to all forms of sweeteners."/4

It is clear from the above that the technological impact of HFCS on Europe and subsequently on the Caribbean through the Lome Convention would depend on what future policies emerge in the Community. We shall return to this issue in the final chapter of Part I of this study.

Section (vi): Other HFCS Producers

A miscellaneous group of countries in Eastern Europe, Asia and Latin America produce or have plans to shortly commence the production of small quantities of HFCS. In 1981 output from these sources totalled 181,000 tonnes and by the end of 1982 output is projected at 200,000 tonnes. Data on these producers are hard to come by, and what follows below is a summary of the latest position as it is available to me. It should be noted that in all the instances cited below, HFCS production is, or will be, geared to the beverages sector of the sweetener market.

Europe

Yugoslavia has announced definite plans to establish at least one new HFCS plant, with another under consideration. Spain has three plants producing HFCS with a capacity of 70,000 tonnes and an output in 1980 of approximately 55,000 tonnes. The future of the industry is however bound up with the eventual outcome of its relations with the EEC. In Eastern Europe one plant is about to be commissioned in Hungary. This will produce 50,000 tonnes of HFCS. In the USSR, Romania and Bulgaria discussions are advanced for the construction of HFCS facilities. Reports indicate a 70,000 tonnes plant will soon come into operation in the USSR, while the Romanian and Bulgarian projects are being hampered by foreign exchange scarcity.

Latin America

In Latin America, Argentina is the only producer of HFCS at present. Current output is approximately 60,000 tonnes. Uruguay has recently announced its intention of starting the construction of an HFCS production facility shortly. This will produce 20,000 tonnes annually. Significantly the consortium planning this includes the local Coca Cola bottler. Mexico has recently commissioned a 100 tonnes per day plant to produce glucose corn syrup, while the Brazilian subsidiary of CPC has commissioned a 200 tonnes per day plant also to produce glucose corn syrup. The construction of wet milling plants to service these corn sweetener plants may well be the fore-runner of HFCS production. Finally, from commodity intelligence reports Peru seems to be on the verge of taking a decision to start an HFCS venture to produce approximately 50,000 tonnes per annum.

Asia

In Asia, Indonesia has one small plant in operation, and it is being claimed that there is government interest in establishing others using cassava as the starch base. Pakistan has also announced an interest in HFCS production and the plan here is to use broken rice as the starch base for a 45,000 tonnes plant. Taiwan had about a year ago announced an interest in HFCS production but this seems to have been deferred on account of declining sugar prices. South Korea has HFCS plants in operation and it is said that output currently accounts for ten per cent of South Korea's total sweetener market. Korea has always had a relatively strong corn sweetener industry. In 1980 about 378,000 tonnes of corn was processed - one-third of this amount (125,000 tonnes) was used as sweeteners in a total market of approximately 650,000 tonnes for all types of sweeteners.

Notes to Chapter 3

1. The estimates are given on a raw sugar equivalent basis, revised in later issues of the various publications cited in the text, as more complete information becomes available.

2. HMSO, March 1980, p 72.

3. *ibid*, p 60.

4. *ibid*, p xix.

Chapter 4: THE ECONOMICS OF HFCS PRODUCTION

Following on the technological innovations of HFCS, world-wide experience gathered so far point to certain basic factors which would seem to determine whether an industry can be successfully developed in a country or not. The following are the most important:

1) For HFCS to be commercially produced the levels of income and the degree of industrial development should be such that the demand for sweeteners is high - particularly for industrial purposes. In the US market about 60 per cent of the sugar consumed is for industrial purposes, while in the Caribbean, despite high levels of per capita consumption of sugar, the industrial uses of sugar is less than 40 per cent.

2) In considering the industrial demand for sweeterners it is important that a high proportion of this should constitute a demand for liquid as opposed to solid sweeteners. For this to exist there must be a highly developed processed foods and beverage industries, which in turn depends not only on the prevailing levels of income, size of market and the extent of industrialization, but on such social factors as the degree of urbanization, cultural patterns in food consumption, and so on. In the USA both economic and social factors favour a highly developed "convenience foods" industry and this has no doubt facilitated the rapid growth of HFCS in that country.

3) The market configuration as outlined in (1) and (2) above means that there is a high price elasticity of demand for sugar. In general, industrial users of sweeteners are far more ready to substitute one

sweetener for another, given favourable price changes than households. Such substitution of course varies from firm to firm and from one segment of the market to another, but the limits of substitution are effectively those posed by the technical characteristics of individual sweeteners and the foods in which they are to be used. Thus as Crott has observed:

"High prices of sugar have more influence on industrial users; price elasticity is greater for them than for household users (except with very high prices in the case of low income groups). However, surveys indicate that industrial users are equally concerned with stability of price and purchasing prices not higher than those of their competitors. Thus the quantity demanded by industrial users is more responsive to changes in relative prices than the quantity demanded by household users."/1

4) Because HFCS is raw material intensive in its production process there should be an abundant source of cheap starch, whether in the form of domestic produce or cheap imports. In the US,corn supply is abundant so that after satisfying direct consumption requirements and animal feed, large quantities are available for export and diversion to HFCS production. The other HFCS producers (Japan, Canada, EEC) do not have abundant supplies of domestic corn so that their industries, unlike that of the US are more dependent on the availability of cheap imported corn.

5) Other things being equal, where a country is a net importer of sugar, its incentive to substitute with HFCS is greater. As we shall see, HFCS production is highly capital intensive, but the investments may be considered strategically necessary in order to reduce dependence on the vagaries of the international sugar trade. As we have pointed out

the US is a large importer of sugar, along with Canada, Japan and the EEC. In the case of the EEC, however, obligations through the Lome Convention has reduced its capacity to substitute sugar imports with HFCS.

6) HFCS production is also favoured in circumstances where, although domestic sugar is being produced this is at a relatively high cost. If this situation exists it encourages protection of the domestic market and increases the competitive edge of HFCS. There is of course the extreme circumstance of the EEC where domestic sugar might be protected to the point of the deliberate exclusion of HFCS.

7) Because of the capital and skill intensive nature of HFCS operations, capital must be available in large quantities along with the associated expertise in construction and operation of the facilities to make production feasible. Again this favours relatively developed economies, with a broad base of industrial skills in food, enzyme, and automated flow technologies.

8) Finally, as we have seen the production of HFCS is highly dependent on associated industries, mainly, chemicals, enzymes, transportation, storage and utilities such as water, energy, etc. The chemicals and enzymes used in HFCS production require modern bio-technological industries, which are mostly to be found in the industrialized economies. The volume of products and by-products entailed in HFCS production is also huge and the conditions of storage and transport have at all times to be closely controlled. Again this places great emphasis on the availability of such facilities. Finally, the industry requires reliable energy and fresh

water supplies to fuel it. Thus countries or locations with efficient public utilities systems are also favoured.

An examination of cost structures of HFCS firms, particularly in the USA show that the major components of cost are those displayed in Table 34. From this schedule it can be observed that the competitive

Table 34

Major Components of HFCS Production Cost

1. Cost of corn (3 bushels, 168 lbs, to produce 100 lbs of HFCS)

2. By-products credits per bushel of corn
   a) 1.75 lbs of corn and oil
   b) 1.5 lbs of gluten feed
   c) 2 lbs of gluten meal

3. Labour

4. Utilities (water, energy, etc.)

5. Enzymes

6. Fixed costs (overhead)

7. Freight

position of HFCS depends on the cost of corn, the price of corn by-products, the cost of labour, utility supplies, enzymes, freight and fixed overheads. Unlike the situation in cane sugar where a major by-product (bagasse) can be used to generate its own energy for processing; HFCS is a net and substantial user of energy. However, its by-products are considerable (corn oil, corn feed and corn meal) and as we shall see depending on prices these can account for more than one-half of the raw material cost of production. In addition, two other considerations figure prominently in HFCS production economics. One is of course the prices of cane and beet sugar, which are the major competing product. HFCS prices in the US have been offered at discounts on sugar prices and these have declined from 85 per cent of sugar prices in 1975 to 73 per cent of sugar prices in 1981, or an average of 75 per cent during the period 1977-81. These data are shown in Table 35 below.

Table 35

HFCS and Sugar Prices[(1)]

Year	HFCS Prices	Sugar Prices	Ratio of HFCS/ Sugar Prices
1977	12.44	14.66	84.9
1978	12.12	17.16	70.7
1979	13.15	18.49	71.1
1980	23.64	30.76	76.9
1981	21.47	29.29	73.3

Note 1: Prices are cents per lb. HFCS price is the Chicago-West 42 per cent fructose price. The sugar price is bulk dry beet sugar f.o.b. plant.

Source: USDA, Sugar Statistics

The second consideration is the price of oil, since corn can be alternatively used to produce ethanol for use as a gasolene extender. Several corn wet-millers are evaluating this possibility and it is expected that by the end of 1982, 10-15 per cent of corn processed by US wet-millers could be devoted to fuel alcohol. This has been reported in a recent US Department of Agriculture, Sugar and Sweetener Report (February, 1981):

"Several corn wet-milling firms are evaluating the ethanol (alcohol) market for blending grain alcohol with gasolene to make gasahol. One wet-milling firm is currently producing fuel grade alcohol at its Decatur, Illinois, facility, and also plans to produce fuel-grade alcohol in 1981, under a joint agreement with a large gasolene company. Other firms may follow suit. A major consideration in producing ethanol from corn is whether a Federal loan guarantee can be obtained for all or a substantial portion of the cost of investment."/2

As regards ethanol production, a very important consideration which should be borne in mind is that since producers can switch from HFCS to ethanol using the same plants, the seasonal nature of HFCS consumption may lure some producers to switch facilities in the off-peak periods. Table 36 overleaf highlights the seasonality of HFCS consumption in the USA.

In Table 37 we present two estimates of the production cost of HFCS in the USA. These show operating costs ranging from 13-16 cents per lb of HFCS 42 per cent variety on a dry equivalent basis and can be compared with the data on prices paid for HFCS presented in Table 35. The two estimates given in this table have been supported by persons knowledgeable in the industry. It would be useful therefore if we examine these data with a view towards highlighting factors of considerable

Table 36

Seasonality of HFCS Consumption (U.S.A.)

Month	1979 (% of total)	1980 (% of total)
January	6.2	6.0
February	5.9	5.7
March	8.1	8.3
April	8.1	8.3
May	9.0	9.0
June	9.5	9.4
July	9.2	9.3
August	11.1	11.4
September	9.6	10.0
October	8.4	9.7
November	7.2	6.1
December	7.6	6.8
Total	100%	100%

Source: Drexel Burnham Lambert Incorporated estimates, World Sugar Journal, 1981, p 22.

Table 37

Production Cost of HFCS	US (cents per lb.)	
1. Raw Corn Cost (1980)	9.03	
2. Return from by-products[1]		
a) oil	1.38	
b) feed	2.79	
c) meal	0.75	
	4.92	
3. Net Raw Material Cost (1-2)	4.11	
4. Other costs	Estimate A[2]	Estimate B[3]
a) Enzyme	0.40	0.40 - 1.20
b) Operating Labour	2.00	0.80 - 1.20
c) Utilities (energy)	0.70	1.20 - 1.00
	3.10	2.40 - 3.40
5. Total Variable Costs	7.31	6.51 - 7.51
6. Fixed costs (overhead)	2.00	2.00 - 2.00
Freight	1.75	1.75 - 1.75
7. Total (1-6)	11.06	10.26 11.26
8. Capital investment costs	2.40 - 4.50	2.40 - 4.50
9. Total (7 and 8) (42% HFCS)	13.46 -15.56	12.66 -15.76
10. Total (55% HFCS) + 15%		

Note
1. Three bushels of corn to produce 100 lb HFCS dry.
2. Brook, E. (1977)
3. Nordlund, D. E. (1980)

Source: Adapted from, E. Brook (1977), D. E. Norlund (1980) and R. Crott (1982).

importance to the economics of the industry. To begin with the data in this table reveal that raw corn cost is easily the most significant cost item in the production of HFCS. Within the industry the rule-of-thumb on which operations are based is that a 50 per cent reduction in the price of corn equates to a one cent per lb improvement in the cost of producing HFCS, all other factors being equal. Second, the processing of corn generates by-products and these have accounted for nearly two-thirds of the corn over the period 1978-81. In Table 38 we present data on corn costs for US No. 2 Yellow Maize and the by-product credits obtained by the industry for the period, and the net maize input costs which followed. This shows the substantial savings obtained from by-products. Because of this it follows that the market prices of corn oil, corn feed and corn meal are important considerations in determining the final price of HFCS. The prices of corn feed and corn meal are sensitive to the animal feed market where most of it is consumed, while corn oil price is somewhat independent, as it is influenced principally by the edible oil market. It should be observed in Table 38 that the by-products credits have ranged from 51-72 per cent of raw corn cost, based on the average of annual prices over the period 1978-81.

Third, labour cost in the industry is relatively small, ranging from 7 per cent of total cost in the lowest estimate to 15 per cent. The industry's operational norm is that labour costs account for 10 per cent of the cost of producing HFCS. Enzyme costs are also low, ranging from 3 per cent to 7 per cent. The industry's operational norm is 5 per cent. Energy costs in the estimates are lower than those currently obtaining in the industry, because of the rapid rise in energy price in the US.

Table 38

Corn Prices and By-Products Credits (cents per lb.)

Year	Corn Prices	By-Products Credits	Net Cost of Corn Inputs
1978	6.87	4.95	1.92
1979	7.85	5.58	2.27
1980	8.95	5.17	3.78
1981	9.44	4.80	4.64
1982 (January-March)	7.86	4.99	2.87
1982 (April-June)	8.29	4.73	3.56

The levels of capacity utilization or operating rates in the industry have a significant impact on cost, reflecting the high levels of capital intensity and high fixed charges for capital. In the estimates given,these are as high as 35 per cent of costs of operation. Because of this the industry tries to operate at above 90 per cent of engineered capacity for about 330 days a year.

Since HFCS operation capacity was first established in the US important changes have taken place affecting its production costs. To begin with, while a decade ago the cost of enzymes accounted for 16 per cent of total production costs, now the estimate is only 5 per cent. This substantial fall in enzyme costs reflects the rapid development of the bio-technology industry of the USA, from which HFCS production has benefitted. At the present levels of development of enzyme technology it is as Nordlund speculates, a further significant lowering of these costs would have to await breakthroughs in "enzymatic genetics or the discovery of more heat stable varieties".[/3] Even so the savings to be expected would fall within the five per cent range of total costs of production. So that even if costs were halved, the impact on total production costs would not be very significant.

As a result of the developments in fractionation technology discussed in Chapter 2, product recovery in the industry has been increased by 10-15 per cent. It is also claimed that water usage has fallen by half when compared to the batch production processes used in the first phase of HFCS production.[/4]

In so far as HFCS production may be seen as the convergence of two industries, viz., enzyme production and corn wet-milling, the industry has clearly benefitted considerably from the developments in the bio-technology of enzyme production. However, while significant cost savings do not presently exist in this sphere, I would like to re-iterate the observations made in the previous chapter. That is, one should not under-estimate the impact on costs of the progressive improvements of an incremental sort in enzyme technology and isomerizing conditions.

In keeping with similar developments in other spheres of US industrial life, HFCS plants have been continuously upgraded, and a number of labour saving devices has been introduced. Present day operations are far more automatic and computer controlled than previously. This has led to a drastic reduction in labour input requirement, while at the same time the level of skills in the present labour force has been substantially increased. Thus it is claimed that: "a high fructose syrup plant which required a work force of 130-150 people in 1972 can be manned by 75-90 employees today if full use is made of automation and computer technology."/5

Contrary to the above, investment costs and energy costs have, however, risen substantially. Increases in the former set of costs reflect inflation rates over the past decade and the high interest rates prevailing in the USA. The industry rule-of-thumb is that whereas initially a new facility would cost $1 million of investment for every 1,000 bushels of daily grind, by 1975-76 this cost was $2 million; by 1980 $3.5 million and by 1981 it had reached $4.0 million. The U.S. Department of Agriculture in its Sugar and Sweetener Report (February 1981) put it as follows:

"a medium-sized wet-milling plant with a daily grind of 75,000 bushels (to come on stream in 1983) would cost around $300. million versus $150. million just 6-7 years ago. Moreover, current financing charges are much higher, and stricter environmental and health standards through EPA and OSHA regulations must be met"./6

The world-wide increase in petroleum prices is too well known for us to dwell upon here. The effect in the industry has been an estimated increase in energy costs from 4 per cent of total costs in 1972, to about 15-20 per cent today. The industry has responded by seeking to conserve energy used in the production of HFCS. Installation of equipment and devices such as mechanical compressors, heat exchangers, vapour compression steepwater evaporation systems, high pressure boilers and turbine systems for generation of electricity and process steam has become standard in corn refining plants. Currently it is estimated that these equipment and devices have resulted in a saving of 30-35 per cent of energy use, as compared with first generation HFCS plants.

In order to highlight the changing elements in the cost of producing HFCS, a comparison can be made between the operating costs data presented in Table 37 and an earlier indication of cost ratios derived from a study by the Department of Agricultural Economics at Purdue University. This is presented in Table 39 below.

Table 39

Cost Components of HFCS Production (%)

Components	Estimate
Corn	50
Energy	20
Labour	10
Chemicals	10
Enzymes	5
Miscellaneous	5

Source: Cubenas, G. J., et al, (1979)

In this study the cost estimates arrived at were, 9-13 cents per lb for 42 per cent HFCS, dry equivalent with the 55 per cent variety costing an additional 7-15 per cent./7 The study also showed that scale of operations is highly significant. Scale economies in HFCS production are considerable. The study was based on three different capacities namely, 36,000, 72,000 and 108,000 bushels per day and six different operating rates. Table 40 shows a summary of the estimates of the cost of producing HFCS for various

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plant sizes and operating rates. From these data we can see clearly both the scope for scale economies in size and the significant economies to be derived from different operational rates. As scale increases costs fall, and as operating rates rise within any given capacity costs also fall.

The cost analysis undertaken in this study indicates that the cost of processing corn into HFCS is not particularly sensitive to any single factor, except of course corn prices and operating rates. The approximate relationship between production costs and operating rates which the study establishes is that "a one per cent increase in the specified operating rate lowers production costs by 0.3 per cent". /8 The approximate relationship between corn prices and cost of production, assuming by-product prices remain constant, is for a "one per cent increase in corn price, the cost of production increases 0.6 per cent". /9 As the study concludes there is therefore a strong incentive for HFCS producers to run a plant as close to maximum capacity as possible. The revealed cases of under-utilized capacities shown in the earlier tables are clearly not welcome by the firms in the industry. Indeed if capacity is under-utilized and these firms do not adhere to implicit price arrangements, then the variations in processing margins can be very wide. /10

All the studies of the HFCS industry in the US, and the sweetener industry generally indicate that the costs of producing HFCS are lower than that of domestically produced sucrose, whether it is beet or cane sugar. A study conducted under the auspices of the US Department of Agriculture shows sugar cane-production costs in the US per acre, excluding land at $1,029. in the 1981/82 crop year. The figures ranged from $505 in Louisana to $3,162 in Hawaii. The per ton cost of producing and processing sugar cane, (excluding land costs) was $28.80. The cost of cultivation of sugar cane was 13.8 cents per lb. for the 1981/82 crop year. Sugar beet had $535. per acre for non-land costs of cultivation. Non-land costs of beet sugar cultivated was 11.6 cents per lb. Processing costs for cane sugar per lb. was 12.2 cents - giving a total of 26.0 cents per lb. If by-product gains are taken out the net cost of cane sugar was 24 cents per lb. The processing costs of beet was 17.8 cents per lb. Allowing for by-product credits the net cost was 25.3 cents per lb. These costs are significantly in excess of those estimated for HFCS.[/11]

Estimates of European HFCS costs indicate a figure of 17 cents per lb. in 1977.[/12] This cost of production was sufficiently low to permit selling prices of HFCS in Europe to be below sugar prices. For the years 1978 to 1980 HFCS prices in the EEC expressed as a fraction of sugar prices was 88, 77 and 77-86 per cent, that is an average discount of 20 per cent which can be compared with the US discounts presented in Table 35 above. Current estimates generally make EEC costs of producing HFCS on average 15 per cent lower than that of sugar. We have already noted, however, that for the immediate future, macro-economic, political, and social policies of the EEC Commission, rather than the competitive effectiveness of any particular sweetener will determine the pattern of EEC output of HFCS and sweeteners generally. The conflict of interests between sugar beet producers and their demands for protection, the ex-colonial arrangements of cane sugar marketing and the rising industrial and consumers interests in favour of HFCS will be determined more by politics than economics. Nevertheless, the cost advantage of HFCS cannot be ignored, for if this is sustained over the long run it could well emerge as the single most important factor in favour of the expansion of HFCS output.

Notes to Chapter 4

1. R. Crott, (1982) p 40.

2. USDA, Sugar and Sweetener Report, Vol. 6, No. 1, February 1981, p 18.

3. D. E. Nordlund, (1980) p 22.

4. D. E. Nordlund, (1980) p 22.

5. D. E. Nordlund and Liebenow, R. C., (1981).

6. USDA, Sugar and Sweetener Report, Vol.6, No. 1, February 1981, p 8.

7. G. J. Cubenas, (1979).

8. ibid, p 36.

9. ibid, p 36.

10. ibid, p 41.

11. See USDA Sugar and Sweetener Reports, 1982. Earlier cane sugar cost of production estimates are given at 10.06-14.01 cents per lb. in G. A. Zepp (1977). Beet sugar cost of production estimates were given as 8.6-11.5 cents per lb. in E. V. Jesse (1977). Comparing these to the Purdue University figures given in Table 40, we can see that HFCS was competitive at that time also.

12. See, I. Smith, (1978), Grosskoph and Schmidt, (1977) and Crott, (1982).

Chapter 5: HFCS AND THE FUTURE: AN ASSESSMENT

Section (i): Some Current Views

A good place to begin an assessment of the technological impact of HFCS development would be to look at some prevailing views. Although the literature here is very sparse, the judgements which have been formally expressed by knowledgeable persons both within and outside the industry unanimously stress the fundamental nature of the transformation of the sweetener industry which HFCS development has made inevitable. Consider as examples the following published views:

T. C. Earley, formerly Senior Staff Economist, Council of Economic Advisers, Office of the President of the USA:

"[HFCS] has been one of the main forces affecting the market during the past few years and will continue to be so in the future because most of us have still not fully adjusted our thinking and our analytical techniques in response to the very changed circumstances which HFCS has created".[/1]

N. A. Kominus, President, US Cane Sugar Refiners Association:

"Change is the name of the game. The advent of HFCS has changed everything. Unfortunately, not everyone in the US sugar industry has come to accept this change. And I am troubled to find that many world sugar exporters seem to be somewhat indifferent to the threat of HFCS. Hopefully this conference may open some eyes ... our members are concerned over the technological progress in the corn sweetener industry. The corn people have almost unlimited resources for research and development."[/2]

N. Rivero, Chief Commodity Group, OAS, Washington:

"With regard to the US sugar market the single most important phenomenon of the 1970's was the establishment of the HFCS as a nutritive sweetener."/3

D. E. Nordlund, Chairman, President and Chief Edecutive Officer, A. E. Staley Manufacturing Co., USA:

"One can conclude that the future is promising for high-fructose corn syrup in the United States. It is not without its problems and limitations, but it continues to evolve in a positive manner."/4

G. Samuels, Agricultural Research Associates, USA:

"From all indications, in the next decade, corn derived sweeteners will continue to substantially increase their share of the market at the expense of sugar."/5

S. Vuilleumier, Researcher:

"Future fructose production and consumption is expected to expand beyond traditional areas. Structural changes are taking place in several countries that may eventually create an environment favourable to HFCS development."/6

Jose A. Cerro, Market Analyst, GEPLACEA:

"All the foregoing clearly shows that the most important competitor for sugar on the sweetener market is HFCS. Its present participation in sales is, per se, high, and everything seems to indicate that it will continue to rise."/7

G. Rodrigo Steed, Farr Man & Co. Inc., USA:

"Looking at the investment side of corn sweeteners, there is no question that HFCS is very capital intensive, but the feeling we get is that, one way or another, the necessary funds will be available for further expansion. Some reports indicate in the next three to four years 1.5-2.0 billion dollars will be invested in the Wet Corn Milling Industry, and judging by the industry's performance over the previous years, there is no reason to doubt these estimates. We can thus say that the Wet Corn Milling Industry is here to stay, and is the only area of the US sweetener picture which will continue to show a vigorous expansion."/8

All the judgements expressed above support the view that the HFCS threat to the sweetener market is indeed formidable. As with most technological threats, however, there are two dangers to guard against: an overstatement of the benefits of the new products by adherents newly won over to the innovation, and self-protecting scepticism expressed by established interests in the industry, who decry the limitations of the new products. As experience has shown the most likely eventual result usually falls somewhere between these two extremes. It is my view that the HFCS innovation will conform to this experience. After all, it should be remembered that market estimates of output vary between 5-8 per cent of total world output of sweeteners by 1990, although in its leading market, the USA, this could probably represent as much as 30-40 per cent of its market. Such long range projections are of course always highly speculative - particularly as the data in Chapter 3 above show, the output projected by one study for 1989-90 (Earley, 1980) was less than that projected in the course of 1981 for 1981 (Vuilleumier, 1981)!

It should also be realized that business outlook in the HFCS industry, is, like other industries, strongly influenced by the general level of economic activity. In the mid-1970's, because of the dizzying heights of sugar prices (1974-75) abounding optimism prevailed and this prompted rapid expansion of capacity. But as sugar prices subsequently fell and temporary over-capacity emerged, pessimism grew, to the point where some even claimed that the threat of HFCS had been overstated:

"The fears that arose in the mid-70's have gradually disappeared. It has been recognized that the impact on the international sugar cane industry would be less than feared. At the present time the only country where HFCS is estimated to make a major in-road is the US ... however the change in the sweetener market in the US brought by HFCS could have a real importance for its traditional sugar supplies."[19]

When prices revived in 1980-81, optimism returned. Currently, with depressingly low sugar prices pessimism has reasserted itself. In making judgement on the long run impact of a technological innovation it is important to appreciate these cyclical phases in business outlook. Such swings in outlook, although often exaggerated, do reflect objective changes in the course of economic activity and are not only the subjective whims and fancies of producers. It is important therefore that we guard against treating the prevailing business outlook as <u>the</u> only reality and not simply as being unreal. The objective status of HFCS as a cost competitive alternative sweetener should never be overlooked, if we are to accurately gauge its eventual impact on the world's sweetener industry.

Section (ii); Long Run Considerations

The precise nature of the substitution of one technology for another is not very well-known. The common view is that based on the product life cycles in marketing, an S-shaped curve would represent the process of substitution. This means that sales of the new product begin slowly, then there follows a period of rapid substitution, followed by maturity to a plateau from which they eventually decline. The product being replaced has a similar S-shaped curve of decline. While empirical studies have not always supported this hypothesis, one early paper by Fisher and Pry (1971) postulated that the substitution of one technology for another follows the product substitution S-shaped curve./10

A later study by Cooper and Schendel (1976) elaborated on the patterns of technological substitution./11 They found inter alia that after the introduction of the new technology, sales did not always decline immediately. In a couple of cases, sales of the old technology continued to expand over the entire period, even as sales of the new technology expand. When sales of the old technology did decline it took about 5-14 years to fall below the sales of the new technology. They also found that where capital requirements were not large the new technology was generally innovated by new firms outside the industry, while generally, firms outside the industry first developed the new technology. The new technology was very frequently expensive and relatively crude at first, leading to scepticism about its eventual usefulness. Later, as scepticism receded, the new technology often created new markets which were not available for the old technology. The process of expanding sales of the new technology was to capture sequentially a series of sub-markets. Finally, they found that erratic growth patterns of the new technology could be occasioned by "abnormal" economic and social conditions, e.g. war.

How do these generalizations in the literature stand up in this particular case? To begin with the case of HFCS represents a new technology which is principally being introduced by firms either within the broadly defined sweetener industry or firms linked to the corn wet milling industry. The precise nature of these connections will be elaborated a little further on as it is an important indicator when assessing the future impact of HFCS technology. Secondly, the new HFCS technology is highly capital intensive and consequently the possibility of new firms entering the industry has so far been confined to its ancillary processes, e.g. production of enzymes. Third, the commodity produced is a basic agricultural product which competes in a market for an agricultural staple that is homogeneous and pure. The production conditions of the range of products consumed in the sweetener market is highly variegated, combining rich and poor countries alike and all the varied production conditions implicit in this. Because of such factors, extra-economic considerations play an important part in production and consumption decisions. In such circumstances therefore, the industry is unlikely to follow closely the classic pattern of technological substitution, even though we cannot rule out entirely the possibility that some aspects of this pattern may be reflected. Already one aspect of this, e.g. the sequential capturing of a series of sub-markets is very evident.

Of prime importance to us at this stage of our analysis is not only the issue of the threat of technological and product substitution but the responses of the existing enterprises to this threat. Response refers here to the ability of those threatened to both recognise and assess the threatening innovation. For this purpose the traditional intelligence activities of the sugar producers which have focussed only on other sugar producers (whether they be beet or cane) must shift to include innovations in HFCS, as indeed all other sweeteners, including the non-caloric types. As it has been observed elsewhere:

> "It would be a mistake to wait until decline in sales of the old technology triggered the need for appraisal of the threat. By then, much of the lead time would have passed. However, this means that the new technology must be appraised when it is still relatively crude ... it is not enough to judge that someday a new technology will replace an old one. Rates of penetration must be determined."/12

In the face of a technological threat, firms responses strategies may be categorized as follows:/13

1. Do nothing.
2. Monitor new developments.
3. Step up public relations and legal activity to deter market acceptance and expansion of the new technology.
4. Increase flexibility of the existing enterprises/plants so as to be able to respond to future developments, if necessary.
5. Take evasive action by decreasing dependence on the most vulnerable segments of the market.
6. Upgrade the existing technology.
7. Resort to price cutting, sales promotion techniques, etc. to maintain sales.
8. Participate in the new technology.

In the instance we are dealing with, while the new technology is being developed within the corporate structure of the most industrialized capitalist country, the principally threatened product, sugar, is produced in a wide array of agricultural systems of the developed and underdeveloped world.

Confronting the highly olijopolistic structure of the US high fructose syrup industry is a multitude of inadequately organized agricultural producers. Indeed, the producers of the two main forms of sugar (beet sugar and cane sugar) stand in direct competition to each other. This means that a coordinated sugar industry response would be particularly difficult to achieve.

Furthermore, the cane sugar producing industry is several centuries old and in its maturity it has tended to ossify around certain R & D practices. These are confined to improved cultivating practices, improved plant varieties, better pest control and more efficient conversion processes from sugar cane plant to sugar. Developments which have occurred in sucro-chemicals and which will be examined in the next section have all been pioneered by the TNCs who process this sugar in the industrialized countries. Within the Caribbean region, which we believe to be typical of other underdeveloped regions, these developments are not being monitored. Indeed knowledge of HFCS and the threat it constitutes is vague. From all appearances, therefore, the Caribbean cane sugar industry is responding by "doing nothing". What ever monitoring of global developments is taking place is perfunctory and confined to occasional studies by researchers in such organizations like GEPLACEA.

The technological impact and the future growth of HFCS would seem at this stage therefore, to depend very heavily on the following factors:

First, it will depend on the overall growth of the demand for sweeteners which is a function of population growth, incomes, etc. As we have noted, the revealed pattern of demand is a nearly static or low overall global demand (unlikely to exceed in the best estimates 2½ per cent per annum). In the developed countries per capita sweetener demand is tending to fall or at best remain static. In the underdeveloped countries, per capita demand is rising, but from the existing pronouncements and agricultural plans, the drive seems to be for self-sufficiency in sugar production, consequently the impact of this rising demand on world trade will be largely negated.

Second, it will depend on the technical substitutability of corn sweeteners for sucrose. The tendency is for corn sweeteners in the industrialized countries to increase its range of users and so outstrip the growth of sucrose sweeteners both liquid and solid. As this substitution of corn sweeteners for sucrose develops, the growth of HFCS will further depend on its technical substitutability with other corn sweeteners, i.e. corn syrups and dextrose.

Third, since HFCS is liquid, its growth will be highly contingent on the development of the market for liquid sugar. In turn, this market growth depends on the growth of the processed foods and beverages sector, in particular the latter which is the largest consumer, or potential consumer of liquid sweeteners.

Fourth, because the output of HFCS is directly competitive with sucrose, the future course of sugar prices will determine the extent of the market. This factor is distinct from the technical scope of substituting sugar with HFCS. Unfortunately, sugar prices are extremely difficult to forecast. While in the post-war period a more or less definite, six-year cycle of sugar prices seemed to have emerged, since the commodity boom of 1974 and the subsequent collapse,stagflation,and emergence of major structural problems confronting the global economy, the future course of all prices are in doubt let alone a highly volatile price like that of sugar. It is true that an International Sugar Agreement exists, but as we have already seen, this agreement is still to become an effective and efficient regulator of sugar prices. As a result one might well conclude that the past and likely future volatility of sugar prices will operate as a dis-incentive to the use of sugar and an incentive to the substitution of the much more price stable HFCS. This effect will be independent of the effective differential between the price of HFCS and sugar prices.

Fifth, the growth of HFCS will depend on the future course of corn prices. The price of corn (both gross and net) is the principal cost factor in HFCS production. In the US, corn is produced in abundance so that direct consumption needs and animal feed are amply met. The by-products prices of corn are also dependent on these factors. To date HFCS has been marketed at a discount against sugar prices. One advantage of the corn price is as we have seen it is a stabler price than that of sugar. But because corn can be used to produce ethanol, the future course of corn prices will also be dependent on the price of petroleum products. In other territories where corn is imported and an HFCS industry exists, e.g. Japan and the EEC, the course of international grain prices will determine the degree of substitution which takes place.

Sixth, although many technological innovations have occurred since HFCS was first commercially produced, it is still by industrial standards a 'young' product. This means that there will almost certainly be further technological improvements. The speed with which these occur and are commercially adopted will determine the future competitive threat of HFCS. The critical technological hurdle which remains is the crystallization of the product. While this is already technically possible, the process is not yet commercially successful. The small plant producing crystalline HFCS which is in operation in Savannah, Illinois, sells the price of its product as high as $1.00 per lb. Crystallization of HFCS still remains the 'big prize' to be seized in the sweetener industry. This apart, however, other significant technological improvements can be anticipated, notably in the field of enzyme efficiency, energy saving, and labour saving automated processes. Whilst proportionally these gains will not be as large as previously, the continuous upgrading of the product which they constitute can only enhance its competitive position in the sweetener market.

A seventh consideration is that the commercial application of HFCS technology depends on the availability of capital and the likelihood of processing margins being wide enough to justify investments in the product. Over the past six years the world economy has gone through major upheavals and the process of structural re-adjustment is still underway, and far from completed. In these circumstances business outlook is not usually as sanguine as it would be in periods of boom and rapid expansion. As a consequence, investments in a new technology will be approached with greater caution and hesitation. The first introduction of HFCS occurred in a period of boom in sugar prices. Since then, evidence of 'over-capacity' in the industry had emerged in the late 1970's and the industry no longer supported the buoyant expectations of the earlier period. The partial recovery of sugar prices in 1981 led to some return of optimism. Presently, however, sugar prices (third quarter of 1982) are at a 5-year low with a glut of world sugar. The situation has been worsened by both the US decision to place restrictions on sugar imports and the bumper EEC beet sugar crop. The current outlook therefore, is not particularly encouraging for investments which will mature in the medium term.

An <u>eighth</u> factor which will determine the growth of HFCS is the development of the non-caloric sweetener market. At the moment this is small, less than one per cent of sweetener consumption. However, health concerns are driving consumers in the wealthy countries to look for a safe non-caloric sweetener which meets the qualities of taste etc. discussed previously. If this can be found, not only HFCS, but indeed all caloric sweeteners would be threatened. As we have pointed out a number of such sweeteners exist. The two most hopeful are <u>Talin</u> a white crystalline powder developed from a tropical berry grown in the West African rain forests, and modified sucrose. Both will be discussed in the next part of this study, particularly the latter which falls within the ambit of sucro-chemical research. The former depends on the possibilities of commercial production of a natural product. The fruit is called Thaumatoccus Danelli (TD) and it is claimed to be 3,000 times sweeter than sugar. This is supposed to be the world's sweetest natural substance.

The <u>final</u> factor which will be mentioned here is the sweetener policies which are pursued in both the established HFCS countries and those likely to move into production in the near future. As far as the latter group are concerned the main incentive would be the production of a domestic starch, an insignificant or insufficient sugar industry, and a significant soft drinks sector. Already as we have seen, countries like Pakistan, Korea, USSR, Argentina, Indonesia and China are producing or have advanced plans for the commencement of HFCS production. In all these cases the soft drinks sector is the main target, and in at least two cases a substitute starch is being used, (that is broken rice in Pakistan and cassava in Indonesia). Since isoglucose can be produced from other raw materials e.g., wheat, potatoes, cassava and rice, the availability of rice, sweet potato and cassava should make a difference. However, the Caribbean region is already well endowed to produce sugar cane and it is unlikely that the substitution in favour of HFCS would occur. In other Third World countries, however, where corn is available or domestic production of cane is not feasible, HFCS may emerge as an important commodity. This development is, we believe, likely only over the very long run. For the medium-term, sweetener policies in the established markets, particularly those of the USA, Japan and the EEC will be most crucial for the industry. We have already indicated the major policy directions in these markets. In the EEC over the next five years production of HFCS is being deliberately limited to 200,000 tonnes as the Community pursues its policies of support for its domestic beet farmers, and its obligations under the Lome Convention. Market forces are therefore presently playing a very minimal role in the evolution of HFCS output in the EEC. In the US the position is somewhat to the contrary. Despite concern for its domestic sugar producers and the import policies being pursued market forces are the key elements in the growth of HFCS in the US. Because of this it is important to note that the US firms which produce HFCS have substantial stakes in cane, maize, and beet sugar production, as well as other agricultural based products, e.g. soybean, and flour. Despite the stake in other sweeteners the tendency, as we have seen has been to expand HFCS production. Thus to take a few examples: American Maize (corn) and Amalgamated Sugar (beet) have a joint venture HFCS project to expand capacity by 100 per cent; Amstar (the largest US cane refiner and second largest beet producer) is to expand capacity by 80 per cent; ADM (soybean, flour, corn) will expand by 50 per cent; CPC (corn) will expand capacity by 180 per cent; Great Western (beet) will expand HFCS capacity by 400 per cent; and Holly Sugar despite declining earnings and a long (21 months) proxy war is also expanding new capacity.

In light of the interests in various sweeteners which these firms have, their willingness to expand HFCS is to my mind the single most significant pointer to the confidence which they have in HFCS as the sweetener of tomorrow. This confidence does not rule out periods of pessimistic outlook, as when sugar prices are very low and over-capacity manifests itself, as it has already done from time to time. But because the long run commitment is there such periods of downturn in HFCS activity may lead to price cutting given the large capital intensive overheads of these industries. If the gains of the new technology are seriously reversed then a switch to ethanol production becomes possible as this production basically uses the same plant designs as HFCS.

As developments proceed the HFCS producers who presently sell at a discount on sugar prices are more and more likely to set price ceilings which will progressively eliminate all inefficient cane and beet producers. These latter groups will have to depend more and more on subsidized or protected arrangements, whether they be domestic support policies of the US and the EEC or regional and international price support schemes like the Lome Convention and the ISA.

In conclusion therefore, HFCS represents the introduction of a sweetener based on very highly advanced sections of modern industry, e.g. bio-technology, automated flow processes, and waste management. To a mature traditional industry like sugar, developed and still largely practiced on the basis of inefficient agricultural methods and systems, the threat of HFCS is very likely to be all but mortal. It is well to bear in mind the following observation of the Cooper and Schendel study referred to earlier:

> "that traditional firms ... continued to make substantial commitments to the old technologies, even when their sales had already begun to decline ... perhaps this demonstrates the difficulty of changing the pattern of resource allocation in an established organisation."/14

The threat posed to organizations which are "established" and "traditional" should be combined with an appreciation of the fact that industrial changes are most radical where the newly innovated product serves more or less the same purpose as the existing one but has an entirely different technological base - as is the case with sucrose and HFCS. Furthermore, although HFCS is already a technically advanced product, experience in other industries would suggest that technical improvement will continue and peak after experience in its commercial application is deepened. Already in the short period of time since it has been introduced this can be observed. The threat to sugar, therefore, is one which will progressively get worse unless cheaper and entirely new ways of cultivating and processing cane sugar and beet sugar are found. Unfortunately, no such technological innovations are on the horizon.

Section (iii): <u>The Caribbean Position</u>

Whatever will be the eventual outcome of the competition between HFCS and other sweeteners in the market of the USA, Canada, EEC, and Japan, one result is beyond doubt, that is, the brunt of this competition will be borne by imports. It is only to be expected that if internal adjustments of sweetener markets are taking place that domestic public policy would shift as much as the burden as is possible onto foreign producers. One can therefore anticipate that as HFCS output grows imports will be the first casualty as import restrictions are imposed. If this occurs, Caribbean sugar, which is mainly export sugar is bound to be affected.

This position is not intended to make light the obligations held in the industrial countries to give support to Third World exports. The US import quota system, the Commonwealth Sugar Agreement (CSA) and later the Lome Convention, all testify to the fact that policies of guaranteed market and prices have been introduced by these industrial countries to foster the growth and eventual competitiveness of Third World sugar exports. But as we have seen with the CSA and later the Lome Convention these arrangements have had to struggle to survive against powerful economic and political pressure groups within the industrial markets. While traditional sugar refiners may favour the policy of encouraging the exports of Third World raw sugar, other domestic sweetener producers and consumers are bound to resist this if it means high prices and/or external subsidies.

Given these realities an important case can be made for a Caribbean approach to an International Sugar Agreement which does not only advocate an agreement for sugar - but an international plan to regulate the development of all sweeteners including HFCS, in an effort to ensure an orderly and planned evolution which does not protect inefficiency indefinitely but which at the same time does not presume that market allocations of sweetener production capacity will necessarily be socially just and equitable. A first step in this direction would be a call for the revision of the present International Sugar Agreement in order to include HFCS. The HFCS producers have an interest in stable sugar prices, even if they oppose subsidies to cane and beet sugar producers. This interest should be exploited to the mutual benefit of both types of sweetener producers.

As we saw in Chapter 1, although sugar output has been declining regionally, sugar is still an important part of Caribbean economy and society. The region's commitment to an orderly and rational development of the world's sweetener industry should therefore be as great as that of any other country or group of countries. Because of this, a definite response that is more than the "do nothing" policy which is presently being practised is called for. The first and most important step in this direction would be to make efforts to provide on a regional basis an efficient intelligence and monitoring capability to cope with the threat posed by HFCS to the region's overseas markets.

Monitoring is a vital aspect of managing technical innovation. According to Bright monitoring involves four basic activities:

1) Scanning the scientific, industrial and social environment for key signals that may be indicators of important technological changes to follow.

2) Closely identifying the possible consequences of the technological changes perceived.

3) Verifying the speed and direction of the technological changes and the effects of its use, by the institution on whose behalf the monitoring is undertaken as well as its use by competitors.

4) Presenting the data in a way which can make it possible for management to decide about its organization's reactions./15

Such activities are inevitably complex and the difficulties which they entail should not be underestimated by regional authorities in the sugar industry. Indeed, it is perhaps such difficulties which have contributed much to the response of "doing nothing". The uncertainties surrounding technical changes have been categorized as those of a "generalized" type which stem from an insufficient knowledge of cause-effect relationships; those of a "contingent" type which stems from the fact that no organization can control all the elements of the environment whose actions can impinge on it; and "internal" uncertainties which exist in all organizations because they are based on limited resources, interdependent groups and functions and are also affected by decisions made within them./16 In response to this situation Utterback and Brown have suggested a simplified but effective method of monitoring which basically involves two steps, namely:

" 1) identifying 'signals' of change in embryonic stages;

and 2) gathering information on appropriate phenomena and parameters to determine the rate of advance as well as the character and form that potential impacts of the change might take. This is essentially a method for dealing with contingent uncertainty. Prediction is improved by waiting for at least some of the environmental reactions to become clearer and by following this process until one or a few alternatives are clear"./17

It is monitoring along these lines which I am recommending. Needless to say such monitoring to be effective should at least be as international in character as the diffusion of the technology. Because of their relatively closer affinity to our environmental conditions care should be taken to monitor the arrangements surrounding HFCS production in the Third World and E. Europe. This is always very difficult because of data flows, and indeed this study while hopefully adding to the informational pool available to the region is most deficient in this area. It should be constantly remembered also that diffusion of technology is not only a multi-step process, but the probability of a given firm (or country) adopting a product or process is an increasing function of the number of firms(countries)in the industry already using it and an increasing function of the profitability of doing so.

The pursuit of an international agreement to regulate the production and marketing of all sweeteners, together with the development of a regional intelligence and monitoring capacity do not constitute a sufficient response to the threat. Such measures are primarily defensive. What is also needed is the rational pursuit of efforts to determine what are the technological possibilities of using sugar for something more than a sweetener. This task constitutes the subject of the second part of this study, to which we shall now turn. One final word is, however, needed. That is a reiteration of an earlier observation that the <u>interconnection</u> between the threat of HFCS and the development of alternations technologies to transform sugar into products other than sweteners must constantly be kept at the foreground of our understanding. If this is done then it would be seen that the recommendations which emerge from the first part of the study are not only incomplete, but logically cannot be taken further at this stage.

Notes to Chapter 5

1. T. C. Earley, (1980) p 63.

2. N. A. Kominus, (1980) p 47.

3. N. Rivero, (1980) p 158.

4. D. E. Nordlund, (1980) p 22.

5. G. Samuels, (1982) p 2.

6. S. Vuilleumier, (1980) p 229.

7. J. A. Cerro, (1979). Summary published by GEPLACEA Secretariat, p 29.

8. C. R. Steed, (1981) p 6.

9. R. Crott, (1982) p 42.

10. See W. E. Cox, (1967), whose empirical studies of ethical drug products and of non-durable goods did not always support the S-shaped sales curve. The Fisher-Pry study was broadly supported by Hatten and Piccoli's (1973) empirical studies.

11. See A. C. Cooper and D. Schendel, (1976). This empirical study was based on twenty-two separate firms in the following industries and technologies:

    steam locomotives _vs_ diesel electric
    vaccum tubes _vs_ transistors
    fountain pens _vs_ ball point pens
    boilers for fossil fuel power plants _vs_ nuclear power plants
    safety razors _vs_ electric razors
    aircraft propellors _vs_ jet engines
    Leather _vs_ polyvinyl chloride and poromeric plastics.

12. A. C. Cooper and D. Schendel, (1976) p 66.

13. _ibid_.

14. _ibid_, p 68.

15. J. R. Bright, (1970). See also J. M. Utterback and J. W. Brown, (1972).

16. J. M. Utterback and J. W. Brown, (1972). pp 5-6.

17. _ibid_, p 6.

Part II: THE PROMISE: THE TECHNOLOGICAL IMPACT OF SUCRO-CHEMICALS

Chapter 6: THE INDUSTRIAL USES OF CANE SUGAR BY-PRODUCTS

Throughout its history the cultivation of the sugar cane plant has been primarily oriented to the production of sucrose with varying but nevertheless limited uses of its by-products. In this chapter we shall provide a starting point for our inquiry into the promise held by sucro-chemicals in delineating the broad industrial potential of the sugar cane plant before pin-pointing the industrial potential of one of its products – sucrose.

On average, for every 100 tonnes of sugar-cane ground the following is produced:

(i) 11.2 tonnes of raw sugar (98.5 Pol.);
(ii) 5.0 tonnes of <u>surplus</u> bagasse (49 per cent moisture) = 1,300 k.w.h. surplus electricity;
(iii) 2.7 tonnes of molasses (89 Brix; sp. gr. 1.47);
(iv) 3.0 tonnes of filter mud (89 per cent moisture);
(v) 0.3 tonnes of furnace ash;
(vi) 30.0 tonnes of cane tops/trash.

The quantities given above are industrial averages and therefore vary considerably between countries and between installations in the same country. Thus in the Caribbean as the factories have declined in efficiency, we find that whereas a decade ago the average of 11.2 tonnes of raw sugar per 100 tonnes of sugar cane ground was close to the average for the region as a whole, presently the ratio is as low as 7-8 tonnes of raw sugar per 100 tonnes of sugar cane-ground. Or to take another example where the plant is burnt before it is reaped, there will be no cane tops/trash recovery. One set of products excluded from the above list is fly ash and carbon dioxide which escape from the boiler stacks in the factories.

Our area of investigation in this study is the industrial uses of raw sugar only in the sense of Paturau's definition: "the conversion of sucrose by chemical mechanisms into products of greater worth".[/1] The precise mechanisms of this chemical conversion will be discussed in the next chapter, but it should be noted here that it is this area which constitutes the focus of sucro-chemistry. The utilization of the by-products (items (ii) to (vi) above) falls into the area known as "extended chemurgy".[/2] As indicated in the first paragraph, despite our primary focus, it would be useful to look at the broad features of by-product utilization of the sugar-cane plant before we proceed.

Bagasse which comprises cellulose (paper products), pentosans (furfural), and lignin (plastics) is a principal by-product of the sugar-cane plant and studies have established that it has a wide range of industrial uses. The most important are indicated below:

<u>Bagasse</u> -

(i) <u>fuel</u> (electricity, charcoal briquets, methane and producer gas);

(ii) <u>fibrous products</u> (pulp and paper, paper board, fibre board, and particle board);

(iii) <u>miscellaneous products</u> (furfural which is used as a selective solvent in the production of lubricants, furfilic alcohol and certain pharmaceuticals and pesticides; alpha cellulose used in the manufacture of rayon and acetate fibres, cellophane, plastics, explosives, films, lacquers and fine papers; plastics; poultry litter and mulch; animal feed; begasse concrete; and soil amendments).

The use of begasse to fuel sugar-cane factories is universal, making the production of sugar from the sugar-cane plant energy self-sufficient. In a number of countries fibrous products are made from the begasse along with some of its miscellaneous uses, e.g. poultry litter and mulch.

A second by-product is molasses which is rich in sugar and so can be used as a chemical raw material, nutrient for micro-organisms or in specific chemical reactions. Its principal uses are listed below:

Molasses - (i) direct utilization (fertilizer, animal feed);

(ii) distilling industry (rum, ethyl alcohol, rectified spirits, power alcohol and alcohol derivatives);

(iii) other fermentation industries (vinegar and acetic acid, acetone-butanol, citric acid, glycerine and yeast);

(iv) miscellaneous products (aconitic acid, monosodium glutamate, dextran).

Like bagasse, molasses is an important by-product of the cane sugar industry. Its principal uses are as animal feed and in the fermentation industries. As an animal feed it is heavily traded and competes directly with maize, thereby providing yet another major inter-connection between HFCS and sucrose. The use of molasses in the distillation industries is world wide. Recently, however, some countries have been moving to develop gasolene extender programmes, e.g. Tanzania and Mauritius, and they are using molasses as the feedstock for alcohol production, rather than the direct production of alcohol from sucrose.

Filter mud is not a widely utilized by-product. Its major uses are indicated below:

Filter Mud - fertilizers and soil conditioners, animal feeds, wax and fats, and building materials extender.

The wax and fats in filter mud derive from the water repellant property of the cane skin. This, however, only represents about 0.18 per cent of the cane weight. From all indications most of the filter mud is either

wasted or added to soils and feeds.
The <u>furnace ash</u> derived from the factories can be used as building materials. This however, constitutes only 0.3 per cent of the sugar-cane plant. The <u>cane tops and leaves</u> make up the bulk of the by-products of the sugar plant, accounting for as much as 30 per cent of its weight. It's principal use is in the form of animal fodder, but its availability is contingent on whether the canes are burnt or not prior to reaping.

In the Caribbean region by-product utilization is rather limited and the focus of the industry is overwhelmingly in favour of sucrose production. So far molasses is used to produce spirits, while some of it is used also as animal feed domestically or exported. In the distillation of spirits from molasses there is no significant use of the carbon dioxide and the distillery stillage which are further by-products. The latter consists of unfermented carbohydrates and dead yeast and usually it goes to waste. Indeed there have been times when molasses has been so "plentiful" that it has been buried as a means of disposal. Bagasse is of course widely used in cane grinding factories as fuel. Some of the surplus also finds its way into poultry litter and plant mulch, while a small amount of bagasse board is produced. In the case of filter mud this is generally spread on the fields as a fertilizer and soil conditioner. The fly ash is sometimes used in this way also. Where the cane tops and leaves are not burnt, small amounts find their way into animal feed.

This relatively limited utilization of by-products in the region is combined with an underdevelopment of local production of refined sugars and syrups. These sugars and syrups are used in the confections, beverages and food processing industries and it is not unusual to find local processors requesting licences for their importation. As a result we can conclude that the focus of the region's industry is not only on the production of sucrose, but even more narrowly on the production of sucrose for export and further refining abroad. As we have noted in Chapter 1, the region's per capita consumption of sugar is high. As a consequence, future growth in demand is likely to favour a substitution of industrial for household uses of sugar, rather than a rise in per capita consumption. The need for domestic refining capacity is therefore likely to increase.

In our study of the HFCS industry in Part I we indicated how important the corn by-products credits were to the industry, accounting for nearly two-third's of the gross raw material costs of the industry. Reliable data on by-products credits in cane sugar cultivation in the region are not available but the evidence suggests that these are small, about 5 per cent of production costs. Beet sugar production also yields by-products, the major one being sugar beet pulp. This is usually available in molasses form (dried and wet) and is almost entirely confined to providing animal feeds.

Bearing in mind this broad background picture of the potential uses of sugar-cane by-products, we can now proceed to an examination of the industrial potential of sucrose itself.

Notes to Chapter 6.

1. J. Paturau, (1969), p 11.

2. *ibid*, p 11.

Chapter 7: THE POTENTIAL OF SUCROSE AS A CHEMICAL FEEDSTOCK

Section (i): The Properties of Sucrose

As pointed out in the previous chapter our concern is with sucrose as a potential feedstock for a chemical industry and not the utilization of the traditional by-products of cane sugar production. Our investigation in the previous chapter filled in some background information, as it were, on traditional by-product utilization. These same by-products would still be, of course, available, if the sugar-cane plant is used to produce sucrose which is then converted into a chemical feedstock rather than consumed in the way it is at present. In this sense therefore the description of the previous chapter would still remain an ancillary aspect of the industry and should therefore not be discarded merely on account of the shift in emphasis we are pursuing in this study.

Approaching the study of sucro-chemistry from a 'non-chemistry' background, I have found a useful starting point to be a general understanding of the chemical properties of sucrose, particularly, as many chemists themselves are not familiar with the field of sucro-chemistry. On the basis of literature surveys, and discussions with knowledgeable persons in the field I believe the following to constitute a fair summary of the more important chemical properties of sucrose, and therefore those vital to an evaluation of its potential as a chemical feedstock.

(i) Sucrose is the largest single quantity of a pure defined organic compound available to man. It has a low molecular weight (342) and great chemical versatility. It is so pure that ordinary table sugar contains 99.96 per cent of the molecule sucrose with more than one-half the remainder being water. Even the "raw sugar" shipped from the Caribbean has a purity ratio as high as 97.5 per cent. Its bulk derives from the fact that world output of sucrose is currently approaching 100 million tonnes annually. These two properties, bulk and purity constitute important assets of sucrose when considered from the point of view of its use as a chemical feedstock.

(ii) Sugar is chemically versatile. As Vlitos points out because it constitutes a "cheap polyhydric alcohol [it] can be used in a wide range of reactions to make resins, plasticisers, surfactants". /1 Indeed, sugar is so versatile that it is claimed that it is technically possible to produce from sucrose all the chemicals currently produced from petroleum feedstocks.

(iii) Sucrose is water soluble, and in some chemical reactions this is an important asset, while in others it can constitute a disadvantage.

(iv) Sucrose is readily metabolized by micro-organisms, plants, animals, etc. This property makes it bio-degradable and constitutes an important advantage over some petroleum derived chemicals, e.g. detergents.

(v) Sucrose is non-toxic. Not unexpectedly this property widens its range of useful applications, particularly in such areas as food, pharmaceuticals, and cosmetic preparations.

(vi) Sucrose readily forms complexes with some metal ions.

(vii) Sucrose is hygroscopic, that is, it has a tendency to absorb moisture.

(viii) Sucrose is an important raw material for microbial conversion processes and because of this it has been traditionally used in the production of alcohols, organic acids, and so on.

(ix) Sucrose is unstable to heat and this had tended to pose problems in certain chemical processes.

(x) Sucrose does not only produce energy but it also constitutes mass. This gives it an important edge in the search for alternative energy systems, since some of the alternatives being investigated, e.g. wind, nuclear power, and water systems while producing energy, they do not constitute mass in themselves which they can pass on to other products.

(xi) There are two manifest chemical reactions of sucrose which must be continuously appreciated. One is <u>hydrolysis</u>, that is the inversion of the angle of polarisation in the presence of Lewis acids. With water inversion yields two simple sugars D-glucose and D-fructose. For our purposes the point of significance is that for most sucro-chemical processes, inversion is undesirable. This therefore poses the requirement that reactions must be carried out in the absence of Lewis acids. The other manifest reaction is <u>pyrolysis</u> which is a more complex reaction than hydrolysis. It is a part of the familiar process of carmelisation which occurs when sugar is heated much above $140^{o}c$ in the presence of salt or acid catalysts. The products yielded are water and an exceedingly complex mixture of degradative products. As would be expected, pyrolysis would generally be an unwanted reaction in sucro-chemical processes, and therefore such reactions would have to be insulated from direct contact with Lewis acids and also operate at moderate reaction temperatures.

(xii) Sugar molecules (sucrose, hexoses, etc.) are notoriously unstable. As Paturau observes:

"These molecules play a most important part in the plant kingdom where they are constantly being formed, broken up and transformed". /2 But what is an asset in biological reactions can constitute serious obstacles in chemical reactions.

(xiii) Sucrose hydroxyls are usually less reactive than water. This property poses a problem when making derivatives of sugar in aqueous media.

(xiv) Finally, in sucrose the high ratio of oxygen to carbon puts a limit on the number of organic solvents which can be used. Petroleum is generally low in oxygen or has exclusively carbon and hydrogen atoms. As a chemical feedstock this makes for good yields:

"Thus the theoretical yield/weight from petroleum derived ethylene is 165%, whilst ethanol production by fermentation results in discarding two-thirds of the oxygen and one-third of the carbon, the maximum theoretical yield being 54 per cent." /3

Such limitations do not constitute insuperable obstacles. As we shall observe later there are ways around them;one being to focus on derivatives which while having poor to moderate yields may not be easily substituted by other products. Another would be to focus on reactions where a biological process is used, e.g. citric acid, and yet another would be to focus on those reactions where weight loss is minimal but where alternative routings are not easily pursued e.g. sorbitol, mannitol.

Section (ii): Chemical Operations with Sucrose

The schematic presentation in the previous section of the important chemical properties of sucrose equips us for the next step of the analysis, which is to determine the nature of the chemical processes on which a sucro-chemicals industry might be built. We shall attempt this very important task in the present section, referring from time to time to the significance of the properties listed above.

The fundamental issue is that in order to be able to utilize sucrose commercially it must be transformed to other products of greater worth either chemically or microbiologically. Unfortunately the phrase "of greater worth" is sometimes overlooked in the excitement over important technical discoveries whose importance as a contributor to net worth cannot be presently justified. Leaving this issue aside for the moment, however, there are two major routes in the chemical transformation of sucrose, that is chemical degradation and directed synthesis with other chemicals. We therefore have in total three routes, namely,

- microbial conversion
- chemical degradation
- chemical synthesis.

Each of these will be examined in turn.

Microbial Conversion:

In the case of microbial conversion there are basically two points which should be observed. First, this approach is traditional and perhaps is best exemplified in the familiar fermentation processes. In this conversion certain vital factors should be appreciated:

(i) The use of micro-organisms in the conversion of one chemical product to another is relatively non-specific. This means that after suitable treatment most carbohydrate sources, not only sugar, can be made into feedstock. To use this process would mean that a chemical industry based on sucrose must be highly competitive, cost-of-raw-material-wise, with other carbohydrate sources, e.g. corn, rice, wheat, potato, cassava. In other words the specific advantage of sucrose could well be lost in the non-specific microbial conversion process.

(ii) Because micro-organisms are used in the conversion process yields are inevitably low, since the micro-organism must metabolize a proportion of the sucrose as a source of its energy.

(iii) The microbial conversion process has low reaction rates, and requires large volumes of the product and long residence times. Although research is improving on these variables, as we noted in the case of isomerization of corn to fructose where the use of immobilized enzymes has replaced the older batch production process, the cost of doing so relative to other processes, e.g. petro-chemicals, is a factor which has to be taken into account.

(iv) The separation of the wanted product from others in the microbial process poses major technological problems whose solution inevitably raises costs. Thus for example the presence of water would normally require an energy input to concentrate and separate the product.

While the above observations show how restrictive the microbial process is, some of these restrictions can constitute advantages in certain circumstances. To take a few examples. The presence of water and associated non-sugars in chemical operations may be desirable. Or the microbial processes can be seen as permitting complex multi-step and stereo-specific reactions and with improved conversion efficiencies this can be an important advantage. Similarly, this process can often utilize substrates of quite low purity and therefore can be an important element in the exploitation of what would normally be treated as waste residues.

The second point to observe is the range of products which can be produced by microbial conversion. A wide range of products can be produced as a result of the metabolism and growth of micro-organisms in a carbon and energy source such as sugar. The technical task is to find the particular micro-organism which can carry out the specific chemical transformations of the sucrose molecules which are required. While some of these are beyond the current capabilities of organic chemistry the following constitutes the major products which can be produced:

(i) A wide range of antibiotics which is of course used in the health sector.

(ii) Gluconic acid. The yield here is 70 per cent of the sucrose used. This acid finds applications in: pharmaceutical preparations where salts are used as a means of introducing trace elements to the diet, e.g. ferrous gluconate (iron) and calcium gluconate (calcium); food and feeds where it can be used as a source of calcium for chickens, or used as a stabilizer in shortening, or used to prevent excessive browning in deep fat frying; cleaning compounds, where it is useful for cleaning bottles and metals because as a cleansing agent the acid has low toxicity and corrosive powers; paints where it is used for its anti-corrosive properties in marine applications or it is used as an additive to water based paints in order to prevent "flashing" due to the presence of calcium and magnesium.

(iii) Xanthan gums. The yield here is 65 per cent of the sugar used Xanthan gum is a pseudo-plastic material with unique rheological properties combined with resistance to temperature and pH changes. It is used in: foods in order to improve mouth feel, freeze-thaw stability in frozen foods, act as a suspending and thickening agent in relishes and salads and to provide the characteristics of gluten in non-wheat flours; cosmetics as a suspending and emulsifying agent in toothpastes, ointments, creams, etc.; oil well drilling as a fluid additive because of its compatibility with salts and its resistance to temperature degradation. For oil well applications it is useful as it has a high fluid carrying capacity and low water loss properties. It is used in many industrial products also as a suspending, emulsifying and stablizing agent especially for some difficult to stabilize polishes, cleaners, ceramic glazes and print pastes.

(iv) Bio-polymers. The synthesizing of high molecular weight polymers from sucrose is a quite well-known process. It is claimed that this process is an integral part of the metabolism of all micro-organisms and is not a surprising occurrence in view of the important role of lipopolysaccharides in the structure of most micro-organisms. The best known of the bio-polymers is dextran. The yield of dextran is 33 per cent of the sugar used. It finds useful applications in medicine, as a blood plasma volume extender; food processing, as a thickening agent and in oil well drilling. There are several plants producing dextran around the world and one is located in the Caribbean (Cuba).

(v) D-araboascorbic acid (iso Vitamin C). The yield here is very low, 15 per cent of sugar used. It is normally produced using a preparation of dried cells of penicillin notatum in sucrose.

(vi) Kojic acid along with derivatives for use as pesticides. The organism used is Aspergillus flavus.

(vii) Fructose, which can be produced from sucrose by the organism Aspergillus niger.

(viii) Ethanol. This can be produced directly from sugar-cane juice or from molasses. Ethanol can be used as a fuel extender; to make potable alcoholic beverages, as an intermediate chemical and as a chemical feedstock. It is the most important product of this route and as we shall discuss in Chapter 9 it is seen by some as the major future product of sucrose.

Chemical Degradation

The second process is that of chemical degradation. The diagram shown overleaf summarizes the process. As we shall observe more fully in the next chapter, this route has typified the research work of the International Sugar Foundation. Experience has shown that it has been from a commercial standpoint, a generally fruitless endeavour, although as we shall see many technical results have been achieved. The major problem with this route appears to be that degradation products of sucrose are of

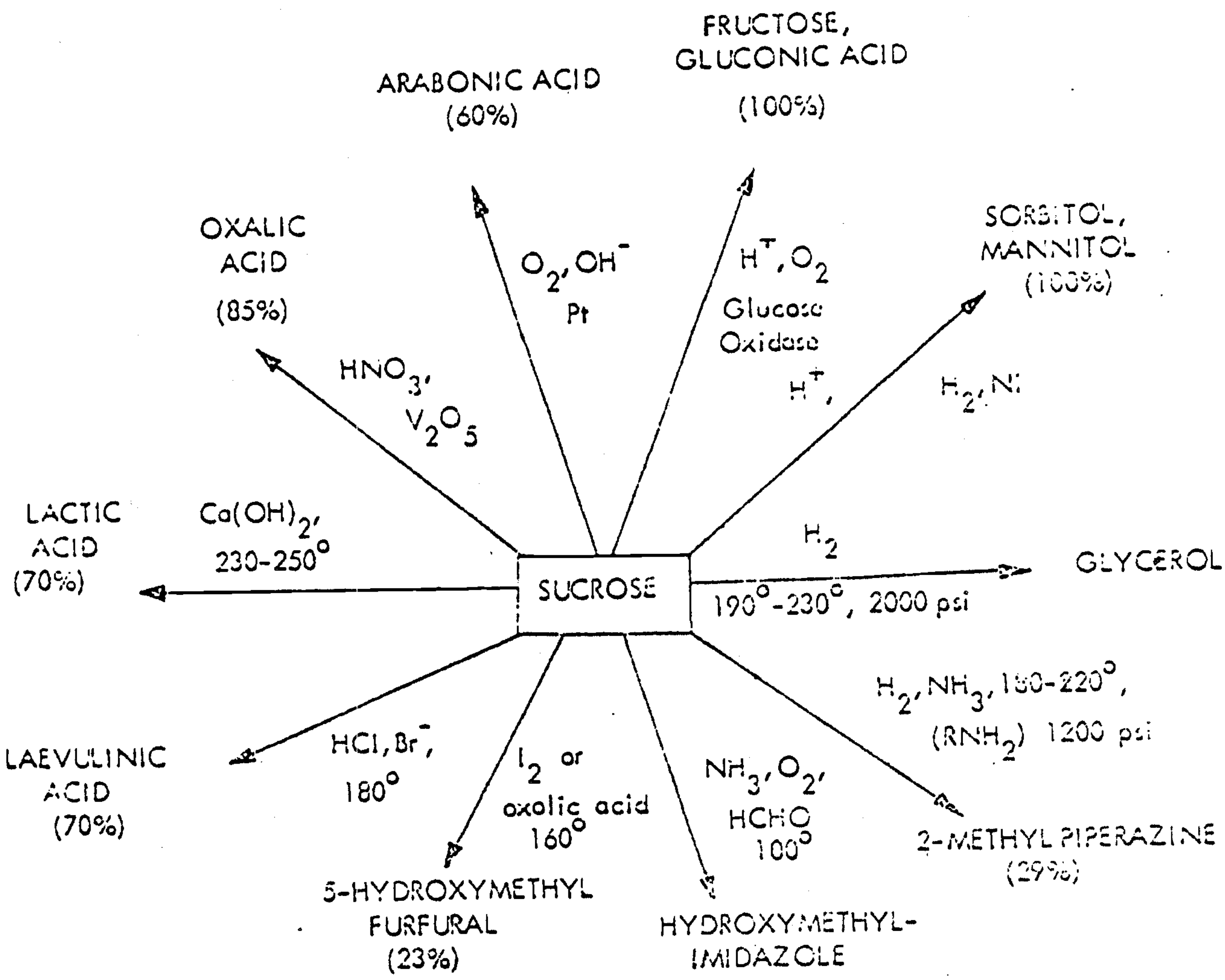


Figure 1: DEGRADATION REACTIONS OF SUCROSE

a lower molecular weight thereby permitting their synthesization either from cheaper sources of carbon, e.g. petroleum, or even from carbohydrate wastes. There is the additional factor that chemical degradative reactions proceed in a relatively "uncontrolled" fashion thereby yielding a mixture of products from which the required product has to be then isolated. It would appear therefore, that on purely a priori grounds the effectiveness of this route has to be restricted to special circumstances where no competitive products can be easily produced. This position is supported by Khan and Forage:

> "Despite extensive research in the past in degradation reactions of carbohydrates to yield a variety of products this approach, at present, is non-competitive."/4

With these cautions in mind we can complete the description here by observing the various degradation reactions which have been identified and which are summarized in the Figure above. These reactions are as follows:

(i) Mild conditions of catalytic hydrogenation of invert sugar. This yields the hexitols, mannitol and sorbitol. These are special products and their output via this route is already commercialized. The sucrose demand, however, is limited as very little sucrose is used in their production.

(ii) Vigorous conditions of catalytic hydrogenation of sucrose. This yields glycerol with by-products being propanediol, ethyleneglycol and erythriol. It is estimated that in the mid-1960's about one-tenth of US production of glycerol was produced in this way. However, competition from synthetic glycerols led to the closing down of the major plants in 1969.

(iii) Hydrogenation in the presence of amonia or primary amines. This yields 2-methyl-piperazine or the N-alkyl derivatives. The yield has never increased beyond 30 per cent and the result is thought to be uneconomical.

(iv) Direct reaction of sucrose with amonia. This yields a complex mixture of nitrogen heterocycles in which dimethyl-imidazoles predomiante. Yields are also unpromising and this route is thought of as being uneconomical as well.

(v) Weak acid catalysts at elevated temperatures. This yields 5-hydroxymethyl furfural. Yields are low, below 25 per cent and demand for this product is limited.

(vi) Strong acid catalysts at elevated temperatures. This yields laevulinic and formic acids. This route has not been exploited commercially because these products can be obtained from furfural.

(vii) Alkaline degradation of sucrose in the presence of lime. This produces lactic acid in good yield (70 per cent). The lactic fermentation process is however better (yields 85 per cent) and so is the preferred route. Synthetic lactic acid is also being produced.

(viii) Nitric oxidation of sucrose. This produces oxalic acid in good yields, but is still uneconomic when compared with the use of cheaper cellulose and carbohydrate wastes.

(ix) Aerial oxidation of sucrose in the presence of platinum catalysts. This yields arabonic acid in good quantities and research chemists are sanguine about this possibility.

(x) Aerial oxidation of sucrose in the presence of immobilized glucose oxidase. This produces gluconic acid and fructose and the yields here are also thought of as promising.

Directed Synthesis

Given the limited scope for economical application of sucrose through both the processes of microbial conversion or chemical degradation, any promise of a thriving sucro-chemical industry has to be based on technological breakthroughs, along the third route, namely directed synthesis. The two routes already considered basically seek to use sucrose as a source of simpler products. The approach of the directed synthesis regards sucrose as a primary raw material itself and seeks to exploit the opportunities of synthesizing it with other chemicals in order to produce higher valued products. This approach makes use of sucrose in the form it is normally marketed, that is its pure anhydrous state./5 The potential for using sucrose in this way is bound up with the chemical properties of sucrose identified in section (i) above, for the object of directed synthesis is to produce reactions with selected synthesizing compounds, and these reactions will be determined ultimately by the reactivity and stability of the sugar molecules.

Because sucrose is essentially a polyhydric alcohol chemists point out that it has the potential to give rise to an almost unlimited range of derivatives./6 It will undergo all the typical reactions of alcohol. Following Vlitos we can present these potential derivatives by function as is shown below./7 The right-hand column indicates the potential industrial use of the derivatives, based on current knowledge.

The first function is esterification of sucrose using conventional methods leading to poly-ester. The resulting products would depend on the conditions and the acylating agent which is employed. The second function is etherification and this is also available by conventional routes, although not without some difficulty. The third function is the production of urethans.

The fourth function is the production of xanthates, and the final function is the production of acetals.

(i) Esters

Monostearate Monoacetate	Surfactant emulsifier Humectant
Distearate	Emulsifier
Hexalinoleate	Surface coatings
Octa-Acetate	Denaturant Plasticiser
Octa-Benzoate	Plasticiser
Di-isobutyrate Hexa-Acetate	Viscosity Modifier
Monomethacrylate	Resin Monomer
Polycarbonate	Resin Intermediate

(ii) Ethers

Mono-octadecyl ether	Surfactant
Hepta-allyl	Drying Oil
Octacynaoetlyl	Dielectric
Octa-Hydroxypropyl	Cross-linking agent in polyurethane resins

(iii) Urethanes

N-Alkyl Monoxanthates	Surfactants, chelating agent

(v) Acetals

Cetyloxyethyl Sucrose	Surfactant

A major obstacle in the development of synthetic sucrose derivatives is the "restricted solubility of the reactants in solvents other than those which are similar in reactivity to sucrose itself". As we shall see in the next chapter, some of the solvents used e.g. pyridine, dimethylformamide, dimethylsulphoxide are very costly if considered on a commercial scale. This has encouraged the search for products which would require no solvents or alternatively products that can sell at a price to recoup the cost of such expensive solvents. These issues will be taken up in later chapters, for here our objective is limited to the presentation of the major technical issues at stake in the production of sucro-chemicals.

Section (iii): Conclusion

The first two sections of this chapter sought to highlight the technical problems involved in the production of sucro-chemicals. Although the focus was on the 'chemistry' of the problem, it was impossible to avoid indicating some of their commercial implications as we proceeded. The presentation on the chemistry issues began with a summary of the chemical properties of sucrose in order to identify its potentiality as a chemical feedstock and then I proceeded to discuss the technical routes towards the production of sucro-chemicals. Three routes were identified and each was discussed in turn. Directed synthesis was identified as the preferred route and a presentation of sucrose derivatives by chemical function was displayed in the schema above. By way of concluding this chapter, an alternative presentation which groups the products that sucrose can produce by the type of reaction which produces them is offered. This is based on an earlier work of Paturau, and is offered primarily for the sake of completeness of the presentation of this chapter./2 While it adds no new information, nevertheless it alters the perspective from which the potentiality of sucro-chemicals is presented. In this way it might deepen our understanding of the issues at stake.

Type of Reaction	Product
1. Fermentation	Ethanol, butanol, acetone, acetic acid, citric and lactic acid.
2. Esterification	Sucrose octa-acetate used in adhesives, as a denaturant, plasticizer and in cellulosics; fatty acid esters; and sucrose octanitrate (explosives).
3. Allyation	Allyl sucrose used as coating materials, adhesives, fast drying paints, varnishes, etc.
4. Reaction with propylene	Hypose SP80 which is the trade name for octakis (2-hydroxypropyl) - sucrose used in polyurethane foams as a plasticiser, in resins and glue starches, etc.
5. Reaction with phenol and formaldehyde	Explosives.
6. Oxidation	Food and pharmaceutical products e.g. D-arabonic acid used in the manufacture of Vitamin B_2.
7. Hydrogenation	Sorbitol and Mannitol which is used as a humectant in medicine (e.g. laxatives and blood pressure depressant); propylene glycol which is used as a polyester resin; and glycerol used in resins and gums.
8. Acid degradation	Furfurals used as plasticizers, food and pharmaceutical additives, etc.
9. Alkali degradation	Lactic acid which has a wide variety of uses; methyl acrylate which is used as an adhesive; polymer; protective coatings, etc.
10. Hydrolysis	Fructose used in food and pharmaceutical preparations.

Notes to Chapter 7.

1. A. Vlitos, (1979) P.E. 14.

2. J. Paturau, (1969) p 11.

3. ibid, p 12.

4. R. Khan and A. J. Forage, (1979/80), p 178.

5. See, K. J. Parker, (1979); (1980); and K. J. Parker and R. Righelato, (1980); J L. Hickson, (1977); A. Vlitos, (1977) and A. T. Vlitos and K. T. Parker, (1981).

6. A. Vlitos and K. Parker, (1981) p 40.

7. A. Vlitos, (1977).

8. K. Parker, (1979).

9. J. Paturau, (1969).

Chapter 8: HISTORICAL/FUNCTIONAL ANALYSIS OF THE DEVELOPMENT OF SUCRO-CHEMISTRY

With the chemical features of sucrose and the technical routes towards the production of sucrose chemicals behind us, we can now turn to a brief examination of the historical course of research in this field. Only the most general of outlines will be attempted here, but hopefully this should be adequate for deepening our understanding not only of the course technical innovation has followed, but of the technological hurdles which still have to be overcome. Hopefully, also this would bring greater coherence to the analysis presented thus far.

If careful consideration is given to the evolution of the chemical industry it would be observed that agricultural raw materials have always been an important feedstock for this industry. Sugar, starch, potash, cellulose, and vegetable oils are among the better known and most widely used of biomas materials. However, following on the great oil boom in the middle of this century, petro-chemical feedstocks became the major input into the chemical industry. Thereafter,the chemistry of agricultural raw material utilization in industry was replaced by the focus on a more and more efficient utilization of petroleum fractions and their derivatives. This substitution in favour of petroleum, affected not only biomass, but was also to the disadvantage of coal, until then also a major industrial input into the chemical industry.

From the industrial point of view chemistry cannot be looked at in isolation from energy. Energy is needed to power industry, to energize our transport and communication systems, to heat our places of living and working as well as for producing the fertilizers, pesticides, weedicides, etc., without which a modern agricultural system capable of feeding large urban populations would be impossible. Energy is also needed to produce the minerals which we need, as well as the clothing, housing, recreation and entertainment facilities without which we cannot live full lives as humans. All this is familiar, but it takes on added significance in face of the current fuel crisis. The current fuel crisis is the second major fuel crisis to be identified in the period of capitalist industrialization. The first is usually located in the early years of industrialization in the middle of the 19th century in the United Kingdom, (and much later in the United States), when fuel wood which was then extensively used, became scarcer and scarcer.

In all the major energy systems used so far: coal, biomass and petroleum, the raw material has produced both energy and mass for chemical utilization. Some of the newer energy systems being contemplated, while producing energy do not produce mass. In so far as mass, or as it is sometimes put a "harvest of tons" is required by industry, biomass has the advantage of being a truly regenerable resource which can meet the large variety of human energy needs as indicated above. This constitutes what I believe to be the long run inherent structural advantage of biomass and so long as it remains this way, the search for breakthroughs in the efficient utilization of biomass will proceed. It is true that in the past the search for breakthroughs was intensified during periods of critical shortages of fuel (necessity is the mother of invention!) and has receded in times of apparent bountifulness, but the underlying drive in this direction has nevertheless continued, and will continue. It is within this category of general considerations therefore, that the industrialization of sucrose has to be evaluated.

The development of sucro-chemistry as a defined field of study is associated with the establishment of the Sugar Research Foundation in 1943. The establishment of this institution came at a time not when fuel was scarce, but sugar was thought of as plentiful, and there were fears of disposal of surpluses. The Foundation was established with the aim of pursuing on its own initiative, nd supporting elsewhere, studies on the non-food utilisation of sugar. Despite this mandate, however, during the first eight years of its life the Foundation concentrated on improving sugar consumption through the systematic dispelling of what it termed as "myths and misconceptions" of the health and dietary consequences of increased sugar consumption.[/1] This purely defensive attitude changed somewhat with the appointment of Prof. H. B. Hass, who as Hickson describes it "had gained an enviable reputation by taming the halogenation and nitration of carbohydrates in the vapour phase".[/2] It was under his leadership that a programme of sucro-chemistry research was officially launched. This programme was defined by Hickson as "the conversion of sucrose by chemical processes, into materials of commercial value".[/3] It was this definition he claims, which Prof. Hass christened as sucro-chemistry. Interestingly, the definition given is not only technical, but is commercial in its orientation as well.

The issue of satisfactory solvents for use in sucrose derivatives was raised in the previous chapter. It was not until the 1950's that a major set of new solvents became available to chemists, principally, N, N-dimethylformamide (DMF) and Dimethylsulfoxide (DMSO), which could be used in the production of esters and ethers. In the decade, 1950-60, after some promising discoveries chemists in the field became optimistic and began to proclaim that "the non-food uses of sugar would be the panacea for surplus production".[/4] Hickson describes it graphically: "the Foundation of the mid-1950's developed a high expectation for the potentials of the sucro-chemical programme. An eager technical press greeted each new finding, lauding the programme as a breakthrough in the utilisation of biomass resources ... this fanned the hopes of the sugar producers supporting the Sugar Research Foundation. It certainly was great while it lasted."[/5]

The promising technical results however, could not be translated into commercial successes and as Paturau remarked: "it was soon found that the industrial production and marketing were indeed more difficult than had been expected, especially when in competition with the powerful petro-chemical industries and other vested interests".[/6] This should not have been surprising as it is estimated that there are 3,000 known surfactants alone so that market penetration would always be a formidable task.

The work of Prof. Hass and his colleagues did, however, provide some important discoveries with commercial potential. One good example of this was the production of a surfactant ester under a process which was licensed by Dai Nippon Sugar Manufacturing Coy of Tokyo in 1960, and continued by Ryoto Coy in a joint venture with Mitsubishi, to produce the Ryoto esters used in food, pharmaceuticals and cosmetic industries. The original reaction solvent that was used was DMF, but because of problems of potential toxicity etc., the company had to invent a process which did not require it use. A second good example of the work of this period is the process for producing sucro-glycerides, which is a mixture of sucrose esters and fatty glycerides. This was first used in production under licence by Melle-Bezons of Paris and later the licence was acquired by Rhone-Poulence. The trade name is Celynols. This process is capable of reducing the residues of DMF, which is used as the reaction solvent, sufficiently to permit applications in the food industry. The main market, however, is animal feeds where it is used to reconstitute vegetable oils into skimmed milk for feeding calves. This latter process has been substantially modified and developed by Tate and Lyle and will form the subject of some extended discussion later.

It is claimed that the very first commercialized sucro-chemical to be produced was octa-acetate. The development of this product was due largely to work done in the Mellon Institute in the USA. This product has found two principal uses to date. One is as a plasticiser in the cellulose esters where it is used as a bonding agent in laminated safety glass, and the other is as a denaturant, e.g. in pharmaceutical ethanol. This product has an exceedingly bitter taste and it is this property which favours its use as a denaturant. The combined markets for these products, however, is small, totalling approximately 50 tons per year.

The work of the Sugar Research Foundation was often done in collaboration with, or at the prompting of other institutions. Thus the work on the sucrose monoesters of fatty acids was done at the request of the State Government of Nebraska which was then looking for markets for inedible animal fats, principally tallow. Research into sucro-chemicals was also not confined to the Sugar Research Foundation even during its hey-day. We have already referred to the early work of the Mellon Institute. The Kansas State University has also done important work in the area of testing sucrose esters and other surfactants in the baking industry where several important roles have been identified. In addition Tate and Lyle and its associated research laboratory at Reading University has been the organisation most consistently committed to a comprehensive programme of technical work in the area of sucrose chemicals during the last decade or so. As Tate and Lyle will form a special chapter of inquiry,(Chapter 10) we can suspend discussion of these issues until then.

While the work of the Sugar Research Foundation dominated sucrochemistry research up until a decade or so ago when this role was assumed by Tate and Lyle, the object of the Foundation's research was to generate information on the chemistry of sucrose, evolving syntheses of sucrose, and determining the properties of the new sucro-chemicals created. The emphasis was more scientific than technological./7 It certainly was not commercial as Hass definition suggests. One result of this has been a virtual neglect of the class of materials known as urethanes. Urethane technology in the West has developed in the industrial milieu of chemical TNCs and the Foundation expected this to continue. In any case it felt that it did not have the resources which were required to make a significant contribution in this area.

A central criticism of the Foundation's research is that it proceeded with far too heavily an emphasis on the degradative products of sucrose. The long list of degradative reactions which was identified in the previous chapter is largely the product of chemical research in one way or another associated with the Sugar Research Foundation. The criticisms of this approach which were made there, therefore hold true for the Foundation's work. It was not until after much effort in this direction that the

Foundation came to accept that this was a dead end route in commercial terms. It was the route of directed synthesis which would offer the best prospects, but by the time this was realized Tate and Lyle had assumed a commanding role in the field. The story of the historical development of technical innovation in sucro-chemicals will therefore, have to await the discussion of Chapter 10 for completion.

A second major criticism of the Foundation's work is the energy "wasted" in trying to disprove the health charges laid against sugar in order to "stimulate" its consumption. This effort was revived again in 1959-60 and lasted until 1969 as the foundation concentrated on trying to prove the health dangers of cyclamate, the non-nutritive sweetener which seemed to threaten the sugar market. Referring to this period Hickson points out that after the introduction of cyclamates:

> "the sugar industry became justifiably dismayed and drafted the Foundation to become the point of its defensive stand. Essentially all other kinds of research were abandonned to concentrate a maximum of effort on protection from this extreme economic pressure."/7

This extreme reaction hindered the Foundation's role in the emerging technology and helped to confirm the dominance of Tate and Lyle in this field. We will therefore take up the analysis of this development in Chapter 10.

In summary we can therefore make the following observations:

1) Research into the non-food uses of sugar was prompted by the surplus of sucrose combined with the need to find a regenerable resource which could provide an important input into the chemical industry.

2) The responses of the industry was to establish the Sugar Research Foundation in 1943 whose initial interpretation of its task was to disprove the allegations made about the dangers of sugar in the human diet.

3) While the defensive outlook still continued, later by 1952, under the guidance of Prof. Hass, sucro-chemistry, as a new field of technical work was commenced.

4) The work of the Foundation in this area was helped by discoveries of new solvents, although these were too expensive for commercial use.

5) Unfortunately, oost of the research was focussed in the area of the degradative products of sugar, which from a commercial standpoint is basically uncompetitive.

6) The later development of the approach of directed synthesis was to be associated with the shift in the center of research from the Foundation to Tate and Lyle Ltd. and its associated laboratories at Reading University.

7) While the Foundation shifted the emphasis of its research as indicated in (3) and (4) above, the development of non-nutritive sweeteners, particularly cyclamate led to a recrudesence of defensive research work aimed at proving the health dangers of cyclamates. This occupied the Foundation from the early 1960's to 1969 and helped lay to rest its once dominant role in the newly emerging technology of sucro-chemistry.

Notes to Chapter 8.

1. See J. L. Hickson in Birch, G. and Parker, K. (eds.), (1979), pp 156-157.

2. *ibid*, p 157.

3. *ibid*, p 157.

4. J. Paturau, (1969) p 11.

5. J. L. Hickson, in Birch, G. and Parker, K. (eds.), (1979) p 172.

6. J. Paturau, (1969) p 11.

7. Kollinstich

8. J. L. Hickson in Birch, G. and Parker, K. (eds.), (1979) p 173.

Chapter 9: SUCRO-CHEMICALS: SOME GENERAL ISSUES

Having examined the properties and technical routes towards sucro-chemical production, I shall discuss briefly in this chapter some of the general issues which underline the potentiality for a large-scale development of a sucro-chemical industry. This would serve as a vital prelude to the analysis of Tate and Lyle which follows in the next chapter.

The first issue to be examined is the production of ethanol. This subject is not dealt with at great length in this study, because the terms of reference of the project more or less specifically excludes it, and leaves it to be studied as part of the technological impact assessment of alternative fuel systems. This of course presumes that the production of ethanol for use as a fuel extender will be the principal economic application of this product. The focus developed here is one in which the directed synthesis of sucrose is the new technology which may permit the most profitable line of development of sucrose as an input into the chemical industry. But as we have seen in Chapter 7, the fermentation of sugar-cane juice or molasses in order to produce ethanol, although employing no new technology, is a possible route to the chemical industry also. Fermentation ethanol is an organic chemical with four major applications, namely,

(i) the production of potable alcoholic beverages,
(ii) for use as an intermediate chemical,
(iii) for use as feedstock to produce other chemicals,
(iv) for use as a fuel extender.

Presently, the major uses of ethanol are to produce alcoholic beverages, to act as a chemical solvent, to serve as a gasolene extender, and finally to produce a very small volume of other chemicals. Traditionally the main uses of ethanol "have been to produce potable alcoholic beverages and as a versatile speciality chemical. The recent interest displayed in its use as a fuel extender, in the wake of the oil crisis", particularly in Brazil and the USA, has somewhat diminished the priority of these roles. Nevertheless, it is estimated that on a global basis they are still the leading users of ethanol./1 When used as a solvent, ethanol finds its principal uses in the production of toiletries and cosmetics, detergents, paints and varnishes, disinfectants, processed foods, drug manufacture and pharmaceuticals, surface coatings, etc. Fermentation ethanol is usually preferred to its synthetic counterpart when used in potable products or on the body, e.g. toiletries. Indeed because of this preference it is able to command a premium price over its synthetic competitor./2

As a fuel extender ethanol has three potential uses, namely,

(i) boiler fuel,

(ii) diesel substitute, and

(iii) gasolene substitute.

As a diesel substitute there are a number of technical drawbacks which limit its use, while as a boiler fuel it is thought to be an inferior use of what is deemed to be a superior liquid fuel. Its major fuel application therefore is as a gasolene extender, where it has demonstrated superior characteristics. Because of these characteristics it is felt that: "its unique physical/chemical properties increase ethanol's value, beyond its heating value, as gasolene substitute"./3

As a chemical feedstock fermentation ethanol has first to be converted into ethylene. Approximately 1.7 lbs. of ethanol are required to produce 1 lb. of ethylene. The theoretical conversion ratio of sugar into ethanol is 51 per cent. In practice it is claimed that 3.7 lbs. of fermentable sugars are needed to produce 1 lb. of ethylene. /4 In the petroleum industry the primary products of crude oil are fuel oil and petrol. The refinement of petroleum by means of catalytic cracking produces ethylene, propylene and C 4 hydrocarbons (butane, butenes, butadiene) in quantities determined by the throughput and process conditions. The ethylene produced in this way is followed by conversion into ethanol and finally production of the chemical product from ethanol either by dehydrogenation or by oxidation. Ethylene is the most important intermediate product in the petro-chemical industry.

While fermentation ethanol can be dehydrated to produce ethylene, the use of fermentation ethanol is more economical for products involving oxidation and dehydrogenation. The last two processes give ethanol a higher value than ethylene, whereas for the first the opposite holds true. All the ethanol conversion processes currently in use are designed for small-scale operations, compared with the tremendously large-scale plants using ethelene based processes and reaping considerable economies of scale.

Because of the factors identified above, any major substitution of petroleum products would depend on the economic relationships which exist between fermentation ethanol derived ethylene and petroleum derived ethylene. The inflationary increase in petroleum prices has brought the question of its substitution by cheaper raw materials to the fore. But as the World Bank study quoted earlier concludes:

"Among the technologies currently available, ethylene production from biomass ethanol is unlikely to be competitive with petroleum derived ethylene until the crude price of oil reaches $40-$45 per barrel, (assuming an economic cost of sugar-cane at $10-$12 per ton). It is therefore, unlikely that large-scale substitution of petroleum derivatives (e.g. naptha or ethane) for the production of petro-chemical products based on ethylene as an intermediate, can be justified on economic grounds in the immediate future. This conclusion could change in case petroleum prices rise much faster than projected by the World Bank, or new technologies and catalysts are developed to reduce the cost of ethylene production from ethanol. Many chemical firms are working on the latter issue and it is possible that ethanol use in the chemical industry would become economic in the next 5-10 years."/5

Another estimate is that:

"without allowing for processing or capital costs, at the current price of ethylene (24 cents per lb.) sugar would have to be available at 6 cents per lb. for the process to become economically feasible"./6

Or alternatively it has been claimed:

"allowing for capital and production costs, it has been estimated that for ethylene derived from fermentation ethanol to be competitive at current prices, the fermentable sugars would have to cost no more than 1 cent per lb. Conversely ethylene prices would have to reach 36 cents per lb. equivalent to oil at around $45 per barrel"./7

As I have indicated in Chapter 7, microbial conversion processes are non-specific, in the sense that any carbohydrate source can be used. It is this which explains the frequent references to this product as "biomass alcohol", "fermentation alcohol" and so on. While the conversion process is non-specific, sucrose however has two distinct advantages over other carbohydrate sources. One of these is that its carbohydrate content is already in the form of fermentable simple sugar. The other is, because of the utilization of one of its by-product (bagasse) to fuel the factories which process it, sucrose production from the sugar-cane plant is energy self-sufficient. In constrast, starches, because of their greater molecular complexity have to be broken down first into simpler sugars. This therefore adds a further "process-step" thereby raising processing costs. In addition of course these other products require outside sources of energy, although it should be reported that efforts are being made to reduce this by more scientific use of their by-products.

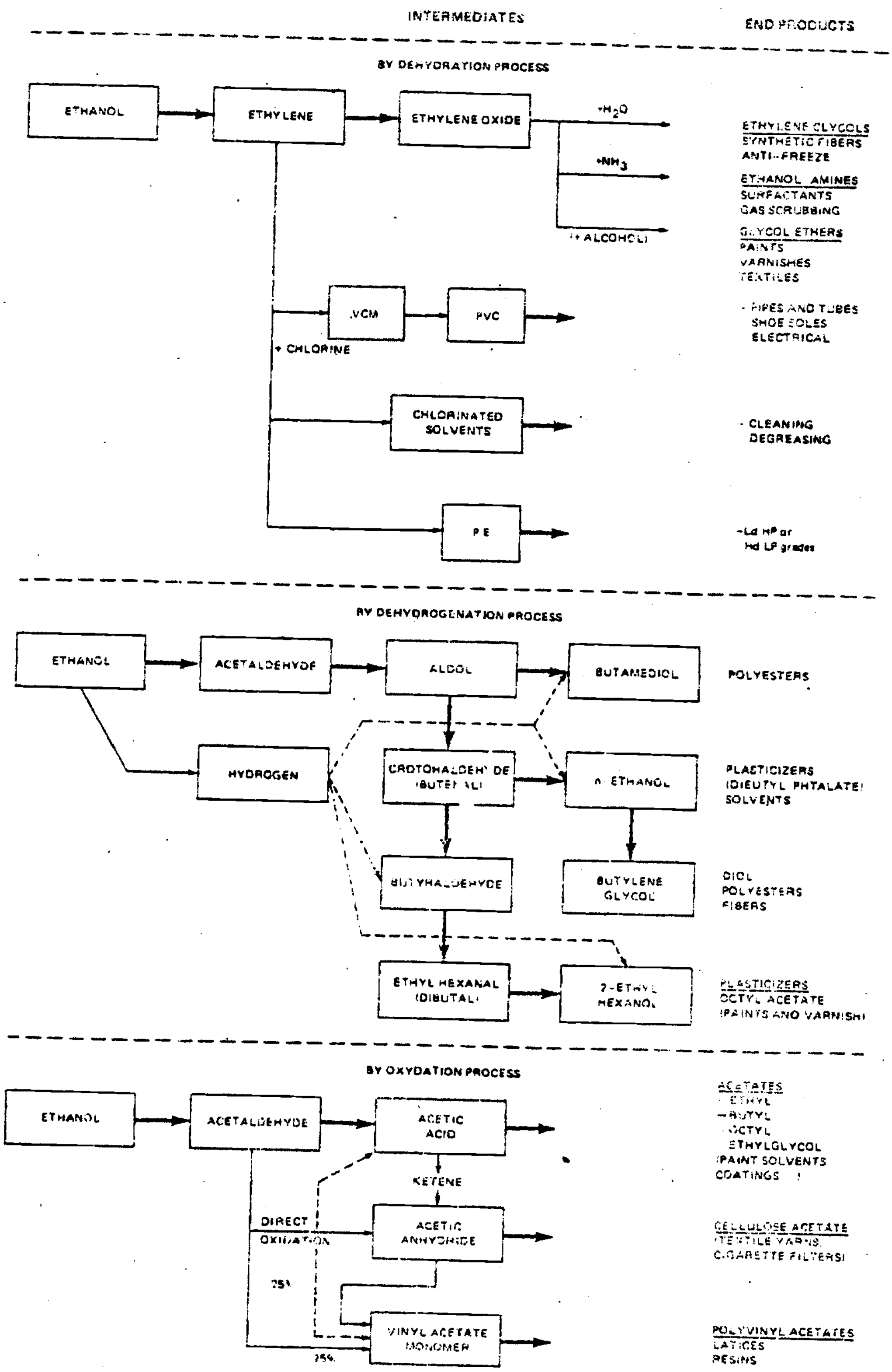
The advantages which exist in relation to other carbohydrate sources also exist in relation to other forms of biomass, e.g. celluosic materials. Indeed it has been pointed out tnat the advantages here are even greater because the cellulosic materials have a far more complex molecular structure than the starches and have to be converted to fermentable sugars by the complex and costly process of acid hydrolysis. Furthermore, the alcohol conversion efficiency factor for these materials is lower than is the case with sucrose.

While, as we have pointed out earlier, the technology of fermentable alcohol production is old and well-established, there have been significant improvements in this area in recent years. We noted this when we considered the production of HFCS. One example of these improvements is the use of continuous, as against batch fermentation processes, in distillation. It is claimed that as a result, the alcohol yield has risen from the usual 8-10 per cent to as much as 12 per cent. Another very good example is the introduction in the distilleries of the heat recovery designs which have been successfully used in other manufacturing areas in order to improve energy efficiency and save on costs. The general picture therefore, is of significant incremental improvements being made to a long and well established technology and these are enhancing the competitive position of fermentation alcohol.

Whether the improvements in fermentation technology will eventually yield a competitive ethelene production from fermentation ethanol remains to be seen. The fact that it is essentially a well established and old technology would also seem to rule it out of our general purview. Nevertheless the issues associated with the production of fermentation ethanol cannot be ignored in a study such as this. One good reason is that the discussion so far points clearly to the fact that the effective competition to sucro-chemicals is in fact petro-chemicals. While in market systems it would be expected that in the long run the competiting price relation between the two classes of chemicals will determine where profitable investments will be made, to arrive at this position one has to take into account also a number of factors, other than price. Particularly when, as it is frequently the case, the prices quoted are price per unit of ethylene derived from two alternative sources and based on "standardized" factory models.

If we look at the Diagram on the following page we can easily see the chemicals which can be produced from an ethanol feedstock. The wide range of chemicals presented there, reinforces the observation we have made that sucro-chemicals as a class of products would have to substantially displace the petroleum-natural gas-coal based chemical industries now in existence. However, in so far as the chemical industry is predominantly orientated to the petroleum industry and in so far as both industries, particularly the latter, has a high capital intensity and hence a vast and costly world-wide network of production/research

Figure 2: ALCOHOL FROM BIOMASS:
PRODUCTION OF CHEMICALS FROM ETHANOL BY MAJOR PROCESS ROUTES



SOURCE GIRA, RHONE POULENC

facilities these investments cannot be simply wished away. The petroleum companies can be confidently expected to resist any serious inroads into their markets. One important advantage which these companies possess is a flexible marketing structure. This is based on the consideration that the primary products derived from crude oil are fuel oil and petrol. Ethylene, propylene and butane related products are esentially "by-products" whose output is determined by the throughput and process conditions of the refinery. This permits the companies to be flexible in the production of particular chemicals and to apportion costs and charge prices to their various products in a way which would protect any threatened product while optimizing overall profitability from their operations:

> "The pricing policy of the industry will understandably be to spread increased raw material costs over primary and by-products in such a way as to maintain their balance. Inevitably, therefore, significant competition in a by-product outlet will be countered by a price reduction to restore this balance. In this sense, raw material prices will not reflect directly increased oil costs."/8

Such pricing mechanisms constitute a formidable advantage since they reduce the effectiveness of one method of product diffusion, which is to capture segmented markets in a sequential way./9 The cost of penetrating markets on a broad front will be very high, particularly when the heavy capitalization of the petroleum industry is taken into account. By contrast the infrastructure of the sugar industry is perhaps not developed enough to launch a marketing offensive on the scale required.

One further aspect of market penetration which should be mentioned here is that the user industry often finds uses for chemicals which the producer may not have anticipated. There can therefore be a cumulative virtuous circle, of initial market penetration, followed by uses being found by the initial user which the innovation may not have anticipated, which leads to further demands for the product, and so on. But to achieve these the market has to be first penetrated. One successful experience of a sucrose based chemical has been summed up this way:

> "When you have a chemical you need to find a use for it. The sugar industry is not the best suited to find the applications. These have to be developed by the 'user' industry."/10

As the author goes on to point out in the case of its surfactant Tate and Lyle found that while it was produced to service one need that actual use in industry has resulted in "over 15 different potential applications because we found customers, who, in turn, found uses for the product we never even thought of."/11

Because the petroleum and chemical industries are often considered to be strategic industries in terms of national security, an increasing role of governments, over and above that which they normally play can be expected in determining the lines of future energy development. This would be of course, an important countervailing force to the power of the petroleum companies. The lines which any government would pursue would depend on the resource, national security, social and political objectives of the government. Thus in the case of Brazil, government support for its gasahol programme in the absence of significant quantitites of indigenous oil deposits has been decisive in the orientation of both its energy and chemical industries. Similarly, a strategic commitment to nuclear energy has been important in the development of Soviet industry. One index of the significance of the observation made here is the fact that the petroleum companies themselves have been active in the acquisition of technical rights, R and D facilities, as well as production facilities in the "new" energy technologies, as part of their strategic responses to the new technologies./12

In addition to the high cost of market penetration for new chemical feedstocks one must also consider the formidable barrier of expertise which has to be overcome. The orientation of the chemical industry towards petroleum feedstocks has inevitably influenced the pattern of training and skills within the present chemical labour force. Universities, colleges and other training institutions have geared their programmes to the production of these skills and their conversion to sucro-chemistry cannot be contemplated as an over-night affair. Furthermore, the petroleum companies have a reputation for high levels of remuneration and material rewards. This reputation not only encourages the flow of persons into petro-chemistry, but it also raises the cost of developing a skills base in sucro-chemistry.

If the high cost of market penetration and development of a skills base in sucro-chemistry are not enough obstacles in themselves, one must also take into account the cost of developing the new technologies themselves. This cost encompasses the long gestation period while research takes place, the subsequent period of development of the new product or process, then on to pilot testing and the establishment of production facilities. While in the early days some of these costs were borne "collectively" by the sugar producers through the Sugar Research Foundation, the shift of the center of research to Tate and Lyle has put a lot of these costs of development unto this TNC. The results of this will be discussed at some length in the following chapter.

Two major advantages favouring sucro-chemistry are derived from the fact that sucrose is an agricultural product. One of these we have referred to often enough, that is, sugar is a replenishable resource, whereas petroleum is a "finite" resource. One should not, however, overstate the "finite" characteristics of petroleum. The known global reserves of oil and natural gas exceed the amount of hydrocarbons so far extracted. Deposits of coal are projected at being able to meet current extraction rates for another three centuries, while shale oil and tar sands have not been exploited in significant quantities thus far. Furthermore, it should be pointed out that new reserves are being continuously "discovered", while the huge increases in price of this product has stimulated increasing concern over energy efficiency and a search for alternatives, including as we have seen ethanol. There will, however, always be an upward pressure on prices exerted by the inelasticity of supply. While this can be countered by improved recoveries, etc., it is a pressure that over the long run cannot be ignored. As a replenishable product sugar-cane does not face the same difficulty, particularly as in all the discussions so far it is not expected that sucro-chemicals will lead to vast increases in acreage committed to sugar-cane cultivation, except possibly in the case of fuel extenders. /13 The non-food uses of cane and beet sugar are seen as being compensated for by increased output of alternative sweeteners, e.g. HFCS. As a consequence the impact on agricultural land availability is not assumed to be particularly forbidding at this stage.

The second major advantage is the environmental impact. Most sucro-chemicals are bio-degradable, non-toxic, non-carciogenic, etc. This provides for a favourable environmental impact. The major environmental problems are posed when alcohol is fermented and distilled. The major by-products here are carbon dioxide, fusel oils and stillage. The first of these is normally discharged into the atmosphere. Fusel oils, about 5 kg. per 1,000 litres of ethanol can be collected and further utilized. Stillage is produced in large amounts (about 10-13 times the volume of alcohol produced). Because this has potential use as animal feed and fertilizer, it is likely that disposal of this can take place economically. As Vlitos sums it up:

> "In general chemicals derived from carbohydrates or other biomass products are more amenable to degradation in the biosphere, and hence present less of an environmental hazard, than do petro-chemicals, particularly the intransigent aromatic compounds."/14

In light of the considerations raised so far there is merit in Parker's division of the potential sucro-chemicals markets into two broad categories./15 These are the high-valued products produced in small volume, and the low-valued products produced in large volume. In the former market, the chemical process is the important element of cost and selling price. What is being sold are sophisticated chemical processes rather than the raw material sucrose. Examples of such products are expensive to develop systemic fungicides and certain pharmaceuticals. In the latter market, sucrose is being sold as a cheap chemical and the processes used are not costly. Examples of these are the sucroglycerides, animal feed additives, resins, alcohol and plasticisers. This market distinction, by showing an appreciation of the relation of process to raw material cost allows some order/ranking to be imposed on the range of over 10,000 chemicals and chemical intermediates which sugar can produce.

Although at present over 10,000 chemicals can be produced from sucrose, the products which can be produced fall within certain broad market categories.[/16] These are:

1.	Foods	10.	Adhesives
2.	Feeds	11.	Paper
3.	Fuels	12.	Pesticides
4.	Explosives	13.	Plasticisers
5.	Elastomers	14.	Plastics
6.	Lubricants	15.	Surface Coatings
7.	Solvents	16.	Surfactants
8.	Soil Conditioners	17.	Medicines/Pharmaceuticals
9.	Fibres	18.	Cosmetics

The main lines of immediate exploitation of these markets will be discussed more fully in our study of Tate and Lyle in the next chapter. At the moment what we may observe is that the most likely markets to be developed are those listed as (1), (2), (13), (14), (16), (17) and (18) above. This list deliberately excludes item (3) [fuels] as it does not fall within the purview of this study. At present the largest non-food outlet for sucrose is polyurethane resins. The market is growing rapidly, (approximately 12 per cent per annum) and current

US production is 0.75 billion lbs. To produce this quantity requires about 50,000 tonnes of sucrose. The use of sucrose mono-esters world-wide is currently estimated at 12,000 tonnes. As a result, while the industrial potential of sucrose is considered to be great, only about 100,000 tonnes is used in this way, that is considerably less than 1 per cent of the world's output of this product. The reality is that apart from the fairly general consumption of molasses in animal feeds, potable alcohol fermentation from sugar-cane juice and molasses, other microbial routes which can compete with synthetic routes (e.g. citric acid) and recently the gasahol programmes, the industrial use of sucrose has not lived up to its promise. As the then Chief Executive, Group Research and Development, Tate and Lyle Ltd. pointed out the difficulties are that while:

> "Sucrose can be chemically modified or reacted to yield a wide variety of products. Generally these products have not found markets either because (i) the costs of production were too high relative to existing petro-chemically derived product, or (ii) insufficient development work had been done to indicate suitable applications, or (iii) the chemical industry ... was and still is orientated to petro-chemical 'feedstocks' rather than to sucrose. There was no platform or infrastructure either within the sugar industry or within the chemical industry to ensure commercialisation of sugar-based chemicals. Nor was there enough 'patient' money available to invest in a very longterm venture. The sugar industry was not prepared to invest the sums required to launch new chemical products, especially when the initial economics looked unfavourable. A long time lag between the research work and commercialisation inhibited investment. The chemical industry itself was not prepared to invest very much on seeking alternative feedstuffs when petro-chemicals were so abundant and cheap."/17

In conclusion we may say that while the inflation of petroleum/ natural gas prices has altered to the disadvantage of petroleum, its price relative to that of other sources of energy and chemicals, there is as yet not a sufficient alteration as to make the cost advantages of these alternatives demonstrably clear. In any case the price structure of the petroleum industry together with the strategic and political significance of petroleum and chemical products would not allow this matter to be resolved simply in "the market place" - even though price/cost consideration will be important to the eventual outcome. Because of this it is my belief that the future of sucro-chemicals is bound up with its ability to win one or more government's support for it on the basis of social, national, as well as market considerations. It is only national governments which can yield a sufficient countervailing power against the TNCs. The sugar companies alone cannot. This conclusion should be kept in mind as we consider in the next chapter the gains and difficulties confronting the world's leading sucroehemicals firm, Tate and Lyle Ltd.

Notes to Chapter 9

1. World production of ethanol is in excess of 3 million tonnes or 1 billion gallons. Approximately 52% of this is estimated to be fermentation ethanol and the remainder synthetic ethanol. See Alcohol Production from Biomass in the Developing Countries, World Bank, September, 1980.

2. ibid, p 9.

3. ibid, p (iii). These characteristics improve combustion efficiency, improve octane ratings and engine performance in starting, carburation and emissions.

4. A. Vlitos and K. Parker, (1981) p 38.

5. World Bank, (1980) pp 45-46.

6. A. Vlitos and K. Parker, (1981) p 38.

7. K. J. Parker, (1979) p 4.

8. ibid, p 2.

9. This point was discussed in Part I, Chapter 5 in the case of HFCS market penetration.

10. A. Vlitos, (1977) p 343.

11. ibid, p 343.

12. See the statement by the Executive Director, United Nations Centre on Transnational Corporations to the United Nations Conference on New and Renewable Sources of Energy, Nairobi, August, 1981.

13. Brazil is producing about 20% of its automotive fuel requirements from alcohol. The US plans to produce 2 billion gallons of fuel extenders by 1985. This, however, is based on corn, and the estimated consumption is 20 million tons.
To replace ten per cent of US current annual consumption of gasoline by alcohol would require about 2½ times the world's sugar output.

14. A. Vlitos, (1979) p.E. 14.

15. K. J. Parker, (1979).

16. ibid.

17. A. Vlitos, (1977) p 340.

Chapter 10: SUCRO-CHEMICALS AND TRANSNATIONAL ENTERPRISE

Section (i): The Importance of Tate and Lyle Ltd.

Tate and Lyle Ltd., the British owned TNC has been for the past decade and more easily the leading force in the drive to develop sucro-chemicals. Because of its unquestioned leadership in this field of endeavour, its operations are probably the single most important index of the possible impact of technological change in the area of sucro-chemicals in the near to medium term, if not over the long term. Other studies on monitoring technological opportunities reinforce the importance which is attached here to the monitoring of the leading enterprise. Thus Utterback and Brown observe:

> "When a technical field or product area is undergoing rapid change, or in cases where product life cycles are relatively short, it would prove worthwhile to devote more of the forecasting effort to monitoring resource commitments"./1

It seems self-evident that the commitment of resources by an organization, let alone a commercial one, to new product development and new technology should be a fruitful indicator of the commercial assessment of the new product or technology. This point of view is also reinforced, in so far as this commitment is first made by one or a very small number of firms, since it is far easier to monitor this, then it would be to monitor a large assortment of patents, technical papers, product and technology specifications, research in progress, etc. The leading enterprise therefore, can be seen as acting as a guide through this diverse array of documentation. Of course the leading enterprise(s) can, and have made serious mis-judgements in the past, so that this approach while useful still has to be pursued with great care and caution because of the known hazards of forecasting technological opportunities and their commercial impacts.

Tate and Lyle Ltd. is the world's largest privately owned sugar company. It is a UK based transnational which in 1981 embraced 72 subsidiary companies, of which 28 were based in the UK and 44 overseas. In addition there were 8 associated companies, "other" investments in four corporations and a joint-venture with one. The company operates in all the continents with a total turnover of more than $4 billion. Its trading sectors and operating bases are: agribusiness; bulk liquid storage, cane-sugar production and refining; cereal sweeteners and starches; commodity trading world-wide; insurance; malting; molasses trading, storage and distribution world-wide; warehousing, packaging and distribution; and other miscellaneous activities. Details on the turnover and the composition of assets for these ten trading sectors and operating bases are shown in Tables 41 and 42 overleaf.

Because of its substantial trading in sugar, molasses and other agricultural products whose prices are very volatile, the composition of assets and turnover shows wide swings from year to year. Unfortunately, because of substantial accounting changes in the valuation and structure of its assets the data on these sectors and categories are not available for a long time series. However, it has been possible from a study of the company's reports and accounts to pick up the main threads of both the continuities and changes in its major operations. The wide swings in the value of the TNC's assets can, however, be seen from the 1980-81 data alone. Thus in 1981 the value of assets in cane-sugar production and refining was £152 million compared with about half that value in 1980,

Table 41

Tate and Lyle Limited, Analysis of Turnover 1980-1981 (£ million)

TRADING SECTORS AND OPERATING BASES	Turnover 1980	Turnover 1981
1. Agri-business		
United Kingdom	27.2	35.3
North America	2.2	2.7
	29.4	38.0
2. Bulk Liquid Storage		
United Kingdom	9.1	8.8
North America	0.4	-
	9.5	8.8
3. Cane Sugar Production and Refining		
United Kingdom	374.9	350.1
Canada	69.1	106.9
USA	77.9	133.3
Belize	14.0	15.8
Zimbabwe	18.1	26.7
	554.0	632.8
4. Cereal Sweeteners and Starches		
Canada	-	0.4
Europe	38.4	43.5
	38.4	43.9
5. Commodity Trading Worldwide		
Sugar	431.0	1,105.5
Other	54.3	41.5
	485.3	1,147.0
6. Insurance	-	-
7. Malting		
United Kingdom	19.6	18.4
8. Molasses Trading, Storage and Distribution		
Worldwide	222.4	246.9
9. Warehousing, Packaging and Distribution		
United Kingdom	28.4	27.4
Nigeria	20.3	27.7
	48.7	55.1
10. Other Activities		
Shipping - United Kingdom	4.7	0.1
Starch - United Kingdom	48.2	10.0
Other	38.9	63.3
	91.8	73.4
11. Total	1,499.1	2,264.3

Source: Tate and Lyle Ltd., Annual Report, 1981.

Table 42

Tate and Lyle Limited, Analysis of Assets Employed, 1980-1981 (£ million)

£ million		Total 30/10/80	Total 30/10/81
1.	Agri-business	2.8	6.3
2.	Bulk liquid storage	19.7	19.7
3.	Cane sugar production and refining	79.5	151.9
4.	Cereal sweeteners and starches	18.4	28.5
5.	Commodity trading worldwide	83.5	38.2
6.	Insurance	8.5	9.5
7.	Malting	14.9	14.9
8.	Molasses trading, storage and distribution	23.8	36.5
9.	Warehousing, packaging and distribution	11.4	10.7
10.	Other activities	31.0	21.2
	Total operating assets	293.3	337.4
	Speciality chemicals	13.5	7.3
	Central	(12.2)	5.1
	Total	294.6	349.8

Note: Changes in the valuation and structure of assets in 1981 restrict the availability of comparative data to 1980 and 1981.

Source: Tate and Lyle Ltd., Annual Reports, 1980 and 1981.

(£79.3 million). This made cane sugar production and refining the largest trading sector in 1981 but in 1980 it ranked second after commodity trading worldwide. Similarly the valuation of assets devoted to commodity trading worldwide fell from £83.5 million in 1980 to less than half that amount (£38.2 million) in 1981. These wide variations in assets structure reflect the deep involvement of the company in the production, processing, storage and trading of agricultural commodities. As we shall indicate later, this involvement should certainly raise doubts as to whether such a company can in fact sustain a long term interest in the pursuit of an alternatively based chemical industry in the face of a competitor as formidable as the petro-chemical industry.

The wide variations in assets employed are inevitably reflected in the company's turnover, as can be seen from the data in Table 41; although the swings here are either in different directions or reduced in comparison. Thus the near-doubling of assets in cane sugar production and refining between 1980 and 1981 is reflected in a 14 per cent increase in turnover. Commodity trading worldwide grew by a factor of 2.4 between 1980 and 1981 while assets employed fell by a factor of 2.2. Agri-business turnover also grew by one-third between 1980 and 1981, while assets employed grew by a factor of 2.3.

Operationally, the research and development activities of Tate and Lyle, along with its new ventures are located in its New Developments Division. Within this division there is the Talres Development company, a wholly owned subsidiary located in the UK and which forms the "bridge" between research and commercialization. The TNC also maintains substantial research facilities at Reading University. While the research and development activities will be discussed in the next section, we may note at this stage, that the speciality chemicals activities of the company are not unexpectedly, located in this division. The Chemicals Division of the company is a major part of its structure and constitutes one of the four major divisions of the TNC, the others being the UK Division, International Division and the North America Division. Most of the research work in chemicals fall under the general direction of this division.

Studying the accounts and reports of Tate and Lyle it is very evident that a decision was taken in the early 1970's to substantially reduce the company's involvement in sugar and to find a more diversified production base. The assets and turnover structure shown in Tables 41 and 42 therefore, are the product of more than a decade of diversification of the corporation's structure. The TNC's base in sugar was of course the launching pad into other operations. In 1976 the Chairman's Report on the corporation's activities stated as follows:

> "Tate and Lyle's business is to supply, trade and handle commodities and to provide the services for handling other people's goods. The group has used its strong international base in sugar to expand into many other related businesses, resulting in a substantial presence in the worldwide markets for processing, trading and handling many goods, feedstuffs, fuels and chemicals."/2

The pace of diversification of the corporation's structure can be gleaned from the fact that whilst in 1976 the major trading sectors were: sugar, starch, commodity trading worldwide, bulk liquid storage, shipping, warehousing and distribution, and engineering and consultancy; by 1981 the last item was well established as an agri-business complex; malting, insurance and speciality chemicals were added to its list of activites and the shipping fleet of the TNC had been dissolved. The diversification into

North America was also rapid - leading to the creation of a whole new division to cover these activities.

The diversification thrust of Tate and Lyle had been brought on by a number of major developments confronting the TNC. One of these has been the rapid and unfavourable changes in the structure of the world's sweetener industry. This was discussed at some length in Part I, and the points of major importance to note are the extreme uncertainty of sugar prices; the rise of beet sugar production and consumption, particularly in Europe; the growth of the HFCS industry; the slow growth of global consumption of sucrose; and the drive for self-sufficiency in sweeteners among the developing countries, whose consumption of sugar is rising. A second development of major significance was the ending of the Commonwealth Sugar Agreement and the entry of the UK into the EEC. Tate and Lyle has built its sugar refining operations on sugar-cane cultivation in the UK's ex-colonies and the preferential access which this sugar had into the UK market. With the UK's entry into the EEC this came to an end and was replaced from the TNC's standpoint with the less favourable EEC-ACP Agreement. In addition, the sweetener regime of the EEC, and in particular its strong support for European beet sugar, has created major obstacles for a company traditionally based on cane sugar production and refining. The effect of these developments has been a drastic rationalization of sugar refining operations in the company; occasioned by the large decrease in the available UK market. Thus in 1981 the company estimated the UK market at 2.3 million tonnes of sugar. Of this total, domestic beet production in the UK would have absorbed 1.1 million tonnes, and imports of white sugars from the EEC, 0.15 million tonnes. The total supply of beet sugar would therefore have been 1.25 million tonnes leaving a residual of 1.05 million tonnes for cane sugar. Meanwhile Tate and Lyle's refining capacity was 1.34 million tonnes, that is an over-capacity of about 27 per cent. In a recent report the company listed four causes of the sugar refining crisis confronting it, namely:

- a collapse of export margins;
- an increase in UK beet sugar production;
- a contraction of the UK sugar market;
- the importation of white sugar from the EEC.

The report then goes on to state:

> "Because the cane sugar refining margin is so much lower than that for beet processing, these four factors have forced Tate and Lyle Refineries to seek to reduce refining capacity in line with shrinking demand for its products."[73]

A third development leading to the diversification strategy was the reduced control the TNC could exercise over its investments in overseas sugar cane growing areas. A number of familiar political and social factors is associated with this development and so do not require repeating here. A fourth factor is that over the years of contact with sugar cultivation and refining the company has developed a wealth of expertise in related activities, e.g. shipping, bulk storage, engineering and cultivation consultancy capability in tropical agriculture, molasses handling, and so on. It was therefore logical, that in a period of crisis a constructive response to protecting the TNC's interests would have been to exploit the skills capabilities which it had developed over the years.

The last and perhaps most decisive consideration, certainly in terms of timing the transition to other activities was the inflation of oil prices and reported scarcities of this product. This consideration more than any has specifically intensified the search for sucro-chemicals, even though its impact on the company's activities has been far more wide-ranging.

The data in Table 43 below show the TNC's accounting deductions from profit for research and development expenditures and speciality chemicals over the period 1977-81. These allocations are deducted from profits in the year of its expenditure. In the case of joint ventures the figures are net of the partner's contribution.

Table 43

Tate and Lyle: Research and Development Allocations

Year	£ million
1977	3.3
1978	2.9
1979	3.5
1980	5.4
1981	6.8

Source: Tate and Lyle Ltd., Reports and Accounts (various issues)

Section (ii): Tate and Lyle: Research and Development Activities

In this section, I shall highlight the main research and development activities of Tate and Lyle in the general area of our interest in an effort to pin-point the crucial growth points over the near to medium term. Emphasis will be placed on the immediate pre-commercialization activities. The analysis does not treat adequately with the TNC's activities connected with the improvement of cane sugar cultivation and processing in which the TNC has made important technical innovations recently.

1. Degradation of Sucrose

We have already discussed at some length the limitations of the degradation reactions of sucrose as a route towards the production of chemicals. Much of the literature cited in this context, e.g., Parker, Hickson, Vlitos, Hough and Righelato comes from scientists and scientific managers associated with Tate and Lyle's laboratories. The only significant research in this area is the effort by Tate and Lyle to improve the yields of mannitol and sorbitol. In many ways it can be siad that Tate and Lyle's research and development work in speciality chemicals has been founded on the explicit recognition of the exhaustion of the possibilities of this route, and its consequent willingness to commit resources in the pursuit of the development of other routes to chemical production from sucrose.

2. Sucro-esters

Work on the production of sucro-esters constitutes one of the major areas of Tate and Lyle's research and development efforts and has resulted in significant products reaching the commercialization and immediate pre-commercialization stage. The main effort here has been directed at discovering commercial processes for the production of sucro-esters for use in detergents, as food additives, in cosmetic and skin care products, animal feeds, and polymers. The outstanding technological opportunity so far has been the break-through discovery of the TAL process for producing detergents.

Tate and Lyle's work on the TAL process takes us back to our discussion in Chapter 8, where we observed that the Sugar Research Foundation had pioneered research in the trans-esterification between a triglyceride and sucrose, using dimethylformamide (DMF) as a solvent. The triglyceride used was tallow and followed the initiative of the State of Nebraska in the USA in asking the Foundation for its help in finding uses for its surplus animal fats. As we noted in that chapter the discovery of solvents such as DMF which made this trans-esterification process possible while a critical breakthrough, was nevertheless expensive because of the high costs of the solvents. In addition to this it should be pointed out that the Foundation's process of trans-esterification took place in the presence of potassium carbonate K_2CO_2, used as a catalyst at a temperature of 90^oC. The process initiated an incomplete reaction which yielded a complex mixture of mono and diglycerides and sucrose esters. The mixture also contained unreacted mixtures of sucrose and tallow. All these additional factors inevitably raised the costs of purification and analysis. Mention was also made in Chapter 8 that questions were raised about the possible toxicity of DMF. As a result it was stipulated that if it was used in food it had to be done in parts of less than 50 per million.

Some of the scientists associated with this work at the Sugar

Foundation later joined Tate and Lyle where an effort was being made to improve upon this process in order to lower processing costs. This was successfully achieved when scientists in Tate and Lyle's laboratories discovered that under certain conditions sucrose would react directly with a triglyceride in the absence of a solvent. A surfactant was prepared by reacting the following materials:

Tallow	40.0 g	(64.5%)
Sucrose	17.0 g	(27.4%)
K_2CO_3	5.0 g	(8.1%)

This was a simple reaction which yielded a complex mixture with the following properties:

sucrose monoester	27%
sucrose higher ester	3%
sucrose	13%
triglycerides	3%
diglycerides	9%
monoglycerides	15%
potassium soaps	30%

The sucrose based detergents produced from this process has certain highly esteemed properties, viz.,

- complete and rapid bio-degradability
- non-toxicity to mammals, fish and micro-organisms
- low foaming, which enhances its use in automatic machines
- non-irritant
- non-allergenic
- orthodermic
- excellent surface active, emulsification and oil dispersing detergent properties.

The environmental-related advantages are formidable ones particularly as the threat of accumulated detergent residues in inland waterways due to the low bacterial degradation of alkylarysulphonates was acute at the time of this discovery. While the switch to linear alkyl sulphonates has reduced the severity of the situation, it has not entirely removed it. The product's main disadvantages are its thermal instability; its instability to strong alkalis; and its incomplete water solubility. Removing these inhibitors invariably adds to the cost of production.

It is significant to note that in reporting on this pioneering work Tate and Lyle scientists, remark on the "accidental" nature of the discovery - thereby highlighting the "serendipity factor" in scientific discovery:

> "we did not plan to fashion a new surfactant. One of our chemists was working on the general reactivity of sucrose in the absence of solvents: sucrose was reacted with tallow in the presence of potassium carbonate at 125°C."/4

Two features associated with this process and the product are worthy of special note. One is that the triglyceride which can be used need not be tallow. Any triglyceride, whether plant or animal can be successfully used. This of course, widens the range of useful additives (e.g. coconut oil), from the point of view of the underdeveloped countries. Secondly, we should recall the observation made in the previous chapter about the "user impact" on a product, or a new technology. It was this same TAL process which was cited in the example to show that while it was produced with one purpose in mind, actual industrial use had yielded up to that point 15 different potential applications which had not been contemplated at the outset.

Tate and Lyle is completing under the TALRES company an industrial complex at Knowsley which runs a 5,000 tons/year capacity plant to produce a variety of surfactants with different physico-chemical properties. While there have been some significant delays and re-schedulings the aim is to expand this capacity to 22,000 tons/year. In addition to its UK commercial operations in this area licencing deals are underway in the Phillipines for a 25,000 tonnes plant using coconut oil as the triglyceride. Japan and some countries in Latin America have also shown interest. In order to encourage the use of this product the Corporation was able to get the end products of this process classified in Annex I of the EEC's permitted list of emulsifiers and stabilizers.

While the detergent use of this surfactant has been the major break-through in this category of applications, other important developments have also taken place. In the food sector, sucrose based surfactants have yielded the following advantages:

- improved surface appearance
- improved wetting properties in re-constituted dried foods
- improved humectency
- delayed staling properties
- improved oven spring
- crumb softness
- increased number and regularity of gss cells making for more uniform slice
- adds gluten to non-wheaten flours
- fat sparing properties in that it spreads the fat more evenly over the flour granules permitting a good loaf to be made with less expensive shortening.

In the cosmetics and pharmaceutical applications sucrose based surfactants have shown themselves to make superior skin cleansing formulations. In addition the products are non-allergenic, non-toxic and completely orthodermic. In animal foods, sucrose based surfactants produced at Tate and Lyle are thought of as improving the digestion of fat in animal foods.

In <u>herbicides</u>, preparations made from sucro-esters are particularly efficient because they assist the absorption and transport of herbicides in plants. Their non-toxicity is an advantage in that these preparations also leave no persistent or toxic residues.

3. <u>Chlorodeoxy Sugars</u>.

Tate and Lyle laboratories discovered early that 1^1,4, 6, 6^1-tetrachloro glacto sucrose is several hundred times sweeter than sugar. Subsequent investigations have revealed that 1^1, 4, 6^1-trichloro compounds are as much as 2,000 times sweeter than sugar. Most significantly these compounds have a pure sweet taste which experiments have established as being indistinguishable from sucrose. These processes clearly open up the possibility of a new class of low-calorie sweeteners based on sucrose. Currently, toxicological tests are underway as part of a major pre-commercialization effort. As Hickson points out:

> "These chlorinated sucroses really could qualify as the new generation of artificial supersweeteners - that is if they can pass the necessary rigid tests for health safety".[75]

It should be pointed out that 1^1, 2, 6, 6^1-tetrachlorotetra-deoxymannosucrose is an exceedingly bitter substance, having more than twice the bitterness of octaacetate and therefore a major challenger to the markets for denaturants. Closely related also are the 6-chlorodeodymonosaccharides which are being studied for their medical uses.

Table 44 below indicates the relative sweetness of the chloro-deoxysucroses.

Table 44

Relative Sweetness of Cholordeoxysucroses

Sucrose	1
Galactosucrose	not sweet
1^{1} - chloro - 1^{1} - deoxysucrose	20
4 - chloro - 4 - deoxygalactosucrose	5
6 - chloro - 6 - deoxysucrose	bitter
6^{1} - chloro - 6^{1} - deoxysucrose	20
1^{1} - 4 - dichloro - 1^{1}, 4-dideoxygalactosucrose	600
1^{1}, - 6^{1} - dichloro - 1^{1}, 6^{1}- dideoxysucrose	500
1^{1}, 4, 6-trichloro - 1^{1}, 4, - 6 - trideoxygalactosucrose	1,000
1^{1}, 4, 6, 6^{1} - tetrachloro - 1^{1}, 4, 6, 61 - tetradeoxygalactosucrose	200

Source: R. Khan and A. Forage (1979-80)

4. Microbial Conversion

Monitoring of Tate and Lyle's sresearch and development work in the area of microbial conversion indicates three major significant product/process developments. The first of these is the treatment of wastes. As we have seen the processing of sugar yields a number of waste products e.g. stillage. Arising out of its interest in this area Tate and Lyle has embarked upon work in the area of enzyme technology to recover saleable products from wastes. One of the directions of this work is the possible utilization of waste streams and mother liquors from sugar as a substrate for the mixed culture of micro-organisms. Another area is the use of micro-organisms in anaerobic fermentation to produce methane from waste treatment processes. A third significant direction is the use of this technology to improve water purification systems.

The second major area of technical development is the production of microbial polysaccharides. These products are used as gelling, thickening and suspending agents in a wide range of applications. The market for these products is generally not large except for Xanthan Gum which is estimated at 50,000 to 60,000 tonnes annually. In a joint venture with Hercules Inc. (subsequently abandonned), a company which has experience worldwide in marketing water soluble polymers, three sucrose based microbial polysaccharides are being produced. Xanthan gum is produced under the trademark BIOZAN in three grades, viz.,

- food grade
- standard grade (for use in general and agricultural applications)
- oil drilling grade.

The Xanthan Gum has been described as:

> "a high molecular weight, water soluble polymer, with a combination of interesting rheological properties which are maintained even at high temperatures. The gum's unusual molecular structure in which the polymer backbone is protected by negatively charged side chains, promotes its use as a thickener and suspending agent in acidic, alkaline and highly saline media where other water soluble polymers might be degraded or precipitated."/6

The third microbial conversion effort is the production of ethanol. The TNC does not seek to produce ethanol *per se* but to innovate in the processes of ethanol production. As we have seen in the previous chapter the technology of fermentation ethanol is well established. In most cases ethanol concentrations of less than 10% v/v are produced in the space of 20-30 hours with conversion efficiencies of about 90% of the theoretical maximum of 51%. Tate and Lyle research is directed towards developing processes which can:

(i) increase the concentration of ethanol and hence reduce distillation;

(ii) reduce the costs of setting up distilleries.

The company claims that it is able to produce ethanol well in excess of 10% v/v with holding times in a continuous reactor of less than 10 hours, with no consequential loss in conversion efficiency. This permits the installation of smaller, and hopefully cheaper fermenters and stills, with lower capital costs generally and less energy input into the recovery of ethanol. In some publications there are hints of a 30% alcohol concentration and of small efficient converters capable of conversion at ten or more times faster than the normal rate./7

The company's technological effort in this area has followed from its substantial interests in starch, sugar and molasses. The worldwide effort at sugar-cane produced ethanol for energy in the Third World has attracted its efforts in this area. Its long history of direct contacts with sugar-cane and molasses producers has no doubt given a filip to this development. As pointed out the company has announced no plans for ethanol production of its own.

5. Talin Sweetener

Talin Sweetener along with the remaining items briefly discussed below (6-9) do not fall within the ambit of sucro-chemicals, but these activities are important because they indicate the hedging of the corporation. One cutside threat to the sweeteners market which currently exists is the development of a safe low calorie sweetener. Many people who consume sugar (and those who do not) fear its calories while liking the taste. A substantial financial prize exists for whichever enterprise is able to produce a low calorie sweetener with the taste and other acceptable properties of sucrose. The company's investment in speciality chemicals research in the chlorodeoxy sugars reflect its commitment to invest resources in this search. Similarly, is its effort to produce a sweetener from Talin, a West African plant mentioned in Chapter 7, (Thaumatoccus danielli). The berry of this plant is not only several times sweeter than sugar-cane, but is low in calories, non-carciogenic and flavour enhancing.

6. HFCS

While HFCS was discussed in Part I, it should be noted here in the monitoring of Tate and Lyle's activities that along with Talin Sweetener and the Chlorodeoxy sugars, activity in the HFCS area indicates the integrated sweetener approach of the company. The focus of its efforts seems to be the use of enzymes in the production of HFCS. This complements its work in other areas of microbial conversion processes. In collaboration with the British Atomic Energy Research Establishment new techniques for immobilizing enzymes are being pursued. The first successful one was amyloglucosidase. A 500 litre reactor containing this enzyme was in use in the Tate and Lyle glucose factory. An effort is also being made to develop a commercial process for producing HFCS from chicory, an example of yet another "hedge".

7. Cane and Beet Factories

Research and development in low calorie sweeteners and HFCS do not end Tate and Lyle's research in the sweetener industry. A major effort is also being made to develop improved factory processes for sale to cane and beet processing factories. One outstanding innovation for which it has won a British technological award is the TALO process. While we are not concerned with operations in this sector, the range of the company's research effort and its base in the sweetener industry approached as a multi-product industry is definitely highlighted when these activities are noted.

8. Crop Protection

Long contact with tropical agriculture, and more recently with European agriculture has stimulated this TNC to exploit its considerable expertise in crop production. In so far as sucrose based chemicals may yield important chemical oesticides, part of this effort is integrated with its speciality chemicals activities. However, the major effort in this field is to use fungi, bacteria, viruses and other micro-organisms to replace, or complement, the use of chemical pesticides. This is an important area of research as many insects and pathogens are becoming resistent to chemical pesticides. The recourse here to the natural enemies of these pests obviously constitute an important endeavour.

9. Aquaculture

Research and development work here seem to be guided by two major considerations. One is the further exploration of the possible uses of water borne waste materials. The work here therefore complements the work on wastes discussed above. Second, commercial fish-farming is seen as one means of improving food supplies. Tate and Lyle efforts are aimed at developing a saleable technology in this field.

Section (iii): Research Directions: An Assessment

The new directions of Tate and Lyle's research which were highlighted in the previous section followed as a direct result of the diversification programme which the company had commenced just over a decade ago. The variety of research endeavours over the past twelve years fall into one or other of three major categories: food, process technology for producing and processing agricultural crops, and speciality chemicals; all three of these categories in turn find a common origin in the corporation's initial interest in sugar. Diversification for the TNC therefore, did not mean an abandonment of sugar but rather there were controlled efforts to build on the spin-offs associated with sugar, either through moving into new areas of activities or into new geographical regions.

From various reports and discussions it seems as if the company has operated or tried to operate with a 10-year time-horizon as the "minimum" for achieving best returns on its research and development projects. The projects which are currently at the early commercialization stage, e.g., Xanthan gum and TAL detergents, fall within this time frame. It therefore appears to be a reasonable one, if indeed the minimum is intended and this is not converted into a "norm". Delays in the commercialization of both of these products mentioned here, show how important it is not to become impatient, as it were, towards the end. In the Annual Report of the company's New Developments Division for 1979, the position was summed up as follows:

> "The commercial ventures currently reaching maturity - TAL surfactants, Talin sweeteners, Xanthan gum - represent research goals set a decade ago."/8

As the Report goes on to point out:

> "Our long-term research focus is, therefore, on developing the basic chemistry of sucrose and other carbohydrates, and exploring processes for exploiting the potential of biomass as a source of packaged energy. As the basic research advances, the broad approach will converge on identifiable targets on which R and D resources will be concentrated, under the guiding pressures of marketing, environmental, legislative and sociological forces"./9

If it can be said that the diversification of Tate and Lyle's operations and its new research and development activities were stimulated by its fear of the dangers associated with its over-dependence on a commodity as volatile as cane sugar, these efforts have as yet not developed to a point where wide swings in turnover, assets employed and profits (losses) have been eliminated. We have already noted in Tables 41 and 42 how considerable these swings have been in the space of just one year. Data on the corporation's profitability (before deductions) are shown in Table 45 overleaf. These indicate clearly the high level of dependence on sugar which still prevails. Thus in 1980 and 1981, cane sugar production and refining, molasses and sugar trading accounted for 106 and 82 per cent respectively of profits less losses. The volatility of these earnings can be seen in that in 1978 profits from cane sugar production and refining was one per cent. By 1979 it has risen to 21 per cent and in 1980 and 1981 it was 36 and 45 per cent of total profits, respectively. To this basic consideration must be added the structural crisis conditions which have been confronting the capitalist world economy since the mid-1970's. If we bear these two points in mind we would be able to appreciate why, over the past two to three years, the company has come close to panicking over its possible over-extension in research and development, and the over-commitment of its resources to speciality chemicals based on sugar. There has been in other words a substantial retreat from the sucro-chemicals programme started just over a decade ago.

After the boom in sugar prices of the mid-1970's had completely subsided, pre-tax profits of the corporation fell from £52.5 million in 1976 to £43.9 million in 1977 to a further low of £24.6 million in 1978. Given the rapid inflation of prices during this period the real fall in profits was considerably larger than the current values would indicate. These events "coincided" with the retirement of the current Chairman of the TNC (John O. Lyle) and the assumption of leadership of the company by Lt. Hon. Earl Jellicoe. Whatever may be the "inside" events, it is abundantly clear that a number of factors had precipitated the decline

Table 45

Tate and Lyle Limited: Analysis of Trading Profit, 1978-1981

	Trading Profit(Loss)							
	1978		1979		1980		1981	
	£M	%	£M	%	£M	%	£M	%
TRADING SECTORS AND OPERATING BASES								
Agri-business								
United Kingdom	2.6	6	2.2	6	(6.5)	(14)	(0.3)	(1)
North America	1.9	4	0.1	-	(1.1)	(2)	0.1	-
	4.5	10	2.3	6	(7.6)	(16)	(0.2)	(1)
Bulk Liquid Storage								
United Kingdom	1.3	3	1.1	3	2.7	6	2.6	5
North America	0.1	-	0.1	-	0.2	-	0.4	1
	1.4	3	1.2	3	2.9	6	3.0	6
Cane Sugar Production and Refining								
United Kingdom	1.2	3	5.4	15	5.6	12	9.4	17
Canada	1.4	3	1.5	4	3.2	6	3.7	7
USA	(2.8)	(7)	(0.4)	(1)	5.0	10	9.1	17
Belize	1.3	2	1.0	3	2.9	6	2.3	4
Zimbabwe	-	-	-	-	0.7	2	0.0	-
	1.1	1	7.5	21	17.4	36	24.5	45
Cereal Sweeteners and Starches								
Canada	N.A.	N.A.	N.A.	N.A.	(0.3)	(1)	(1.3)	(2)
Europe	N.A.	N.A.	N.A.	N.A.	(0.9)	(2)	0.7	1
	3.3	7	1.9	(5)	(1.2)	(3)	(0.6)	(1)
Commodity Trading Worldwide								
Sugar	19.6	45	9.8	28	19.3	39	9.7	18
Other	(1.7)	(4)	(0.8)	(2)	(2.5)	(5)	(0.1)	-
	17.9	41	9.0	26	16.8	35	9.6	18
Insurance	-	-	0.8	2	0.8	2	1.1	2
Malting								
United Kingdom	2.0	5	2.4	7	2.3	5	2.0	4
Molasses Trading, Storage and Distribution								
Worldwide	6.4	15	8.4	24	15.0	31	10.6	19

Table 45 (cont'd)

	1978 £M	1978 %	1979 £M	1979 %	1980 £M	1980 %	1981 £M	1981 %
Warehousing, Packaging and Distribution								
United Kingdom	N.A.	N.A.	N.A.	N.A.	0.1	-	1.6	3
Nigeria	N.A.	N.A.	N.A.	N.A.	0.8	2	0.6	1
	3.9	8	1.9	5	0.9	2	2.2	4
Other Activities								
Shipping - United Kingdom	N.A.	N.A.	N.A.	N.A.	2.4	5	0.2	-
Starch-United Kingdom	N.A.	N.A.	N.A.	N.A.	(3.2)	(6)	-	-
Other	N.A.	N.A.	N.A.	N.A.	2.2	4	2.3	4
	2.5	6	2.1	6	1.4	3	2.5	4
Total	44.0	100	35.6	100	48.7	100	54.7	100
Research and Development	(2.7)	-	(2.9)	-	(2.5)	-	(2.4)	-
Speciality Chemicals	0.2	-	(0.6)	-	(2.9)	-	(4.4)	-
Net Costs of R and D Speciality Chemicals	2.9	-	3.5	-	5.4	-	6.8	-

Note: N.A. Not available/applicable.
The figures above refer to group trading profit before deductions of interest, central expenses, research and development taxes, etc.

Source: Tate and Lyle, Annual Report and Accounts, 1978-81.

in profits; the main ones being: the fall in demand in the UK refined sugar (mentioned above), the impact of UK membership of the EEC on the sugar regime facing the TNC; the demonstrated excess capacity in the starch and glucose industries, a capacity which had been built up during the buoyant years of the sugar boom; a worldwide decline in shipping rates; the much higher cost of penetrating the North American market than that which the corporation had originally anticipated.

In order to combat the decline in profitability a major restructuring programme was introduced by the new management. These had five major production and trading elements.

One of these was the closure of some sugar refineries in a surgical effort to remove over capacity. The second was to sell and dispose of the corporation's shipping fleet. The third measure was to move out of starch and glucose production in a number of its factories. A fourth was the rather drastic pruning of overheads and central expenditures in the corporation. Lastly, and of particular significance to us, a major re-appraisal of the corporation's research and development work and the speciality chemicals programme in particular was undertaken. Accompanying this restructuring programme was a major re-organisation of the management structure of the TNC, as is usual in such circumstances. As the Chairman put it:

> "Throughout the group we are now setting more urgent requirements for profit return. We have, for example, re-appraised projects for our chemical division on which we are now taking a more conservative view. In surfactants we have decided to write-off our initial expenditure while intensifying our efforts to solve the technical problems we have encountered."[210]

The attitude reflected in this quotation while making "hard-headed" business sense reveals why I raised the question earlier, as to whether a company with as volatile a trading structure as Tate and Lyle can reasonably be expected to sustain the long effort to develop a sucro-chemicals industry. While on the one hand the volatility of the company's pushes it on to find a stable manufacturing base in chemicals derived from sugar, in order to ensure a better regulated sugar demand, on the other hand, the very instability of earnings reduces its capacity to finance a long term research effort. What is therefore reflected in the sentiments expressed in the chairman's statement may be more than the usual pessimism encountered during a downswing of economic activity. It may be the manifestation of this particular dilemma. In any event, the present persistent weakness of sugar prices is adding considerably to the discouragement of the effort in sucro-chemicals.

The approach of the new management to the sucro-chemicals programme was put this way in the corporation's Annual Report for 1980:

> "To develop and make profitable a new chemicals technology is, we have always acknowledged, to accept a major challenge - particularly at a time of acute depression in the chemicals market. With the added burden of heavy start up expenses, we have been in no position to make our planned impact on the market and incurred substantial losses in 1980. It is taking longer than we expected to commission the two new plants of our production complex at Knowsley, Merseyside. With our planned range of surfactant products we have encountered serious technical difficulties and have yet to prove our ability to produce these in volume and on commercially viable basis. We are continuing our efforts to solve these problems but, in view of the high risk nature of this venture, have written our initial expenditure out of our balance sheet."/11

Following this announcement the company has relinquished its share in the bio-specialities programme and has sold its assets. It has also disposed of a major part of its share in the common services at the Knowsley complex. Its joint venture with Hercules Inc. was also terminated. Finally, it has recently concluded an agreement with the chemical TNC Hoechst A. G. to "work jointly in order to exploit our combined skills in some areas of chemistry and biology".[/12] As the corporation has put it:

> "The agreement combines the experience of a major chemical company and a major food company in developing specific new areas of mutual interest in biotechnology and carbohydrate chemistry".[/13]

Our examination of Tate and Lyle shows that to all intents and purposes, the sucro-chemicals programme is well and truly at a cross-roads. While there has been a considerable phasing down of the corporation's efforts in this direction, nevertheless its movement towards joint arrangements with Hoechst A. G. marks an important advance. I say this,bbecause this company brings to the agreement not only a wealth of experience in chemical production and trading but being a major "user" itself, it might very well offer the solution to the question of how to penetrate the existing chemicals markets with sucro-chemicals.

It should be noted that the downturn in profits which had precipitated the drastic changes indicated above has been halted and a definite upswing in profitability had started during 1981. As the chairman remarked:

> "I am very glad to report that 1981 saw the return of the Tate and Lyle Group to an improved quality of earnings and a more acceptable level of profit - £36.3 millio efore tax. This result was achieved in a very difficult ec nomic climate, both in the UK and worldwide. It is encouraging to see a stronger group emerging from the drastic policy of rationalisation which we have of necessity pursued in recent years."[/14]

Unfortunately from the standpoint of sucro-chemicals this was achieved at its expense. In his Interim Report for the six months ending March 27, 1982, the Chairman noted the continued upswing in profits, but goes on to point out that:

> "The containment of expenditure on research and development and substantial reduction of losses in speciality chemicals also had a bearing on the figures."/15

One note on which this chapter must end is a further re-iteration of the observation that a TNC with as volatile an earnings structure as Tate and Lyle cannot be confidently expected to pioneer a massive break-through for sucro-chemicals. At the same time, however, a dozen years of sustained research and the commitment of large sums of money to research in this field constitute an important asset of the company. This TNC is in fact the world-leading institution in the field of sucro-chemicals. This considerable asset should not be easily given up, or worse wasted. Perhaps in some ways the new partnership agreement with Hoechst A. G. may well hold the key to the future. The technical problems which remain in this field are considerable let alone the task of product development and marketing. It would seem as if a new infusion of resources and the opening up of market prospects are needed to get the momentum going again. The question is, however, where will this come from?

Notes to Chapter 10.

1. J. M. Utterback and J. W. Brown (1972), p 14.
2. Tate and Lyle Ltd., Annual Report 1976, p 9.
3. Tate and Lyle Ltd., Annual Report 1980, p 13.
4. P. A. Vlitos, (1977) p 343.
5. J. L. Hickson, in G.Birch and K. Parker (eds), (1979) p 177.
6. J. Lock, (1980) p 433.
7. R. Righelato, (1979) p 150.
8. Tate and Lyle Ltd.: New Developments, 1979, p 14.
9. _ibid_, p 14.
10. Tate and Lyle Ltd., Annual Report, 1980, p 6.
11. _ibid_, p 12.
12. Tate and Lyle Ltd., Annual Report, 1981, p 4.
13. _ibid_, p 4.
14. _ibid_, p 6.
15. Tate and Lyle Ltd., Interim Report, 1982, Chairman's Statement.

Chapter 11: THE THREAT AND THE PROMISE: AN ASSESSMENT

Section (i): Context

In the previous chapters we have presented a large amount of detail on the development of HFCS and sucro-chemicals technology, the structure in which the industries associated with these technical innovations have developed, and the future prospects of these industries. In this chapter, from the perspective of the Caribbean, a general assessment of the impact of these developments will be presented, and certain recommendations will be made. The emphasis here will be judgemental and analytical rather than the repetition of details on market forecasts, trends in capacities, prices, and public policy, and the identification of technical obstacles and problems which remain in the development of these technologies. Certain general propositions about the Caribbean region are implicit in the presentation of the material so far. However, in order to erase any doubts which may linger, about the context in which my judgements are being exercised and the recommendations made, these will have to be made explicit at this point. The first of the propositions is that, historically, arising out of the process of colonisation and exploitation by Europe, our agricultural system has been oriented to the production of export staples for consumption abroad. Coming out of the relatively recent process of decolonisation some efforts are being made at the replacement of the foods we eat which are imported from overseas. So far, however, the diversification of agricultural output achieved under the import-substitution programme has been rather limited and projections into the future do not indicate any dramatic improvements. This is a particularly depressing state of affairs since within the region, the overall food needs exceed domestic supply. It is my judgement that in the present state of

Caribbean agriculture, significant increases in the output of food would depend, inter alia on the following:

- a substantial decrease in losses of output due to pest and diseases;
- a substantial increase in yields and improved regularity of output from presently cultivated areas;
- vastly improved efficiency in the use of fertilizers, water, mechanical equipment and other energy intensive inputs;
- better storage, transportation, distribution and pricing systems;
- improved social amenities in the rural areas, e.g. health, recreation, education, training, etc.;
- a socially just distribution of land and other economic resources;
- improved access to power and the mechanisms of control over their social and political lives by all rural classes, strata and groups which have been historically excluded from these by dominant minority groups.

Many, if not all the above provisions may well be considered as relevant not only to the Caribbean region, but to the world as a whole. Unfortunately, in the latter instance, for those societies in which the improvements can best be afforded, e.g. because there are regular surpluses of agricultural output, they are the least needed, and where they are most needed they are not readily achieved - green revolution notwithstanding.

A second proposition is that traditionally the region has been under-industrialized, primarily for the same reasons of colonial domination which has determined the export orientation of agriculture and the neglect of internal food demand. Arising out of the post World War II decolonisation process there have been determined local efforts at industrial diversification, mainly by way of programmes of fiscal and other incentives designed to substitute imported industrial products with domestically produced ones. In several studies I have already sought to lay bare the essential weaknesses of the industries established in this import substitution process. Here I will therefore simply confine myself to listing some of the major defects, serially:/1

- these industries have low domestic value-added because of their reliance on the assembly of imported knocked-down equipment;
- their labour absorptive capacity is also low;
- there are diseconomies of scale induced by the small and fractured nature of their markets;
- despite small markets there is significant underutilization of capacity ratings;
- the industries create limited inter-sectoral links within the national economy and are therefore incapable of generating autonomous, self-reinforcing sequences of growth;
- despite substantial capital subsidization the industries are high cost producers which shelter behind protected markets and use their monopoly status to pass on these costs to their consumers;
- monopoly power is also exerted through the lowering of quality and standards, poor after-sales facilities, and exorbitant financing charges;
- the industries although designed to save foreign exchange, have very high import intensities suggesting at times negative foreign exchange drains from the national economy, despite high private profitability;
- as branches of TNC's these industries have no serious export interest, except where regional marketing and production conditions make this necessary;
- the industries do little or nothing to encourage the development of an indigenous technological capability.

Recently in some of the larger territories attempts have been made at the development of a basic materials sector, for example Trinidad-Tobago where it is being developed on the basis of its hydro-carbon resources and imported iron-ore.

These efforts are, however, still very much in their infancy. Nevertheless, I do feel that they constitute an important attempt to overcome the limitations of the import-substituting industrialization process highlighted above.

The patterns of agricultural development and industrialization which I have outlined signify a historical process of divergences between domestic resources and domestic production on the one hand, and the needs of the population and the market demand for food on the other. Because of this, the bases (both physical and social), for the development of an indigenous technology are non-existent./2 It was, however, because of this particular historical process of divergences that I have elsewhere advocated an industrialization model based on the first priority of developing a basic materials sector for the national economy./3 The essential point of this proposal is that only if we are able to produce those commodities which are needed for the production of all other commodities that we can aspire to reverse this historical process of divergences and end the perpetuation of the dynamic of underdevelopment. The basic commodities used in the production of all other commodities may be indirectly required (e.g., foodstuffs for wage earners) or directly required (e.g. iron and steel). From this criterion a list of the essential industrial products was drawn up, and in this short list of a dozen or so commodities, chemicals appeared./4

Placed in this context the study of sucro-chemical technology falls within the scope of the search for an industrial base in what is a relatively abundant regional raw material. The study is therefore, in a fundamental sense an examination of the possibilities created by technological advances fro a chemical industry based on sucrose <u>specifically</u>, as opposed to hydro-carbons or even other biomass resources, in the context of the more general search for a pattern of investments, growth, output, consumption and technological change which would be consistent with the development, as against the perpetuation of the underdevelopment of the Caribbean region. It is clear from this that if a chemical industry based on sucrose could become technically and commercially viable, a singificant advance in the cause of Caribbean development would have been made.

The priority search for a capacity to produce the commodities which enter directly or indirectly into the production of all other commodities is not a blueprint for autarchy. It is a programme aimed at the creation of an autonomous, self-perpetuating sequence of investments which would internalize the bases of growth and development of the national economy. Furthermore, the success at creating such an internalized system of sequences would be heavily contingent on the availability of foreign exchange with which to finance it. Profitable trade in existing commodities which are being produced is therefore a vital requirement of the strategy. In other words while the search is for new bases of trade in which foreign demand for our output is seen as the extension of domestic requirements, and our own demand for foreign goods is similarly situated, the model specified also seeks to maximize in this context the gains from existing trade patterns. The threat of HFCS to cane sugar should therefore be placed in this context of a threat to one of the principal sources of foreign exchange earnings in the region.

Finally, from the global and regional natural resource point of view, the sources of organic chemicals are oil, coal and biomass. Because the range of these alternatives is restricted, an important proposition is that the competitive relation between these alternatives is crucial in determining the pattern of resource exploitation. In this competitive relation, I would stress not only price, whose importance should not be under-estimated, but such other factors also as access and security of supplies, national considerations, degree of monopoly control of production and marketing, environmental considerations, and so on. While initially the chemical industry switched from biomass and coal to oil because of cheap oil based on huge discoveries, the recent rapid inflation of hydro-carbons prices, based on their presumed long run scarcities, has been a major push in the direction of using biomass in general, and sucrose in particular as a regenerable source of chemicals. The present petro-chemical industries, however, possess vast resources and an enormous amount of political leverage. They cannot reasonably be expected to yield their gains or their entrenched positions easily. The successful fight for an alternatively based chemical industry will inevitably require winning significant governmental support for it, as a source of countervailing power. Neither the cane sugar industry as it is globally organized, nor Tate and Lyle the major TNC in this field, can reasonably be expected to generate the resources for such a major industrial transformation.

Section (ii): Recommendations

In our study of HFCS in Part I we observed the following:

1) That there was a slow rate of increases of global demand for sweeteners (2-2½ per cent, per annum maximum). This combined a static or declining per capita demand in the developed countries (usually those where per capita consumption of sucrose is in excess of 45-50 kg per annum) and a rising per capita demand in the underdeveloped countries, (usually those where per capita demand was less than 15-20 kg per annum).

2) In the latter group of countries the drive for self-sufficiency in sugar is strong, and as a consequence increased demand does not lead to significantly increased trade. Furthermore, in the former group, countries traditionally thought of as major importers are now major producers and exporters of sugar, e.g. EEC, and this has upset the traditional global demand-supply-trade balances in sugar.

3) Globally, HFCS output is projected to average about one-tenth of total sweeteners demand by 1990 whereas in its chief growth area, the USA, output is expected to be substantially higher, as much as 40-45 per cent of demand.

4) While projections of the sweetener market have always been fraught with difficulties, there is little evidence to suggest so far that these projections have erred on the side of optimism. To the contrary, for to date output has always exceeded projections.

5) The growth of HFCS in countries other than the USA where the industrial configuration favours it, is heavily contingent on the direction of public policy. The extreme example of this situation is the EEC, where presently public regulations severely limit the production of HFCS to only 200,000 tonnes per annum.

6) In some Third World countries, HFCS capacity is being installed. Here the emphasis is either on an abundant raw material which can be utilized (corn, rice, cassava) or a large beverages sector to be serviced.

7) Technically, certain important hurdles need to be overcome before HFCS can completely substitute for sucrose, e.g., crystallization. If these were to be overcome the rate and pattern of its future growth would be even more dramatic and spectacular than it has been so far.

8) Summing up, it was concluded in Part I that the major impact of HFCS growth would be felt on international trade in sugar. We pointed out that only 20-25 per cent of the world output of sugar was traded internationally, and of this 90 per cent was cane sugar. Furthermore, the trade in sugar was riddled with a complex network of bilateral, regional and international agreements which reduced the "free" world market element to an even smaller proportion of this global output, 2-4 per cent. Traditionally the price on the "free" market has been subject to wide swings which have made sugar prices notoriously unstable. The conclusion arrived at was, that in order to protect their own consumers, or alternatively where domestic production of

sweeteners takes place their own producer interests, countries can be expected to restrict imports as a first line of defence if their domestic interests are enhanced or threatened by HFCS growth. In this sense, therefore, the impact of HFCS on cane sugar trade generally and hence on the Caribbean in particular would be far more significant than the output figures of HFCS and other sweeteners would alone suggest.

On the basis of the above observations, two major recommendations were made at the end of the survey of HFCS. The first recommendation was that a strong case could be made out for HFCS production and marketing to be incorporated into the International Sugar Agreement (ISA). This was advocated as a position for the Caribbean to adopt. It was pointed out in support of this idea that the HFCS producers also had an interest in a world sweetener market that was less volatile and unstable, and therefore this interest should be encouraged in every way. In so far as the volatility and instability of sugar prices stem from the peculiar "free" market structure for sugar, the inclusion of all major forms of sweetener production, whether traded or not, into an international sugar agreement is necessary to ensure orderly marketing of all sweeteners. The recommendation therefore, envisaged not only the incorporation of HFCS into the present ISA, but the transformation of the ISA itself into a more general and comprehensive framework in which to plan the production and marketing of all major forms of sweeteners. To the extent that this recommendation aids the formation of a regime of remunerative and stable prices for reasonably efficient sugar producers, to this extent also it promotes a basis on which the planned utilisation of sucrose as a chemical feedstock might be developed.

In other words, all actions which make for a more orderly and stable marketing of sucrose, ipso facto also make for more orderly and stable conditions when promoting its use as a chemical feedstock. From the view-point of science and technology planning this recommendation therefore seeks to suggest ways which might stabilize the production and marketing conditions of sucrose in order to encourage its development as a major raw material input.

The second recommendation made was that the Caribbean region should spare no efforts in developing a monitoring capacity to identify and so permit a planned response to developments in HFCS output and technology. Two points were made with regard to monitoring. One was that it should be seen as systematic intelligence gathering - a necessary function which falls within the framework of national and regional Science and Technology Planning. To reinforce this comment at that point I was careful to identify the functions of what I termed monitoring: (searching for "signals" which are indicators of significant innovation; identifying the probable consequences of these innovations; choosing the context in which one could identify the speed and direction of the technology and the effects of its use; presenting the above data in a timely manner to ensure that effective reactions can be made by management on the basis of an assessment of it). The second point which was made was that for monitoring to be effective it had to embrace all forms of sweeteners. Traditionally cane sugar producers have focussed on the monitoring of each other's activities, with some occasional studies of developments in beet sugar. What is called for here is the incorporation not only of HFCS but other sweeteners, e.g. the low calorie and non-caloric sweeteners into a systematic framework of intelligence gathering. In the particular case of these two examples cited here, the important point was made that a threat which overhangs cane and beet sugar as well as HFCS itself is the possible discovery of a low calorie sweetener with the taste and other major characteristics of sucrose.

Monitoring as an aspect of national and regional Science and Technology Planning should be extended also to include the entire field of sucro-chemicals activities. In other words, both "the threat and the promise" have to be thoroughly comprehended, if a satisfactory regional/national response is to be made. This, therefore, constitutes my third recommendation.

The particular importance of this recommendation to the Caribbean is laid bare when we take into account how mature and ossified the cane sugar industry has become, and how limited has been its research focus and interventions on sugar issues in the region. There is much truth in the observation of Hagelberg and Ahlfeld on both the beet and cane sugar industries:

> "Secure until recently from competition by close substitutes, the industry has felt little need for product development, beyond the immediate areas of refining quality, liquid sugar and dry bulk shipment. While the value of beet pulp and of beet or cane molasses on occasion may have meant the difference between profit and loss, they have remained by-products."/5

The authors go on to point out that:

> "For all the renewed interest in formentation alcohol brought about by escalating oil prices, beet and cane are still grown primarily to produce sugar, and sugar is still used almost exclusively for human consumption, although periodically there has been significant diversions."/6

The authors go on to cite the production of high-test molasses in Cuba, between 1935 and 1958 and the use of fodder sugar in the EEC, during the late 1960's and early 1970's, as examples of those "diversions".

Whatever may be said, it seems to me that the lack of innovatory drive and imagination in the Caribbean sugar industry is largely attributable to the protection and subsidies which have been afforded the sugar planters by various Caribbean and Colonial Office governments. Over the centuries the economic and political power commanded by the region's sugar planters has been enough to ensure them considerable leverage over state policy and they have used this leverage with extreme single mindedness in the pursuit of their narrow interests. In pursuit of their goals they have been aided by the fact that sugar is a very labour intensive activity in the region and as such it has been easy to make any threat to the profitability of sugar quickly translatable into a threat of retrenchment and unemployment affecting the livelihood of hundreds of thousands of West Indian people. As soon as this spectre was presented to governments invariably they have come to the "rescue" of the sugar planters.

The study presented here is in many different ways an initial effort at monitoring developments in the field of sucro-chemicals generally and Tate and Lyle's activity as the leading TNC in particular. From this point of view we concluded the last chapter by noting that the future of sucro-chemicals was at an extremely critical juncture. After more than a decade of consistent research and development work, Tate and Lyle has retreated over the past two years in the face of declining profitability. While as we pointed out its efforts to form a partnership with Hoechst A. G. is a hopeful step, it remains true that the expertize and marketing resources required to penetrate the petro-chemical dominance will require not only more resources but a more stable earnings basis than Tate and Lyle, based as it is on sugar, can command. Yet, paradoxically, as we have pointed out before it is this same dependence and vulnerability caused by its sugar based industrial structure which has sustained the TNC's efforts at a breakthrough in sucro-chemicals.

My fourth recommendation stems from the belief that at this juncture what is required is an injection of entirely new resourcesa and the creation of new market opportunities to get the momentum in favour of sucro-chemicals started again. Since I have pointed out that ultimately only government policy can ensure the required countervailing power to that exercised by the petroleum TNC's my recommendation is that the governments of the region, at a regional level, should consider an agreement aimed at joint research, technology, development, production and marketing of sucro-chemicals with Tate and Lyle. Such an agreement should range over research in progress, new research and development work being contemplated, as well as the licensing of production of sucro-chemicals in the region. It is of course reasonable to expect that through public policy, market development for these products can be guaranteed by licensing, etc. To support this endeavour a regional Venture Capital Fund and a legal entity to operate it should be created and financed out of a levy on sugar production. The idea of a sugar levy of this sort is of course not new, since after World War II the colonial authorities had introduced this in several territories in the region, creating three funds, one of which was directed towards the rehabilitation and re-composition of the capital stock then available to the sugar industry. The difference between then and now is that the recommenddation here involves deliberate risk-taking, and hence the notion of a "venture" capital fund to finance these activities. It is my strong belief that while Tate and Lyle finds itself at the present cross-roads, this is the most opportune time to pursue an equitable arrangement.

Creating a venture capital fund of this sort to finance a joint research and development, production and marketing effort with Tate and Lyle would not by itself be adequate for the purposes at hand. What is also needed is a planned effort to develop an indigenous research capability in this field. The following suggestions in this direction therefore, constitute my <u>fifth recommendation</u>. As I see it what is needed ultimately is a shift from the present research focus in sugar. Efforts designed to ensure such a shift should not only include the incorporation of sucro-chemicals activity but should also cover other areas as fermentation technology (linked to a possible gasahol programme); food technology and carbohydrate uses; process technology in the sugar factories; and cane sugar harvesting and logistical operations. To ensure that this shift in focus takes place the region's training facilities will have to be appropriately geared. A good starting point would be to make available post-graduate training awards and fellowships to persons in the Caribbean. From this programme a corps of persons equipped to offer courses at university level in these fields can be created. As this is taking place, laboratories and other research facilities can be built up. Gaps in resources which are identified can of course be filled by the appropriate importation of skilled persons. Along with these efforts a proper documentation center in the field should also be built up. The aim will be for this center to eventually take over some of the basic monitoring functions indicated in recommendation 3.

One activity which I believe is of some urgency, and which underscores a failure of this study, is the need for on-the-spot monitoring of activities in sucrose chemicals and HFCS from carbohydrates other than corn, which are taking place in other Third World countries. Such activities occur in an environment much closer to ours and the problems encountered in their relationships with the TNC's, the construction of facilities, actual production and marketing difficulties will be of salutary value. In other words we may be able to learn from others' mistakes if we treat such developments in the Third World as a "social laboratory" to be closely monitored. In the literature it is remarkable how many Third World countries have repeated the same mistakes others have made through ignorance.

In conclusion I should perhaps reiterate an earlier observation that although my study does not encompass the use of sucrose as a source of energy, that ultimately the role of sucrose in this regard in the region will be crucial. As we have noted the fermentation technology for ethanol production is not new, although many improvements have taken place affecting yields, residence rates, quality of the substrates in which the micro-organisms are cultivated, etc. The production of ethanol on a large-scale might be feasible in a gasolene extender programme with the use of "excess" ethanol as a chemical feedstock. To my mind, this route to sucrose chemicals could only be a preferred route in the context of such an overall approach. Otherwise, directed synthesis is the preferred route. The question, however, which I want to refer to here is what would be the impact on regional food supplies if land were directed towards sucrose chemicals? The answer is simple. A sucrose chemicals programme which does not envision large-scale gasoline extender production will not require large amounts of sucrose. Indeed, when we realize that the region's current output of sucrose is about 60-70 per cent of the region's capacity to produce sugar, than the programme need not even require the diversion of export sales to service it.

I have been careful not to specify any particular institutional structure to cover the proposals made here. However, in so far as both CARICOM and the CDB are represented in the Coordinating Committee of the CTPS-II, these two regional institutions might well take the initiative to follow up on the proposals made in this Report.

Notes to Chapter 11.

1. For further discussion see C. Thomas (1974, 1979 and 1982).

2. The thesis here is fully developed in Thomas (1974). The main point of the discussion here is merely to introduce the specific location of the sucro-chemicals industry in a re-organized Caribbean developmental focus.

3. *ibid*, pp 177- 227.

4. *ibid*, pp 195-201.

5. G. B. Hagelberg and H. Ahlfeld, (1981) p 3.

6. *ibid*, p 3.

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