High Fructose: The Competition to Sugar

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It is an honor to be the first representative of the corn sweetener industry to appear before a Congress of the International Society of Sugar Cane Technologists. This is a recognition that new dimension has been added to the sweetener world, high-fructose corn syrup (HFCS). High-fructose corn syrups do, indeed, compete with sucrose, especially in the United States. However, this competitive relationship makes companions of corn sweetener producers and sugar refiners, and these companions have similar opportunities and challenges. Everyday, work is done with two of the world's greatest agricultural resources, sugar cane and corn, two renewable resources with untapped potential.

To appreciate fully the economics of high-fructose corn syrups, one must understand that the corn-refining process extracts several valuable co-products, starch, corn oil and corn feeds. Due to the nature of the process, the production of these products is interrelated, and the market value of the corn oil and corn feeds has a direct bearing on the cost structure of high-fructose corn syrups.

In recent years, the demand for corn oil and corn feeds has been extremely strong, and, consequently, by-product recovery has ranged from 50 to 70 percent of the per-bushel corn cost. Obviously, this has had a favorable impact on the economics of all corn sweeteners. There are no present indications that these by-product values will change substantially in the near future. Demand for corn oil remains strong, and corn feeds continue to be a key protein source in poultry and livestock rations.

Turning specifically to HFCS, the concept of converting glucose to fructose is not new. Initial attempts at alkali conversion date back to 1895.
It was not until 1957, however, that the first attempt at enzymatic conversion appeared. In that year, a patent was issued to Marshall and Kooi of CPC International for work with xylose isomerase to isomerize glucose to fructose. In the mid-1960's, Takasaki of the Japan Fermentation Research Institute discovered the first practical organisms, streptomyces, for the enzymatic conversion of glucose to fructose. Commercial development of high-fructose corn syrup in the United States, based upon Takasaki's work, was carried out by the Clinton Division of Standard Brands, Inc., in the late 1960's.

By 1972, two U.S. companies, with a combined annual capacity of approximately 425 million pounds (191,250 tonnes) comprised the entire industry capability for producing high-fructose corn syrup. Please note that all volumes in this article are presented on a dry basis, as opposed to a liquid or commercial basis. The extraordinary circumstances of 1974-1975 in the sugar world caused the formative years of high-fructose corn syrup to be compressed into an abnormally short time frame. The results have been both positive and negative. The sugar price spiral of 1974-1975 helped establish HFCS as a nutritive sweetener, but it also created a major problem for the industry — overcapacity.

Since 1972, some 4.6 billion pounds (2,070,000 tonnes) of capacity have been added by the U.S. corn refining industry. In essence, 15 to 20 years of normal growth have been compressed into a much shorter time frame. Overcapacity, coupled with depressed sugar prices, has led to unattractive returns on investment over the last few years. This condition has slowed further expansion and, as a result, supply and demand in the U.S. are beginning to move toward equilibrium.

Fortunately for the U.S. industry, the markets for high-fructose corn syrup have developed at a good rate. Sales of the standard 42-percent syrup have increased nearly sevenfold since 1972. In addition, a "second generation" 55-percent fructose syrup became a commercial product in 1978. Sales of HFCS in the U.S. in 1979 are estimated at approximately 3.6 billion pounds (1,620,000 tonnes). This represents a volume gain of 30 percent over 1978, with a large portion of the increase attributable to the 55-percent product.

More important than a history, perhaps, would be a forecast of the potential of HFCS for further replacement of sugar in the U.S. Sales of HFCS will continue to grow in the U.S. market, but not as dramatically as in the past. This year (1980), the U.S. corn refining industry is expected to sell about 4.1 billion pounds (1,845,000 tonnes). Of this total, it is estimated that 2.9 billion pounds will be the 42-percent syrup. Essentially all of the remaining 1.2 billion pounds will be the 55-percent product, with very limited sales of 90-percent fructose. From these figures, it is obvious that sales of the 55-percent HFCS are expected to increase substantially — in fact, by more than 50 percent over 1979. The 42-percent syrup will enjoy much more modest growth.

The 55 percent HFCS is the result of new fractionation technology.

1The 42 percent fructose corn syrup is usually sold at 71 percent solids and the 55 percent high fructose corn syrup at 77 percent solids.
involving the chromatographic separation of fructose from dextrose by means of ion-exchange resins. Enzymatic conversion of dextrose to fructose reaches equilibrium at 50-percent conversion and, therefore, the original high-fructose corn syrup contains 42-percent fructose as the commercially practical limit. By using the fractionation technology fructose-bearing syrups of up to 100 percent can theoretically be produced. But, to date, only the 55-percent and 90-percent products are commercial realities.

In taste tests of comparable fructose/water solutions, the 55-percent syrup is judged to be about 10 percent sweeter than the 42-percent product, and this difference generally holds true in most applications. In addition to greater sweetness, the 55-percent syrup has slightly solids, lower dextrose content and a more favorable polysaccharide profile. In total, these characteristics have permitted the 55-percent syrup to compete successfully as a match for medium invert sugar, the most popular sweetener with the U.S. soft drink industry. The success of the 55-percent HFCS makes the near-term outlook for high-fructose corn syrup positive in the United States. Sales of the 55-percent product are expected to more than triple by 1983.

In the same timeframe, a growth rate of only three to four percent per year is projected for the 42-percent syrup, with a relatively mature picture thereafter. Reflecting this slowdown, future expansion of the U.S. fructose industry is anticipated to be more measured than in previous years. One must consider that the euphoria associated with high-fructose syrups in the mid-1970's has been replaced by realism. Producers and users are now fully aware that HFCS is a product of quality and economic advantage, but it also has limitations. A review of the U.S. sweetener market by segments will verify this statement.

Sugar usage in baked goods, cereals and some allied products, amounted to 2.5 billion pounds (1,125,000 tonnes) in the U.S. in 1979. HFCS accounted for an additional 670 million pounds (301,500 tonnes), or 27 percent of the sweetener usage. It should be noted, however, that because of price relationships that have existed, much of the HFCS growth in this market category has been at the expense of other corn sweeteners, dextrose in particular. High-fructose syrup has the potential to gain a 25-percent share in this market segment. Further growth will be prevented by the product's lack of ability to crystallize, coupled with hygroscopic (moisture absorbing) and browning tendencies.

In confections, where 1.8 billion pounds, (810,000 tonnes) of sugar were used in 1979, HFCS accounted for less than one percent of the sweetener total. HFCS usage likely will remain low in this category, since the economics favor continued use of regular corn syrups in combination with sugar. Again, lack of crystalline structure and moisture affinity also will limit use of HFCS in candy. Sugar usage in U.S. dairy products totalled 1 billion pounds (450,000 tonnes) in 1978, with high-fructose syrups adding another 320 million pounds (144,000 tonnes). HFCS usage could increase to slightly more than 30 percent in this category, with its growth being limited by its tendency to lower the
freezing point of products like ice cream.

The U.S. beverage industry consumed 5.3 billion pounds (2,385,000 tonnes) of sugar in 1979. In the same year, this industry used HFCS for 24 percent of its sweetener needs, or 1.7 billion pounds (765,000 tonnes). In this particular market, the potential for high-fructose syrups is considerable. High-fructose syrup could achieve 90 percent of the total if Coca-Cola and Pepsi-Cola eventually approve its use as a total sugar replacement in their colas. Recently, The Coca-Cola Company approved the 55-percent HFCS at a 50 percent sugar replacement level in Coke. This is a major breakthrough for HFCS and leaves the industry short of capacity in the 55-percent product. It should be noted, however, that over-capacity still exists for the 42-percent syrup.

In canned goods, where sugar usage in 1979 was 1.1 billion pounds (495,000 tonnes), high-fructose syrup use amounted to 765 million pounds (303,750 tonnes). HFCS has the potential to displace additional sugar in canned goods, but its browning characteristics will be a growth inhibitor. Some 1 billion pounds (450,000 tonnes) of sugar were utilized in other U.S. processed foods in 1979. In these same foods, which include jams and jellies and catsup, 200 million pounds (90,000 tonnes) of high-fructose syrup also were used. Inasmuch as high fructose is hygroscopic and not economically available in dry form, its future will be limited in this category to 25 to 30 percent sugar replacement.

These statistics and projections emphasize that sugar is, and will remain, the sweetener standard of the United States and, most certainly, the world.

Another reason for projecting slower growth of the U.S. industry is the dramatic increase in capital required to build or expand production facilities. For example, a 400-million-pounds-per-year plant cost $50 million to construct in 1972; the same facility today would require a capital expenditure of $125 million, 2.5 times greater than eight years ago. The high-fructose syrup industry not only is capital intensive, but its economics are influenced by a number of other important factors, including operating rates and the cost of raw materials, energy, enzymes and labor.

Researchers at Purdue University, in West Lafayette, Indiana, USA, recently completed a study2 of the current economics of producing high-fructose corn syrup, taking into account these key variables. Not all data in the study are totally accurate, especially the capital estimates, but the report's conclusions are representative of the experience of U.S. high-fructose corn syrup producers.

U.S. producers do not release their cost-of-production figures. It can

2Department of Agricultural Economics, Cost of Producing High Fructose Corn Syrup: An Economic Engineering Analysis, Station Bulletin No. 229 (Purdue University, West Lafayette, Ind, USA: Agricultural Experiment Station, Sept. 1979).
be assumed, however, that present costs (excluding cost of capital) range from $0.08 to $0.12 per pound for the 42-percent fructose syrup, depending upon the size of plant and the operating rate. Production costs for 55-percent HFCS usually run 15 to 25 percent higher. The operating rate has a significant impact on the cost of producing high-fructose syrup. Because of its capital intensity and high fixed charges, the corn-refining industry tries to operate at above 90 percent of engineered capacity for at least 330 days a year. Published data suggest that a one percent adjustment in operating rates from the 90 percent level changes production costs by one-half percent per pound of high-fructose syrup, a reasonable finding.

The cost of corn is the largest single element in the cost of producing high-fructose corn syrup and accounts for approximately one-half of the total. It is therefore the most influential variable cost factor in high-fructose syrup production. An industry rule-of-thumb is that a $0.50 reduction in the price of corn equates to a $0.01-per-pound improvement in the cost of producing high-fructose corn syrup, all other factors being equal.

Enzyme costs in producing high-fructose syrups have been reduced significantly through improved enzyme technology. Today, enzymes account for five percent of the total cost of producing fructose, compared to 16 percent in 1972. Many organisms have been patented as isomerase producers, possibly as many as 100. For commercial purposes, however, there are five widely used systems today. Each utilizes a different organism, a different immobilization method and has different properties.

Enzyme suppliers have greatly improved the production of glucose isomerase since the early 1970's. None of the leading suppliers have published data, but undoubtedly yields have risen, perhaps by 10 times or more. As a result of this advance and greater competition among enzyme suppliers, the selling price of glucose isomerase has been relatively constant for the past four years.

Immobilization techniques employed by enzyme producers also have advanced. New carriers and immobilization methods have reduced losses and improved the economics for enzyme manufacturers. These new immobilized enzymes have higher isomerizing activities; they are less compressible and more permeable, permitting higher flow rates and better conversion efficiencies. The high-fructose syrup industry also has learned to use its enzymes more effectively, maximizing the productivity of fructose syrup per pound of enzyme.

Details have not been released by producers, but patent literature suggests that enzyme life and productivity can be extended by careful control of isomerization conditions (such as pH and temperature), the removal of trace metals (such as calcium and copper) and the use of selected additives. The end result has been a steady reduction in enzyme costs. In the mid-1970's, enzyme suppliers talked about a guaranteed cost of about $0.75 per hundredweight of high-fructose corn syrup, on a dry basis. Today, the figure is closer to $0.40 per hundredweight and many U.S. fructose producers have even better experience.
While much progress has occurred in enzyme technology, there is additional room for improvement and a further lowering of costs. At this stage, however, most scientists believe another breakthrough may be required in enzyme genetics or in the discovery of more heat-stable varieties before major additional savings can be achieved.

The newest technology to emerge in the corn-refining industry, of course, is the fractionation of fructose and dextrose to achieve the higher or "second-generation" fructose syrups. Initial fractionation processes of three years ago utilized small-scale batch methods. In a short time, the state-of-the-art has evolved into large-scale continuous systems. Several have been commercialized and dramatic improvements in process efficiency and product quality are being reported. Once again, fructose producers have not released scientific information. It can be assumed, however, that product recovery with the new continuous fractionation has been raised by 10 to 15 percent and water usage cut in half, as compared to results of early batch techniques.

One of the more worrisome elements in corn refining and high-fructose syrup production is the escalating cost of energy, which is equally troublesome for the cane sugar industry. In terms of high-fructose syrup production costs, energy has risen to nearly 15 percent of the total, quadrupling in the past six years. Corn refiners, especially in the newer plants, are combating the rising cost of energy by employing such devices as mechanical-recompression evaporators and heat exchangers. By utilizing such technology, a corn-refining plant today can be as much as 30 to 35 percent more energy efficient than 10 years ago. At best, however, this is only a holding action against rising energy costs.

A fifth cost factor in producing high-fructose syrup is labor, which accounts for approximately 10 percent of total operating expense. Again, high-fructose syrup producers have made significant strides in lowering man-hours per hundredweight of finished product. As new high-fructose syrup plants are constructed and existing ones expanded, labor-saving features will become increasingly commonplace.

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.

Elsewhere in the world, the picture is less dynamic. Next year, HFCS will account for only 2.5 percent of the total world sweetener consumption; in 1985, this figure is expected to rise to just over 3.0 percent. The product's growth will continue to be concentrated in major developed countries, having minimal impact on the world market as a whole.

The passage of time has proved many of the early predictions for rapid world-wide growth of high-fructose syrups to be baseless. It also has served to clarify the circumstances necessary for a high-fructose syrup industry to thrive. First, it appears that the producing nation must be a net sugar importer. There also must be substantial consumption of liquid sugar through a well-
developed processed food and beverage industry. An abundant starch supply must be available. Maize, grain sorghum, wheat, white and sweet potatoes and manioc all are good carbohydrate (starch) sources. In most regions of the world, however, these are more valuable as carbohydrates in the diet than as the raw material for fructose.

There are other considerations, such as a labor force trainable in the operation of sophisticated processing equipment; an ample fresh water supply and fuel source; access to processing chemicals and enzymes; and, of course, availability of the considerable capital required to build a fructose facility of sensible scale. A final requirement is a transportation and distribution system advanced enough to handle the special shipping and storage needs of fructose sweeteners, and their co-products (such as corn oil and corn feeds in the case where corn is the raw material). In all, these factors limit the potential of fructose technology to a few of the more industrialized nations, at least for the foreseeable future.

Estimates of sweetener consumption in the highly developed nations place high-fructose corn syrup at 10 to 12 percent of the total usage by 1985. In addition to the United States, only two other areas of the world have developed fructose industries to any marked degree. They are the European Economic Community and Japan. There are many similarities between the fructose industries of the U.S. and Japan, in terms of accomplishments and difficulties. Sugar consumption in Japan increased by two percent for the twelve months ended September, 1979. During the same period, high-fructose sugar consumption increased by 10 percent, for a total gain of 50 percent since 1976-1977. High-fructose syrup now accounts for approximately 10 percent of the total Japanese sweetener market, compared to five percent in 1976-1977.

Nevertheless, high-fructose syrup sales have not met the more optimistic projections. Japanese producers have shared a common malady with their American counterparts—overcapacity. Despite overcapacity, several producers have continued to expand, particularly for second-generation products. Expansion of the 55-percent syrup, undoubtedly, is in anticipation of greater use of the product by the Japanese soft drink industry.

Government policy has been a major force in shaping the progress of HFCS in the European Economic Community (E.E.C.). High-fructose syrup, or isoglucose, as it is more commonly referred to in Europe, emerged in the mid-1970's in the E.E.C. The reception of the new sweetener was aided by the fact that the beet sugar industry was protected by a quota system, elevating the price of sugar as much as 30 percent over the world price to European food and beverage producers. In 1976, approximately 100 million pounds (72,000 tonnes) of high-fructose syrup were sold in the E.E.C. and market projections were calling for 600 to 900 million pounds (270,000 to 405,000 tonnes) in 1978. Longer-range forecasts in excess of 2 billion pounds (900,000 tonnes) were called for by several industry sources. In 1979, the European Economic Community (E.E.C.) announced a decision to restrict the production of HFCS, as the market was perceived as mature.

tonnes were discussed.

Already faced with a beet sugar surplus, the E.E.C. took several steps to curtail the growth of HFCS, including a production levy. In total, the actions seriously affected the economics of HFCS in the Common Market, and several European corn-refining companies initiated legal proceedings. In October, 1978, the European Court of Justice determined that the production levy was discriminatory. Last year, however, the E.E.C. Council of Ministries approved a new plan regulating the growth of high-fructose syrup by means of a minimum/maximum quota system. Under this new plan, producers must pay a levy on any fructose syrup produced above their minimum quotas and not exceeding the maximum quotas. High-fructose syrups produced above the maximum quotas cannot be marketed in the E.E.C.

It would appear that such measures will slow the progress of high-fructose syrup in the Common Market. At the present time, high-fructose producers are operating at levels of production and profitability that might best be described as discouraging. Moreover, their future remains clouded.

There are HFCS developments in other parts of the world, including South Korea, Argentina, Spain, Canada and Eastern Europe, but none are on the scale of those in the E.E.C., Japan and the U.S.

In examining the world outlook for high-fructose syrup, one must keep in mind that the production of cane sugar in tropical regions is the most efficient sweetener system in the world, in terms of solar conversion and its unique ability to use a by-product as a fuel source. Thus, through the next decade it appears that the impact of high-fructose corn syrup on the international sugar cane industry will be negligible.

Your author noted earlier that both corn refiners and sugar processors share a similarity in their work with vital renewable resources. The world’s energy crisis has underlined the growing importance of renewable resources and added a new dimension to the work done by both parties. The graphic evidence lies in the mutual interest of both industries in the production of ethanol as a fuel. No review of high-fructose syrup, therefore, would be complete without giving brief consideration to the implications of ethanol production on the U.S. corn refining industry.

In the U.S., the synthetic fuels program covers a number of alternatives, such as coal liquids and gases, shale oil and other unconventional sources. But most experts agree that ethanol has the most immediate potential. There are, of course, several agricultural raw materials available in the U.S. from which to make ethanol, including sugar, corn, grain sorghum and potatoes. Corn and grain sorghum are considered the most attractive feed stocks in terms of availability and economics. The U.S. corn-refining industry, therefore, is ideally positioned to become an efficient ethanol producer.

To date, the U.S. government’s encouragement to corn refiners for ethanol
development has been confined to motor fuel extenders. It has consisted primarily of the exemption of motor fuels from a $0.04-per-gallon federal tax, if they contain ethanol made from agricultural raw materials. A number of additional incentives are being proposed to encourage greater production of ethanol. These include a permanent waiver of the federal excise tax and additional investment tax credits, loans, grants and loan guarantees for the construction of ethanol plants.

The government believes these incentives can significantly increase production of fuel ethanol from the current level of approximately 60 million gallons (227 million liters) per year. Government officials apparently are not in total agreement as to a reasonable goal for ethanol production. Public statements have ranged from 300 to 900 million gallons (1,137 to 3,411 liters) annually by 1982.

World events have given added impetus to the ethanol program in the U.S. Recently, the government announced a program to stimulate production of ethanol from corn displaced by the U.S. embargo of grain to Russia. A goal of 500 million gallons (1,895 liters) by next year was mentioned.

Whether any one of these projections becomes a reality remains to be seen, but one thing is undeniable. The development of ethanol as a fuel in the U.S. will affect the future of HFCS. From a positive view, a number of U.S. corn refiners now have completed feasibility studies regarding the diversion of existing processing capacity to the production of ethanol. As much as 100,000 bushels of daily corn processing capacity conceivably could be switched from corn sweetener production to ethanol. Should this occur, the supply-end-demand picture for corn sweeteners would be changed dramatically.

On the other hand, a major building program in terms of new facilities and the expansion of existing ones would be required if the government's goals of greater ethanol production are to be achieved. Large additions of new corn-processing capacity to produce ethanol will result also in large increases in corn feeds and corn oil. This, in turn, raises the difficult question as to what price level might be required for these additional by-products to be absorbed in the marketplace.

A rapid expansion of corn-refining capacity for ethanol production would probably raise the cost of corn and substantially lower by-product credits, making it more difficult for high-fructose syrup to maintain its traditional cost differential to sugar. Expansion of U.S. corn refining facilities for ethanol also raises the longer-term specter of overcapacity, should government policy toward fuel alcohol change at a future date. A shift in government policy could depress the ethanol market, with a result that corn refiners might be forced to operate their plants for starch or add finishing capacity for corn sweetener production, depressing margins for both products.

At this point, it appears U.S. corn refiners have not made a final decision on the amount they will commit to the production of ethanol, but clearly
the future of high-fructose syrup is interrelated with ethanol in the U.S., as is sugar on an international level. The concept of ethanol fuel from sugar cane and corn is a common denominator for those industries. Of greater importance, it symbolizes the untapped values within the raw materials and may well be the first step in a global movement toward fuller utilization of the world's renewable resources. It is a movement long overdue and vastly underrated in its significance. The attitude of corn refiners and sugar cane processors is important. Progress can be encouraged by redefining both industries beyond their traditional roles as suppliers of nutritive sweeteners, and by concentrating energies on a broad spectrum of opportunities rather than a limited group of products.