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Corn Industry Statistics

Foreword

Kyd D. Brenner
Interim Director

On the threshold of a new round of global trade negotiations, we have many exciting events to look toward that will bring change to the corn refining industry. International trade is only one of the many arenas where the corn refining industry has reason for a positive outlook. Innovative ideas in product development, application research, equipment enhancements and improved inputs are further reasons for optimism for the future of the industry. Corn refiners embrace change whether it is positive or negative in nature: maximizing the effects of positive change and channeling negative change into positive results. 2001 was no exception.

Although it meant losing our leader, we were delighted that President Bush chose Chuck Conner to serve as Special Assistant to the President for Agricultural Trade and Food Assistance last fall. Chuck did an outstanding job on behalf of the corn refining industry during his four and a half years as President of the Association.

I have been pleased to continue my ties with the Association as Interim Director. I speak on behalf of all the CRA staff and board members in expressing our gratitude to the Association's Chairman Mike Jorgenson. Mike has been an effective leader and an invaluable asset to the Association during this time of transition. I would also like to thank Mike for his insightful review of the events affecting our industry over the past year.

In this edition of the Corn Annual, we look at several issues significant to the industry with the hopes of capturing a glimpse of the future. Many thanks to Ambassador Allen Johnson for providing his thoughts on the upcoming global trade round and other trade issues that are of great importance to our industry. A lot of excitement has been generated by research on a new way to process corn. Researchers Vijay Singh and David Johnston explain a new concept in wet milling using enzymes to reduce steep time. New applications of membrane separation technology hold much promise for corn refiners. Rodney Simms provides an excellent review of these upcoming applications for membrane systems. Larry Miller discusses improvements in centrifuge technology that benefit corn refiners. Since corn refiners depend on the availability of high-quality grain, the future of the grain handling system is very important to the industry. Dr. Nicholas Kalaitzandonakes provides a look into the future of identity preservation. We have also included a section on new product development.

I would like to thank all the authors in this year's Corn Annual. I hope you find their contributions informative and useful.

Introduction

The year 2001 brought many challenges to the corn refining industry. For the first time in years, growth in several major products slowed. Excluding ethanol, overall shipments were down some 3 percent. Although volumes in several categories of products for export were up, overall revenue from exports was off due to a slumping world economy.

One cannot reflect on the past year without acknowledging the effect that September 11 had on our nation and the world. The corn refining industry responded with generous support to relief efforts and programs for victims. The events of September 11 made food manufacturers and suppliers look closely at the food supply and ways to ensure its integrity. Ensuring the safety of corn wet milled products has always been an integral part of our industry's success and will continue to be a priority for all corn refiners.

Looking to the future, there are many bright prospects for the corn refining industry. The industry's diversified product line and client base contribute to healthy competition, which, in turn, keeps us all working toward improvement. The prospect of expanding export markets resulting from global trade negotiations as well as domestic market development through new product technology and uses for refined corn products is good cause for a positive outlook. The Department of Agriculture (USDA) predicts that the industry will use approximately 1.432 billion bushels of corn through the end of the 2001 marketing year. That is nearly a 50-million-bushel increase over the previous year, mainly as the result of expanded ethanol capacity. Analysts forecast that by 2010, corn refiners will grind over 2 billion bushels of corn a year.

Dr. Michael W. Jorgenson
Chairman, Corn Refiners Association, Inc.
President and Chief Executive Officer, Roquette America, Inc.

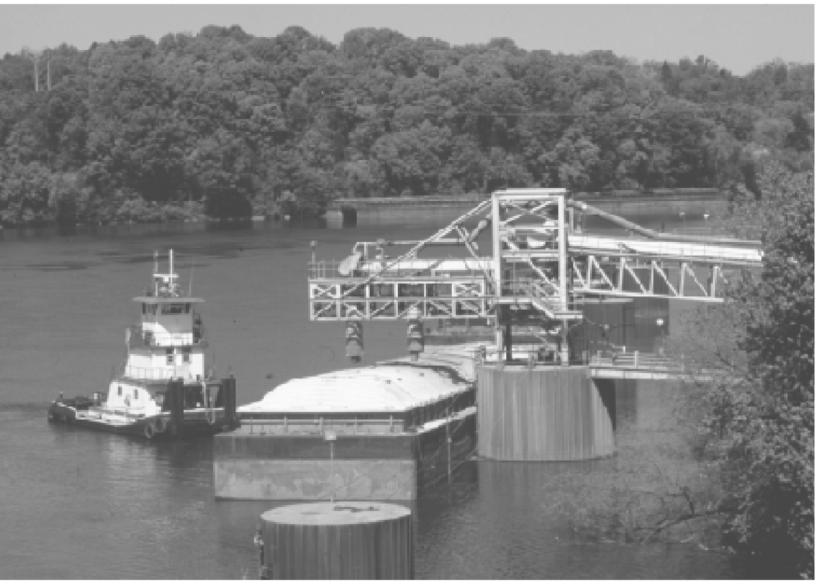
Prospects for Enhanced Export Markets

The Corn Refiners Association (CRA) was pleased with the united efforts of World Trade Organization (WTO) ministers to successfully launch a new round of world trade talks in November. The commitment of WTO member countries to work toward phasing out

Shipments of Products of the Corn Refining Industry—2001

Starch Products (includes corn starch, modified starch and dextrins)	5,898,119,000
Refinery Products (includes glucose syrup, high fructose syrup, dextrose, corn syrup solids, maltodextrins)	32,742,657,000
High fructose corn syrup—42%	9,785,060,000
High fructose corn syrup—55%+	14,012,245,000
Total HFCS	23,797,305,000
Total - Domestic Basic Products	38,640,775,000
Total - Export Basic Products	1,783,762,000
Corn oil (crude and refined)	1,121,284,000
Corn gluten feed and corn oil meal	10,388,556,000
Corn gluten meal	2,652,095,000
Steepwater	1,295,972,000
TOTAL SHIPMENTS	55,882,445,000

Compiled for the Corn Refiners Association, Inc., by VERIS Consulting, LLC. Statistics represent shipments by members of the association. Shipments are in pounds, commercial weights, and do not include co-products derived from ethanol production.



export subsidies, significantly increasing market access and reducing trade-distorting domestic supports, is welcome news to the wet milling industry. CRA is also very pleased that China and Taiwan will be joining the new round of talks as WTO members.

In 2001, the U.S. corn wet milling industry exported 6.6 million metric tons of products worth nearly $1.2 billion. Exports accounted for over 25 percent of total product shipments last year. With the rapid expansion of global food demand and further liberalization of agricultural trade, considerable opportunities for growth in exports exist.

In order for the U.S. to demonstrate strong leadership in the next round of global trade talks, Congress needs to pass Trade Promotion Authority (TPA). CRA has been participating in efforts to support TPA legislation through the Ag for Trade Coalition.

Mexican Sweetener Market

There were positive signs last winter that the long-running dispute with Mexico over market access for U.S.-produced high fructose corn syrup (HFCS) might finally be resolved. The U.S. won its WTO case against antidumping measures the Government of Mexico placed on U.S. imports of HFCS in November. In December, U.S. and Mexican negotiators agreed to begin bilateral talks to resolve the disputes over our access to the Mexican market and Mexico's access to the U.S. sugar market. Unfortunately, the Mexican Congress surprised business and government alike when it passed a tax of up to 20 percent on soft drinks sweetened with HFCS. The effect of the tax rippled throughout the U.S. corn refining industry and damaged corn producers as well.

CRA worked very closely with the National Corn Growers Association (NCGA), the American Farm Bureau Federation (AFBF) and the U.S. Grains Council (USGC) to inform Congress and government officials of the severe problems resulting from Mexico's protectionist actions. CRA will continue to work to eliminate this tax, which has been temporarily suspended until September of 2002.

The actions taken by Mexico to protect an ailing domestic sugar industry are sure to have a negative impact on future foreign investment in Mexico. Not only will the corn refining industry be more skeptical of investing in Mexico, but any industry must question the safety of investments in a country where international trade law takes a back seat to strong domestic lobbies.

Corn Gluten Feed Markets

Last year, corn refiners faced two challenges to the vastly important European market for corn gluten feed. U.S. corn refiners export about 4 million tons of corn gluten feed to Europe annually under a zero-duty agreement negotiated with Europe in the 1960s. That market, worth approximately $400 million a year, was seriously jeopardized by E.U. measures to retaliate against U.S. protection for the domestic wheat gluten industry. The E.U. imposed a 5-euros-per-metric-ton duty on U.S. exports of corn gluten feed after a WTO panel ruled that U.S. import quotas on vital wheat gluten were inconsistent with WTO safeguards law. The combined efforts of NCGA, USGC and CRA were integral to the Bush Administration's decision not to extend the import quota on vital wheat gluten, which ended the retaliatory measure by the E.U. on corn gluten feed.

The second challenge corn refiners were able to tackle that could have had a negative impact on the E.U. market for corn gluten feed has been a recurring challenge ever since the commercialization of genetically enhanced corn. The E.U. has approved less than half of the varieties of biotech corn grown in the U.S. Even though corn gluten feed is a processed product and is not subject to current E.U. approval regulations for biotech products, industry customers have expressed a strong desire that corn refiners only use grain that has been approved for use in the E.U. U.S. corn refiners have worked closely with corn producers, seed companies and distribution channels to ensure to the maximum extent possible that only E.U.-approved varieties are delivered to corn refining plants that export products to Europe.

Europe's system for dealing with applications for approval of new biotech crop varieties has been stalled since 1998, and the U.S. government is vigorously working to have the E.U. restart its regulatory process and remove the uncertainty affecting their food and feed industries. In the meantime, CRA continues to work with both domestic and European customers and suppliers to demonstrate our understanding of their commercial concerns.

Biotechnology

European activist groups have long been critical of biotechnology, and their efforts have translated into a reluctance of European consumers to accept food biotechnology. In an effort to address some of those fears, the European Commission proposed new regulations on traceability and labeling of foods derived from biotechnology in July 2001. These proposals would extend the E.U. food labeling regulation to products derived from, but not containing, genetically modified organisms such as refined vegetable oils and sweeteners. The proposals would require extensive documentation on shipments of corn and corn products made from biotech crop varieties. The regulations would also require a new system of safety assessment for animal feeds produced from biotech crop varieties. CRA, in conjunction with a broad coalition of U.S. food, technology and agriculture groups, has been active in working with the U.S. administration to press for changes in these costly and trade-disruptive proposals.

Recently, China established new import approval and labeling regulations for biotechnology products. The import regulations are vague and have resulted in disrupted trade in agricultural biotech products. Likewise, the labeling regulations are unclear and difficult for food manufacturers to decipher.

More than 20 other countries have either adopted, are preparing or are contemplating legislation requiring some type of labeling of foods from biotechnology.

Although problems that plagued the corn refining industry involving StarLink corn have dissipated, some market disruptions lingered last year. With the withdrawal of StarLink corn from the market for the 2001 and future crop years, these problems should fade. However, the lessons from StarLink should be remembered: Biotechnology companies must be transparent about the products they market and their regulatory status, and the grain and food processing industries must understand the nature of their raw material supply.

CRA, along with other corn, cotton and soybean industry associations, has supported the CSC Biotechnology Committee since 1998 to monitor and advise the industry on international regulatory issues associated with biotechnology. CRA also participates in the Agriculture Biotechnology Planning Committee that has coordinated U.S. industry response to the proposed E.U. biotech regulations. In order to communicate the benefits of food biotechnology to all consumers, CRA participates in the Alliance for Better Foods.

Environment

By converting corn into food ingredients, animal foodstuffs, industrial products and fuels, corn refiners take part in completing the cycle of converting the sun's energy into usable energy for humans and industry. Environmental responsibility is central to the corn refining industry from compliance with environmental regulations in our operations to development of environmentally sound products. CRA is actively involved with a wide range of air quality and environmental management issues. Working closely with industry coalitions and government agencies, CRA supports development of regulations that achieve environmental protection goals while promoting sound economic and industrial growth.

Research

Every year, CRA recognizes outstanding researchers for their efforts to understand and improve the corn refining industry with an awards program presented at the annual meeting of the American Association of Cereal

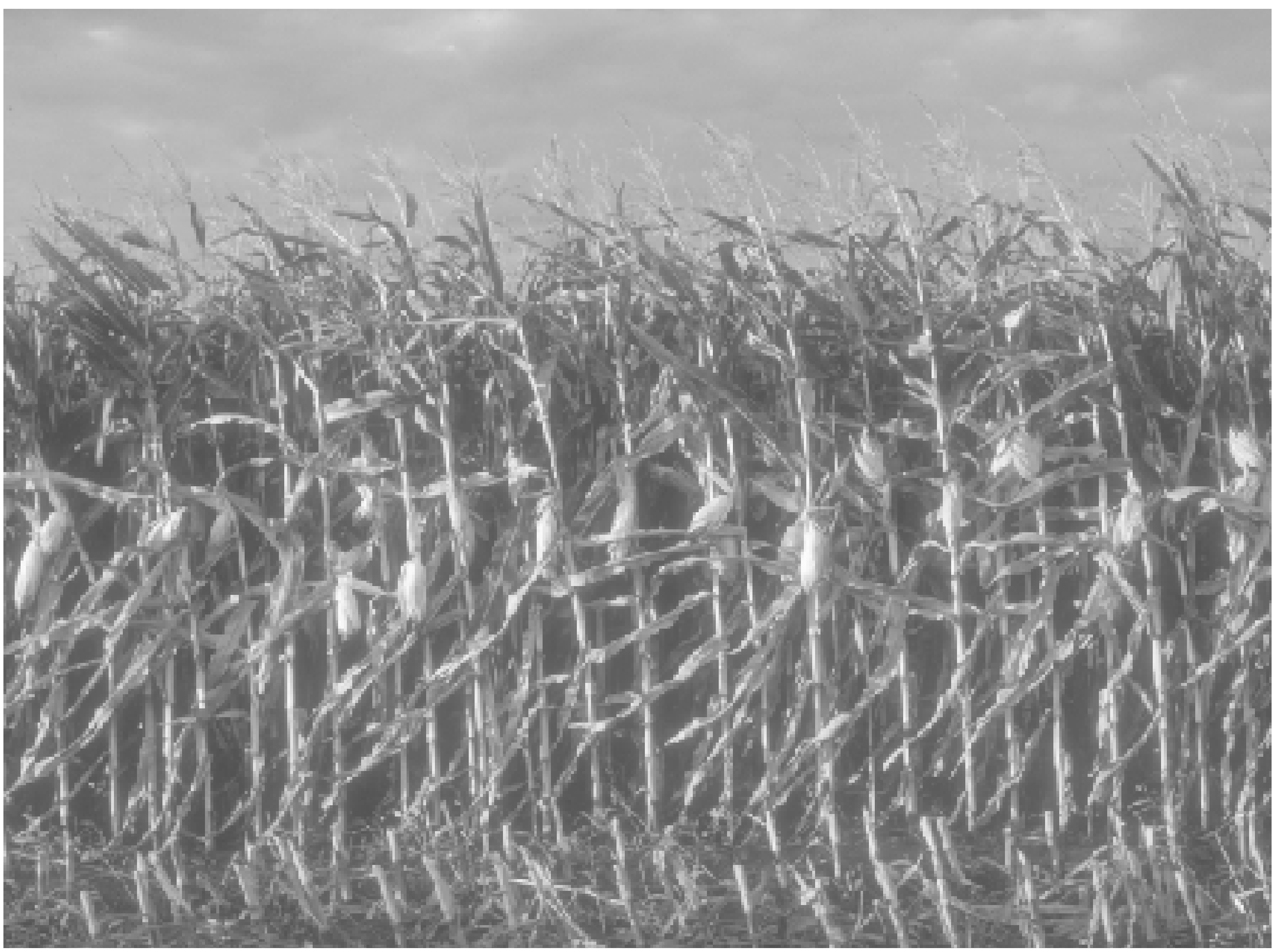
Chemists. This year, the Association will begin a new research program to encourage educational development of students and educators involved in fields related to corn refining. The program will offer grant fellowships to associate or assistant professors within the first five years of their career. The Association also supports research focused on understanding and reducing the impact of mycotoxins.

Industry Relationships

This past year, CRA relied heavily on the support of other trade associations to overcome challenges facing our industry. Our warmest thanks go to our friends at AFBF, NCGA and USGC for their support on a myriad of issues that could not have been resolved without their help. We also value our relationship with our sister processors at the National Oilseed Processors Association and the North American Millers Federation, and the groups representing our industry's major customers in the food, beverage and industrial products sectors.

CRA values all of our relationships with other trade associations and groups, but the kinship developed over the years with NCGA has proven strong. CRA and NCGA promote research toward the development of new uses for corn and applications of wet milled products. We will further explore the relationship between corn refiners and producers at the jointly sponsored Corn Utilization and Technology Conference in June 2002.

The corn refining industry's ability to effectively respond to challenge is indicative of an industry bound for continued success. Whether it be accessing global markets or developing a product to meet a specific application, corn refiners eagerly step up to the challenge. It is that hunger for excellence that keeps this industry healthy.



Product lists are accurate as of publication date but may change with time.

Member Company Products

Starch Products	Archer Daniels Midland Company	Cargill, Incorporated	Corn Products International, Inc.	Minnesota Corn Processors	National Starch and Chemical Company	Penford Corporation	Roquette America, Inc.	A. E. Staley Manufacturing Company
Unmodified, food	•	•	•	•	•	•	•	•
Unmodified, industrial	•	•	•	•	•	•	•	•
Modified, food	•	•	•		•	•	•	•
Modified, industrial	•	•	•		•	•	•	•
Dextrins	•	•	•		•		•	•
Cyclodextrins		•					•	
Refinery Products								
Glucose syrups	•	•	•	•		•	•	•
Maltodextrins	•	•	•				•	•
Dextrose monohydrate	•	•	•				•	•
Dextrose anhydrous		•	•				•	
HFCS-42	•	•	•	•			•	•
HFCS-55	•	•	•	•			•	•
Crystalline fructose	•							•
Co-Products								
Crude oil	•	•	•					
Refined oil	•	•	•					
Corn gluten feed	•	•	•	•	•	•	•	•
Corn gluten meal	•	•	•	•	•	•	•	•
Corn germ or corn germ meal	•	•	•	•	•	•	•	•
Steepwater (CFCE)	•	•	•	•	•	•	•	•
Carbon dioxide	•	•		•				•
Fermentation and Other Chemicals								
Citric acid	•	•						•
Lactic acid	•	•						
Lysine	•	•						
Tryptophan	•							
Xanthan gum	•							
Erythritol		•					•	
Sorbitol	•	•	•				•	
Xylitol		•					•	
Mannitol		•					•	
Maltitol		•					•	
Hydrogenated starch hydrolysates		•					•	
Glucose hydrolysates			•				•	
Other								
Ethanol, fuel/industrial	•	•		•				•
Ethanol, beverage	•							

Agricultural Trade Agenda: The Year Ahead

Ambassador Allen Johnson
Chief Agricultural Negotiator
Office of the United States Trade Representative

This is an extremely busy and important year for the United States in working to advance our agricultural trade interests. We'll be spending a great deal of time pushing our agenda for agricultural trade liberalization both in the WTO and in regional and bilateral trade negotiations. The recent entry of China into the WTO was a momentous event for world trade, and we will be watching China carefully to ensure that it fully complies with its new WTO commitments. We also have major challenges in front of us in working with all of our trading partners around the world in ensuring that they comply with their existing WTO obligations, and in ensuring that markets around the world are open to new and promising biotechnology products.

WTO Ag Negotiations

The importance of the success we achieved at Doha in launching a new trade round cannot be overstated. By launching a trade round, the world made a bold statement: we believe in the future, we believe in a global trading system, and, while it may not be perfect, we want the WTO to move forward so we can control our destiny, and not let others, who do not share our interests, control it for us.

WTO members agreed at Doha to an ambitious mandate for WTO agricultural negotiations including: "substantial improvements in market access; reductions of, with a view to phasing out, all forms of export subsidies; and substantial reductions in trade-distorting domestic support."

We were particularly gratified to obtain hard-fought language on the phasing out of export subsidies. The European Union's use of predatory export subsidies to take valuable overseas markets from the United States is probably the single most egregious practice of any of our trading partners in the world today. We were also able to turn back efforts by the European Community to raise "non-trade concerns" to the same level of attention as the "three pillars," market access, export subsidies, and trade distorting domestic support. We understand the interests that have been expressed about non-trade concerns, but these concerns must be addressed in a manner which is consistent with the WTO and in a manner which does not undermine existing WTO disciplines.

Market access is a key Administration priority in these negotiations. The average allowed tariff on agricultural products around the world is 60 percent. This is unacceptable, and we plan to push aggressively to open new markets for agriculture through our negotiations in Geneva.

Our specific objectives in these negotiations include:

- substantial reductions in all tariffs and increases in all tariff-rate quotas, in all markets and for all products;
- elimination of export subsidies;
- disciplines on state trading enterprises;
- simplification of rules applying to domestic support, and establishment of a ceiling on trade-distorting support that applies equally to all countries.

Why is the WTO and getting a round launched so important to U.S. agriculture? Simply put, it is the only negotiation where all of our potential customers - 144 countries, including China and Taiwan, with a population of 6 billion people - are all at the negotiating table. It is also the only negotiation where all the trade distorting measures of countries around the world are on the table for discussion. As we prepare for these discussions, we need to keep in mind a few fundamentally important facts: the EU spends seventy times as much as the United State for export subsidies; world tariffs on agricultural products average 60 percent, while in the United States they average 10 percent; 85 percent of U.S. domestic support for agriculture is non-trade distorting, while in the European Community it is almost exactly the opposite.

It is also important to note that we have an aggressive schedule for these negotiations. The deadline for development of modalities for agriculture is March 2003, with specific modality discussions on export competition to take place in June 2002, and discussion on market access and domestic support in September 2002. Initial submissions by countries of their schedules for reductions of export subsidies, market access restrictions and domestic support are due by the middle of 2003, and the trade round is scheduled to be completed by January 1, 2005.

Trade Promotion Authority

Congressional approval of Trade Promotion Authority, as soon as possible, is essential to our aggressive agenda for the new trade round. With TPA we can negotiate from a position of strength. As I have traveled around the world in representing U.S. agriculture, virtually every country I meet with wants to know where TPA is in the Congress. For these countries, TPA symbolizes the Congress and the Administration standing shoulder-to-shoulder pursuing an aggressive trade agenda. TPA is critical to giving the Administration the authority and credibility it needs to proceed aggressively with negotiations not only in the WTO, but in regional and bilateral negotiations as well.

China Accession

China's recent accession to the WTO has potentially enormous implications for U.S. agriculture. China is already a large market for U.S. agricultural exports, with U.S. exports totaling $1.6 billion in agricultural products to China in 2000. However, based on USDA estimates, U.S. agricultural exports to China could increase to as much as $3.6 billion annually by 2005 because of China's accession to the WTO. This increase will derive from the across-the-board commitments that China made to liberalize market access for agricultural products.

Of course, for us to realize the benefits of China's WTO Accession, it must live up to the obligations it has made. The United States worked closely with the Chinese government and our other trading partners to ensure that trade, including corn, was not disrupted when China's new biotech regulations went into effect on March 20th. Following up on President Bush's recent discussions in China, I led an inter-agency team that included USTR, USDA, and the State Department in meeting with our Chinese counterparts. During a meeting we had in early March, China outlined an interim procedure running through December 2002 that would allow trade to continue for products that have completed the review process in other countries. Assuming that China adheres to the procedures outlined, this should allow for continued exports of U.S. soybeans, corn, cotton and products. We are monitoring closely the implementation of this interim process, and China has agreed to work with the United States on the development of a science-based biotech approval process.

Biotech

Ambassador Zoellick and I share a strong conviction that agricultural biotechnology is critical to the future of agriculture, not only in the United States, but around the world. As the global population increases, agriculture must continue to become more efficient and productive in order to satisfy global food demands. Biotechnology offers tremendous potential for higher crop yields, lower use of pesticides, the development of crop varieties tolerant of environmental extremes of temperature and drought, and important nutritional enhancements.

Despite scientific consensus on the safety of these products, some of our trading partners continue to resist the development and commercialization of this promising technology. For example, the EU continues to block approvals of agricultural biotechnology products. Certain other countries have followed the EU's lead in obstructing or banning the approval of biotech products. These concerns have no scientific basis and are without merit.

As a result of the EU's continuing moratorium on biotech approvals, U.S. corn exports to Europe have been blocked since 1998. This is a matter of increasing urgency and concern to the Administration, not only because of the immediate commercial impact, but because the implications of these actions could go well beyond Europe. We have been working intensively on a bilateral basis with Europe at senior levels and at technical levels to make progress on solving these issues and to resume U.S. corn exports. We are seeking, as a very important step in this process, an end to the current EU moratorium on approval of biotech products. A resumption of the EU approval process would be particularly important in our effort to restore our lost corn market in Europe.

We have also conveyed to Commission officials our deep concern over the Commission proposal for biotech labeling and traceability. The requirements being proposed are unnecessary, unenforceable and would ultimately only lead to increased costs for EU consumers. In making these points to the EU Commission, we have underlined the fact that the traceability and labeling proposals have the potential of disrupting billions of dollars in U.S. exports to the EU.

In addition to our efforts to overcome obstacles to biotech trade in the EU and other countries, we are also working hard to build a coalition of countries that support the development and commercialization of biotech products. Our efforts in this regard are world wide, but have focused in particular on developing countries, which we believe have the most to gain from the development of biotech products. As many developing countries have comparative advantages in agriculture, trade in technologically-enhanced products provides a way to reduce poverty. Moreover, all who participate in the trade, most importantly those in developing countries, are assured a less expensive, more varied and more stable food supply.

Trade Issues with Mexico

Trade with Mexico has both exceeded and confounded expectations created by the NAFTA. Mexico has unilaterally permitted preferential imports of much larger volumes of corn than it was required to do under the terms of the Agreement. Mexico has been an important and predictable buyer of U.S. corn and corn products and looks to become an even better customer. In 2001, the United States exported over $567 million of corn, an increase of 10 percent since 2000, and more than a twelve-fold increase since implementation of the North American Free Trade Agreement.

Expectations are yet unfulfilled for high fructose corn syrup (HFCS). A dispute that arose during the previous Mexican and U.S. Administrations regarding sugar spilled over to effect corn sweeteners, and now threatens corn as well. In the early stages of the dispute, some U.S. HFCS exporters were excluded from the Mexican market, while sales by others were effectively capped. More recently, the entire beverage market for HFCS has become a political football in Mexico, increasing the uncertainty for all sellers and users.

This unsatisfactory state of affairs cannot - and should not - continue. All the interested parties - corn growers and refiners, and sugar growers and refiners in the U.S. as well as sugar and HFCS producers in Mexico - support negotiations to resolve this matter. Both governments also see a negotiated solution as necessary and the only way to create sustainable and liberalized trade in corn and corn sweeteners. USTR is working with the corn refiners to obtain the access to the Mexican market that the competitive advantages of HFCS will naturally bring to it.

Conclusion

While I have covered some of the major challenges in front of us in the coming year, there are many others as well: our FTA negotiations with Chile, which when concluded will create new export opportunities for U.S. agriculture in that country; the FTAA negotiations, which have as their objective the creation of new trade opportunities all across the South American continent; and numerous enforcement actions that we are taking against countries for non-compliance with WTO rules. As we undertake these efforts, it is important that we remain in close touch with key trade groups like the Corn Refiners Association for its views and advice.

Advances in Wet Milling Technology

Throughout the evolution of the corn refining industry, engineering developments have focused on means to reduce costs by cutting labor inputs, maintenance requirements, energy consumption, materials consumption and time. The underlying goal for many improvements is to impact the refiners' bottom line - to reduce operational costs. But many advancements have also provided environmental and product quality benefits.

The following pages focus on three areas of engineering technology development: a new steep process involving use of enzymes, membrane separation and centrifuge enhancements. Other areas of development in engineering technology involve improved efficiency of heat exchangers and boilers.

ENZYMATIC MILLING PROCESS

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Conventional corn wet milling is a very capital and energy intensive process. A significant amount (approximately 21.0 percent) of the capital and energy cost in a corn wet milling plant is associated with the steeping process. Conventional steeping is also a very time consuming process. It takes approximately 24 to 36 hours to steep the corn kernels before they can be milled to yield starch and other coproducts. Additionally, conventional steeping requires the addition of sulfur dioxide (approximately 0.1-0.2 percent) to disrupt the protein matrix surrounding the starch particles and to aid the separation of starch and protein during the subsequent milling.

Researchers have been pursuing the development of an alternative processing procedure that could reduce the steep time and the amount of energy used in the corn wet milling process. Although several attempts have been made, most of the alternative milling processes to date resulted in lower starch recovery or inferior separation. Recently, we have developed an enzymatic corn wet milling process that considerably reduces steep time and produces starch yields comparable to conventional corn wet milling. This process would have a significant impact on the corn wet milling industry. The new process would appreciably decrease operational energy costs, increase plant capacity in existing corn wet milling plants and reduce the capital costs involved in the construction of new facilities.

The enzymatic corn wet milling process consists of two steps: 1) size reduction of corn after a brief water soaking of the kernels, and 2) controlled incubation of the coarsely ground slurry produced with enzymes. The first stage of the process uses a water-soaking step so the germ is completely hydrated and becomes pliable enough that it does not break when the corn is coarsely ground. The second stage involves the controlled treatment of the coarsely ground corn slurry with enzymes. Conventional wet milling steps are then performed following the enzymatic treatment (see figure on page 12). This approach removes the diffusion

Comparison of product yields between the enzymatic (protease) and conventional corn wet milling process*

Fractions	Enzymatic Milling Yields (%)	Conventional Milling Yields (%)	Difference in Yields (%)
Soluble Solids	0.12	4.3	-4.18
Germ	6.15	6.73	-0.58
Fiber	9.83	10.20	-0.37
Starch	70.22	69.0	+1.22
Protein	12.80	9.28	+3.52
Total	99.13	99.51	

*1-Kg laboratory procedure

barriers and allows the enzymes to penetrate inside the corn endosperm and react with the protein substrate.

Benefits of the enzymatic wet milling process are that it reduces the steep time by nearly 70 percent compared to the conventional steeping process, while producing starch yields and quality equivalent to that from the conventional process. The overall steeping time with the two-stage modified procedure ranges from 6 to 8 hours. Significant amounts of capital and energy savings are realized due to shorter steep times. A comparison of product yield between enzymatic milling and conventional milling is shown in the Table on the previous page.

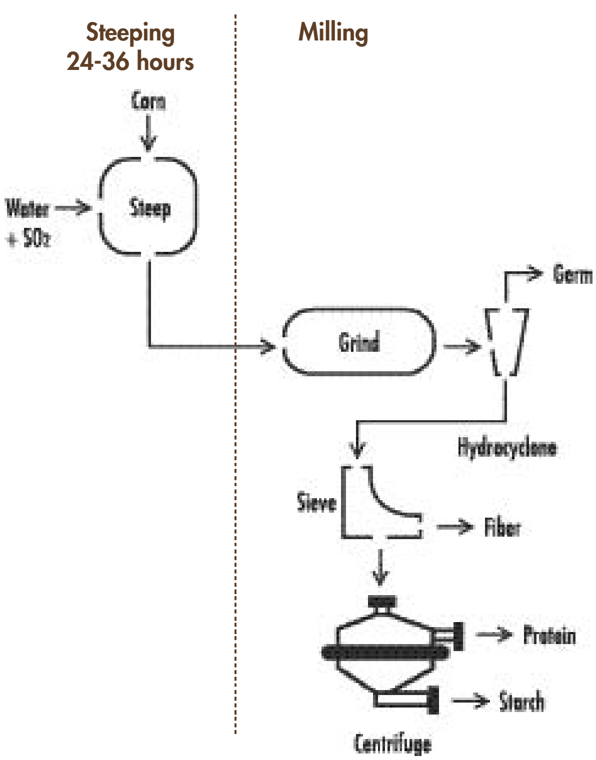
Results from laboratory-scale tests show that significantly higher amounts of starch (approximately 1.0 percent) and gluten (approximately 3.5 percent) can be obtained with the enzymatic milling process compared to the conventional process (see Table). The extra starch recovered in the enzymatic milling process is from the fiber and the gluten fraction. Residual protein and the pasting properties of the enzymatic wet milled starch are better or comparable to the residual protein and pasting properties of conventional wet milled starch. Higher gluten yields can be attributed to the shorter steep time. Germ yield and the concentration of oil in the germ in the enzymatic milling process is lower by approximately 0.5 and 2.0 percent, respectively, compared to the conventional process. More optimization of germ recovery parameters are required to have the germ yield and concentration of oil in germ comparable to the conventional wet milling process.

There are several other process advantages of the enzymatic wet milling process such as reduction in the amount of water used, reuse of enzymes, etc., which cannot be evaluated until the process is tested on a full scale. One of the biggest challenges for the enzymatic corn wet milling process is the cost of the enzymes. However, commercial enzyme companies may be able to address this issue. The enzymatic corn wet milling process has passed the proof of concept stage. A detailed mass and energy balance model is nearly complete and a full plant trial should take place in the near future. Corn refiners could begin to implement this technology within the next 5 to 10 years.

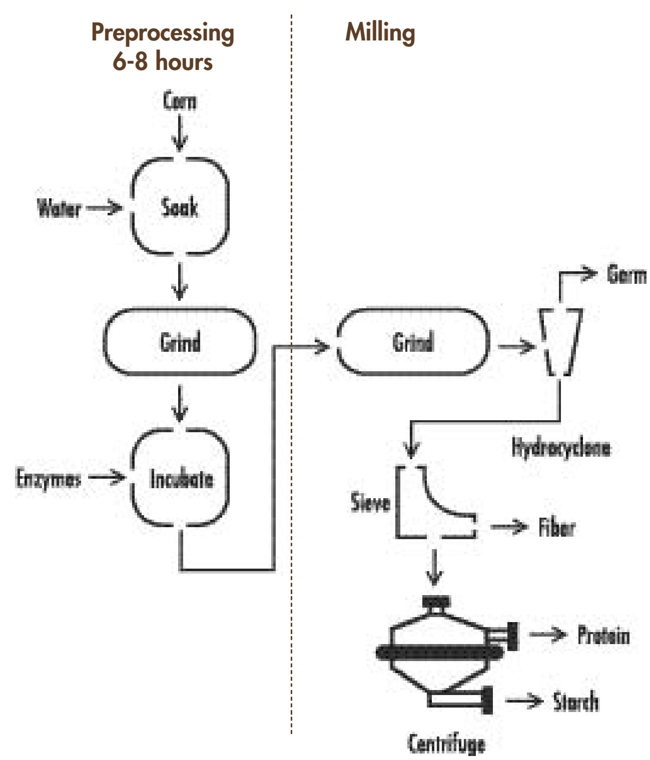
Acknowledgement:
This material is based upon work supported by the Cooperative State Research, Education, and Extension Services, U.S. Department of Agriculture, under Agreement No. 00-52104-9703.

Comparison of conventional and enzymatic corn wet milling procedure. The main difference is in the front end of the process.

Conventional Wet Milling Process



Enzymatic Wet Milling Process



MEMBRANE APPLICATIONS IN CORN WET MILLING

Rodney L. Simms
President, Technology Inc.

Introduction

Membranes have been used in the corn wet milling industry for the past fifteen to twenty years. It is estimated that membrane processes are used to produce at least 70 percent of the fructose corn syrup manufactured in the United States. Beginning in the late 1980s, both new and improved membranes became available opening up new and expanded opportunities for applications in the corn wet milling industry.

Mud Removal from Corn Syrup

When starch is converted to corn syrup using acids and/or enzymes, trace proteins, oils and fiber are released from the molecules. This material, because of its appearance, is commonly called "mud" and, in most plants, pre-coated filters have been replaced with membranes. Plants utilizing membrane filtration for mud removal realize economic benefits from reduced supply costs and reduced costs of subsequent carbon and ion exchange refining needed with other filtration methods.

Filtration of Fructose Corn Syrup

Corn refiners must meet or exceed several quality guidelines. The soft drink industry requires the removal of all biological and particulate matter prior to shipment. Because the viscosity of concentrated fructose corn syrup is relatively high, most companies filter the syrup, using 1.0 to 2.0 micron filters, prior to final evaporation.

The availability of steel membranes has allowed some plants to begin using membranes to filter the final evaporated syrup just prior to shipment, increasing the control over quality. This is a 0.1 micron dead end filtration and requires trans-membrane pressures ranging from 15 to 40 bars requiring the use of a stainless steel membrane. Previous systems could not handle that amount of pressure or the viscosity of the syrup.

Modified Starch Filtration

Starch modification may involve the addition of one or more chemicals into a batch of starch slurry followed by

Corn: Food and Industrial Uses

Year	HFCS	Glucose and Dextrose	Starch	Fuel Alcohol	Beverage Alcohol	Cereal & Other Products	Total
1985	327	169	190	271	83	93	1,133
1986	338	171	214	290	85	109	1,207
1987	358	173	226	279	77	113	1,226
1988	361	182	223	287	107	114	1,274
1989	368	193	230	321	109	115	1,336
1990	379	200	232	349	80	114	1,354
1991	392	210	237	398	81	116	1,434
1992	414	214	238	426	83	117	1,493
1993	442	223	244	458	83	118	1,568
1994	465	231	226	533	100	118	1,672
1995	482	237	219	396	125	133	1,592
1996	504	246	229	429	130	135	1,672
1997	513	229	246	481	133	182	1,784
1998	531	219	240	526	127	184	1,827
1999	540	222	251	566	130	185	1,894
2000	537	221	248	628	130	185	1,948
2001	548	220	250	690	131	186	2,025

In million bushels
Source: USDA - Economic Research Service. Year beginning Sept. 1

a reaction time to produce the desired change in the starch structure. When the reaction is complete and stopped, usually by neutralizing the chemicals added, it is necessary to remove the chemicals and salts prior to drying the starch for sale. Membrane systems capture 100 percent of the starch compared to losses of 5 to 8 percent in traditional systems. This improves starch yield and eliminates the costs associated with cleaning residual starch from the process water.

Steepwater Filtration

Traditionally, corn wet milling plants concentrate light steepwater in an evaporator and add it to the gluten feed during the drying process. Steepwater contains, among other things, some relatively long chain protein components. These, along with sugars, result in significant fouling of the evaporation steam chests during the concentration process adding to downtime and maintenance costs.

Starting as early as 1985, tests were conducted in which steepwater was fractionated using membranes to produce two streams, one, the concentrate stream containing most of the long chain proteins (approximately 10 to 15 percent of the total solids) and the other, the permeate stream containing the remaining steepwater components (approximately 85 to 90 percent of the total solids). The concentrate contains ideal proteins for gluten meal, which is more valuable than gluten feed. Further testing shows the permeate stream can be concentrated to much higher levels without significant fouling. Of particular significance, it was determined that the permeate was pasteurized, which makes it suitable for use as an additive to fermentation processes.

Gluten Thickening

Since gluten meal has a selling price three or four times higher than gluten feed, it is advantageous for any corn wet milling plant to divert as much protein as possible to gluten meal. Following separation of the starch and gluten, the gluten is further concentrated in the gluten thickener. The thickened gluten then goes to a belt filter for further concentration prior to drying. There is a significant loss of gluten through the centrifuge overflow that eventually finds its way into gluten feed.

Studies have been conducted over the past several years using membranes for gluten concentration. Membranes capture 100 percent of the insoluble gluten. There are also indications that as much as 5 to 20 percent of the soluble protein in the feed stream could be captured by a membrane system. This additional gluten would result in a substantial increase in the amount of gluten meal produced. In addition, the resulting permeate being sent back for fiber and germ washing is much cleaner.

Other Applications

While some corn wet milling companies are examining the use of membranes to recover waste starch rather than send it to a waste treatment plant, this application is currently being used most frequently in plants that are

"cooking" starch containing grains such as corn, wheat and rice to produce food products and must reduce the waste starch in the "cook water" prior to waste treatment. The recovered starch can be dried and sold, it can be incorporated into other cooked starch products such as sauces, it can be converted to alcohol, and there is even consideration being given to using the recovered starch as a feed stream to food grade yeast plants.

Membranes can be used for mill stream thickening (MST). This has similar advantages to gluten thickening but does not create the value added of gluten thickening. Most of the value results from the production of a "clean" overflow stream for subsequent use in the milling process.

Membranes can be used as an alternative to clamshell hydroclones to perform the final starch washing step in the millhouse. In general, membranes cannot be cost justified for this operation. However, recent developments in the steeping process, which could substantially reduce the amount of fresh water required for a typical millhouse (as much as a fourfold reduction in fresh water) would likely require the installation of membrane systems to permit the starch washing water to be cleaned and recycled to maintain sufficient flows for processing and washing.

Fermentation of dextrose to produce organic acids produces a fermentation "mass" which must be separated prior to refining of the organic acid. This step is commonly done using pre-coated diatomaceous filters. It is generally necessary to landfill dispose of this spent cake. Membranes can be used for all or part of this process, reducing or eliminating the purchase and disposal costs of the diatomaceous earth. Similarly, in the production of enzymes, it is necessary to separate the enzymes from the fermentation mass. Membranes have advantages for this process, especially stainless steel membranes that can be steam sterilized to reduce the potential for contamination.

Conclusion

Membranes have and continue to offer new processing options for corn wet milling plants. Membrane filtration systems offer benefits such as increased recovery of valuable process strains, a reduction in costly processing aids, lower maintenance requirements and reduced wastewater treatment. As more refiners adopt this technology, other benefits and ideas for applications will arise.

World Corn Production, Consumption and Stocks

Production	***2000/01***	***2001/02***
Argentina	15,500	12,000
Brazil	41,536	36,000
Canada	6,827	8,200
China	106,000	110,000
Egypt	5,636	6,160
Hungary	5,000	7,300
India	12,068	11,500
Indonesia	5,500	6,000
Mexico	17,700	19,000
Philippines	4,508	4,525
Romania	4,500	8,400
South Africa	7,500	9,000
Thailand	4,700	4,400
Ukraine	3,848	3,600
European Union	38,292	39,385
Others	54,720	60,338
United States	251,854	241,485
TOTAL	585,689	587,293
Consumption		
Brazil	34,050	35,000
Canada	9,930	10,930
China	120,000	124,000
Egypt	10,900	11,265
Hungary	4,635	4,700
India	11,950	11,850
Indonesia	6,950	7,150
Japan	16,200	15,490
Korea, South	8,900	7,250
Malaysia	2,320	2,485
Mexico	24,000	24,600
Romania	6,135	6,800
Russia	2,000	1,500
South Africa	7,550	7,500
Others	140,497	140,918
United States	198,259	200,543
TOTAL	604,276	611,981
Ending Stocks		
Brazil	2,186	1,211
China	81,126	64,376
South Africa	980	1,030
European Union	4,630	4,707
Others	15,750	16,361
United States	48,240	40,539
TOTAL	***152,912***	***128,224***

Source: USDA, Foreign Agricultural Service.
Based on local marketing years in thousands of metric tons.

CENTRIFUGE TECHNOLOGY

Larry G. Miller
The Western States Machine Company

Centrifuge development has advanced many fold over the last eighty-five years. Due to robust designs, many centrifuges built fifty years ago are still in daily service around the world. The original idea remains valid for liquid solid separation but refinements in technology allow us to explore easier cost saving avenues in today's market.

One of the major improvements in centrifuges today is the utilization of variable frequency drives. The original 2-speed motor is replaced with a smaller motor and matched variable frequency drive. The variable frequency drive controls the motor through the entire cycle reducing peak power demands and thus reducing

the cost to operate the centrifuge. In addition, the variable frequency drive returns the saved power to the plant grid to be utilized elsewhere in the plant. When converting an existing centrifuge, the existing mechanical brakes are reduced to emergency stop apparatus only as the variable frequency drive handles all normal braking requirements. The entire water-cooling system is eliminated since the mechanical brakes are now emergency use only. The end result is power savings along with maintenance savings in both upkeep and spare parts required.

The servo loading mechanism on batch machines was developed to control the amount of product feeding into the basket. The servo loading devices were a mechanical breakthrough in their day but in the early 1990s capacitance loading sensors were being developed. This unit eliminated moving parts required for adjustment in the servo loading mechanism and expense in upkeep. As technology continued, ultra-sonic loading sensors replaced capacitance loading technology controlling sliding gates and butterfly feed systems. The ultra-sonic load sensor employs sound wave technology to provide greater sensitivity to cake wall thicknesses and smoother process control. Unlike mechanical or capacitance sensors, the advanced non-contact sensor uses ultra-sonic waves to reliably monitor cake thicknesses. The use of sound waves offers unprecedented flexibility for monitoring cake walls within +/-.25 inch of desired cake thickness. The loading gate or butterfly receives the "gate open" signal from the centrifugal controller to initiate loading. After the gate is open, its actions are controlled by the ultra-sonic system. If power fails, the gate will automatically close. The ultra-sonic system evaluates loading time based on a preset desired loading time. If the desired loading is not met, the gate or butterfly is adjusted to meet the preset load time each cycle. This has proven most beneficial for on-the-fly adjustments between pans of product.

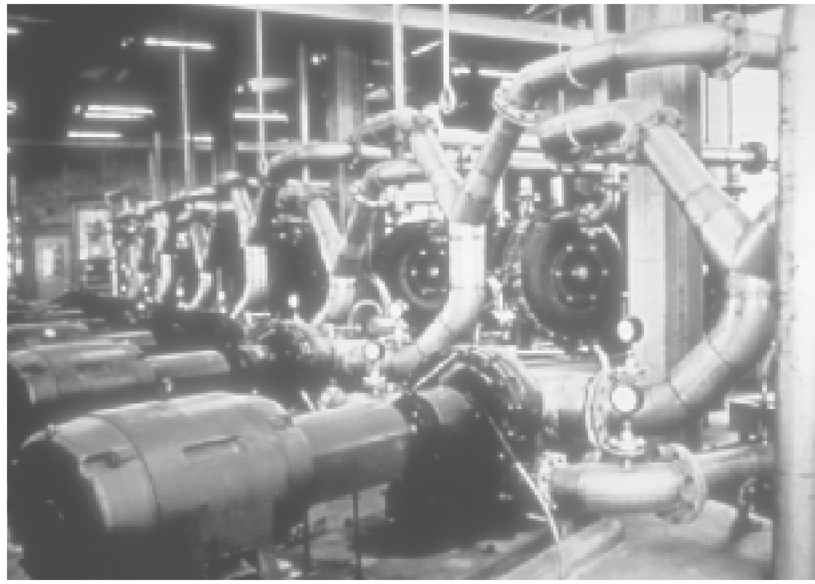
Loading of batch machines was handled via sliding wedge gates or roller wedge gates for many years. New centrifugals required a totally enclosed feed system. The totally enclosed feed system replaces the feeding spout, loading gate and curb top cover with a dual butterfly feed valve arrangement. Feed control is handled by a butterfly valve located next to the mixer tank. A feed back device is mounted to the valve operator and connected to the ultra-sonic load sensor to provide the same sequenced gate closing as the current gate design. Sequenced closing assures the maximum possible load for each cycle by allowing additional massecuite to be added as the gate closes.

A second butterfly valve is mounted directly on the curb top to prevent syrup leakage into the basket. Unlike dip pans which can, over a period of time, become built up with product and allow syrup to drip into the basket, this arrangement assures a liquid tight seal. There are no mechanical drip pans inside the basket. The valve is sequenced to remain open until first wash to allow flushing of the feed spout.

At no time is the feed stream exposed or the curb top open, thereby eliminating the possibility of outside contamination.

Even as new and larger machines are developed, designs are based on equipment developed years earlier. For years, 2-speed motors were used to drive the machines but the technology of the day could not control the large motors during low speed discharging. As a result, the turn-tork clutch was introduced. The small low-speed motor was mounted on top of the 2-peed motor and only operated at low discharge speed. The turn-tork was very successful, but also an additional source of maintenance. To remedy this, the existing 2-speed starter panel was replaced with a panel the exact same physical size but utilizing technology borrowed from the new variable frequency drives. The combination allows the existing 2-speed motor to drive the machine during all speeds eliminating the turn-tork clutch.

As centrifuge evolution continues, manufacturers are faced with new challenges from our end users. We can no longer expect sufficient down time to install modular batch machines in plants where down time is not counted by days but rather hours. New challenges require new designs including freestanding self-supporting centrifugals. Existing centrifugals can be refitted with variable frequency drive technology, ultra-sonic loading, enclosed feed systems and newly refined motor controllers to provide many more years of reliable service.



Corn: Supply and Disappearance

	Supply				Disappearance						Ending Stocks		
Year Beginning Sept. 1	Beginning Stocks	Production	Imports	Total	Food, Alcohol & Industrial	Seed	Feed and Residual	Total	Exports	Total Disappear.	Govt. Owned	Privately Owned	Total
1986/87	4,039.5	8,225.8	1.8	12,267.0	1,216.8	16.7	4,659.4	5,892.9	1,492.5	7,385.3	1,443.2	3,438.5	4,881.7
1987/88	4,881.7	7,131.3	3.4	12,016.4	1,234.4	17.2	4,789.2	6,040.9	1,716.4	7,757.3	835.0	3,424.1	4,259.1
1988/89	4,259.1	4,928.7	2.8	9,190.6	1,279.4	18.4	3,936.0	5,234.4	2,025.8	7,260.1	362.5	1,567.9	1,930.4
1989/90	1,930.4	7,532.0	1.9	9,464.3	1,351.1	18.9	4,381.6	5,751.6	2,368.2	8,119.8	233.0	1,111.5	1,344.5
1990/91	1,344.5	7,934.0	3.4	9,281.9	1,405.8	19.3	4,610.9	6,036.1	1,724.6	7,760.7	371.1	1,150.1	1,521.2
1991/92	1,521.2	7,474.8	19.6	9,015.6	1,513.3	20.2	4,797.7	6,331.2	1,584.1	7,915.3	112.5	987.8	1,100.3
1992/93	1,100.3	9,476.7	7.1	10,584.1	1,537.1	18.7	5,252.1	6,807.8	1,663.3	8,471.1	55.5	2,057.5	2,113.0
1993/94	2,113.0	6,337.7	20.8	8,471.5	1,588.5	20.1	4,684.4	6,293.1	1,328.3	7,621.4	44.8	805.3	850.1
1994/95	850.1	10,050.5	9.6	10,910.2	1,696.9	18.3	5,459.7	7,174.9	2,177.5	9,352.4	42.3	1,515.5	1,557.8
1995/96	1,557.8	7,400.1	16.5	8,974.4	1,608.0	20.1	4,692.5	6,320.6	2,227.8	8,548.4	30.4	395.5	425.9
***1996/97**	425.9	9,232.6	13.3	9,671.8	1,693.9	20.3	5,277.0	6,991.2	1,797.4	8,788.6	2.1	881.1	883.2
***1997/98**	883.2	9,206.8	8.8	10,098.8	1,784.4	20.4	5,481.8	7,286.6	1,504.4	8,791.0	4.3	1,303.5	1,307.8
***1998/99**	1,307.8	9,758.7	18.8	11,085.3	1,826.4	19.8	5,467.9	7,314.1	1,984.2	9,298.3	11.6	1,775.4	1,787.0
****1999/00**	1,787.0	9,430.6	14.7	11,232.3	1,893.0	20.3	5,664.9	7,578.2	1,936.6	9,514.8	14.7	1,702.8	1,717.5
****2000/01**	1,717.5	9,915.1	6.8	11,639.4	1,947.7	19.3	5,838.2	7,805.1	1,935.2	9,740.3	7.7	1,891.4	1,899.1
****2001/02**	1,899.1	9,506.8	10.0	11,415.9	2,024.9	20.1	5,825.0	7,870.0	1,925.0	9,795.0	5.0	1,615.9	1,620.9

Million Bushels   Source: USDA   * Preliminary   ** Projected

The Future of Corn Production and Delivery

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For decades, genetic improvements and innovation in production and processing technologies have shaped the structure and spurred the growth of the U.S. corn industry. The emergence of modern biotechnology is expected to trigger the most significant round of change and growth yet.

First generation biotechnologies that improve the agronomic performance of corn continue to arrive in the market at fast pace. Technologies that confer resistance to corn rootworm, borers, and other insect pests as well

as various herbicides increase yields and reduce production costs and risks. Such gains improve the competitive position of corn against alternative animal feeds and industrial feedstocks and boost the competitiveness of the U.S. corn industry as a whole.

Second generation biotechnologies that add value to corn production through new functionalities, which lead to new products and markets, are also emerging. New functionalities target both feed and processing uses. In animal feed, biotechnology is improving the nutritional value of corn through modifications of its oil, carbohydrate and protein profiles. In processing, biotechnology has already benefited the corn refining industry through enzyme modifications, but modifications of starch and other complex carbohydrates promise to play an important role. Biotechnology innovations target development of various cross-linked cornstarch molecules (as is rudimentarily done in waxy corn) to create new starch properties. Still other innovations target protein and oil characteristics that increase processing efficiency and end product attributes.

Next in line are biotechnologies that internalize processing activities into corn plants turning them into biofactories. Ongoing innovation in the production of bioplastics is illustrative. Commercial production of bioplastics today is based on processing corn plants to yield sugar and converting the sugar into bioplastics through fermentation. These production methods extend existing wet milling operations. Biotechnology is enabling production of bioplastics directly into the corn plant. Bioplastics can then be extracted from the plants through the use of solvents. While corn plant biofactories are far from commercialization, they do provide a preview of the biotechnology innovations to come.

Market Segmentation and the Need for New Delivery Systems

As the pipeline of biotechnology continues to expand, market segmentation will intensify. Market segmentation will be driven by various factors, including: (a) the emergence of specialty markets that capitalize on the expanded menu of corn functionalities; (b) differential levels of regulatory approvals for biotechnology traits around the world; and (c) the emergence of niche markets for corn and processed corn products produced through conventional and organic methods.

To successfully respond to such market segmentation and maximize the value added through production and processing, the U.S. corn industry will have to develop delivery systems that match product and information to the demands of various market segments. As such, identity preservation (IP) systems that allow the source and nature of materials to be identified as they move through the supply chain must be developed. IP programs with loose standards have been used for decades in the production and marketing of specialty corn (e.g. waxy, high amylose and white corn as well as certified seed). Such programs can serve as a base for learning and expansion.

U.S. Per Capita Sweetener Consumption

Year	Refined Sugar	Corn Sweeteners				Honey and Edible Syrups	Total Caloric Sweeteners
		HFCS	Glucose	Dextrose	Total		
		Dry Basis					
1985	63.2	44.6	15.9	3.5	63.9	1.5	128.6
1986	60.8	45.1	16.0	3.5	64.6	1.6	127.0
1987	63.1	47.1	16.2	3.6	66.8	1.7	131.6
1988	62.6	48.3	16.4	3.6	68.3	1.5	132.4
1989	62.8	47.5	16.7	3.7	68.0	1.6	132.4
1990	64.8	49.2	17.4	3.8	70.4	1.6	136.8
1991	64.4	50.0	18.2	3.8	72.0	1.6	138.0
1992	65.1	51.1	17.8	3.8	72.7	1.4	139.1
1993	64.6	53.7	18.0	3.8	75.6	1.2	141.4
1994	65.1	55.3	18.3	3.8	77.4	1.3	143.8
1995	65.2	56.5	18.5	3.9	78.9	1.3	145.4
1996	65.5	58.2	18.8	3.9	80.9	1.4	147.7
1997	65.8	60.8	19.3	3.8	83.8	1.3	151.0
1998	65.7	63.0	18.6	3.6	85.3	1.3	152.2
1999	67.0	64.4	18.6	3.5	86.5	1.4	154.9
2000	65.7	63.2	17.9	3.3	84.4	1.5	151.5
2001*	64.7	62.7	17.8	3.3	83.9	1.3	149.8

* estimate based on preliminary data
Source: USDA--Economic Research Servicein pounds

Operating IP systems with strict standards through the existing infrastructure of the U.S. corn industry presents challenges. Today's infrastructure has been built over several decades in ways that facilitate trade and deal with the structural complexities of corn and other commodity crop supply chains. These supply chains are long and heterogeneous with a large number of geographically dispersed participants that vary substantially in size, sophistication, technology, and organization. Strict product flow control under such conditions is inherently difficult.

Within this context of commodity delivery, infrastructure and minimum quality standards developed to facilitate movement of large volumes across time and space. Corn with differentiable qualities and exceeding minimum standards is not rewarded within this commodity system. Accordingly, the dominant competitive strategy for producers, traders and processors has been cost minimization (e.g. pursuit of productivity gains and scale economies). Over the years, this strategy has propelled the legendary efficiency of the corn commodity system.

Achieving the scale economies that allow this high level of efficiency is critically dependent on aggregation. Production from numerous farms is mixed and blended to meet specific grades throughout the supply chain and, over time, resulting in perfectly fungible and divisible product streams, thereby facilitating aggregation and the efficient use of discrete storage, processing and transportation assets. IP leads to less fungible, batch-based product streams, which complicate aggregation. Limited product fungibility often leads to imperfect matching of IP product streams with discrete storage, processing and transportation assets, and causes inefficiencies. Such potential inefficiencies could dilute the value added through biotechnology and market segmentation. Hence, the cost structure of IP systems becomes an important consideration.

Managing the Costs of New Delivery Systems

Generally, IP systems result in production and handling costs, beyond those incurred in commodity systems, at each stage of the crop supply chain. There are both direct and indirect (hidden) IP costs. Direct IP costs are payable costs. They can vary from one IP system and one stage of the supply chain to another, but they generally result from: (a) increased need for coordination of fragmented buyers and sellers in thin markets (e.g. through contracts); (b) changes in operations (e.g. cleaning equipment, testing and documentation); and (c) increased risks and liabilities.

Indirect IP costs are non-payable costs. They are implicit costs, which result from underutilization of production, storage, transportation and processing resources. Lost profits represent additional indirect costs to IP. For instance, farmers and elevator managers in IP chains must forego storage margins and carrying spreads due to fixed delivery schedules of IP crops. While direct IP costs have been broadly identified, indirect IP costs have been largely overlooked, as they are difficult to detect and measure. Accordingly, IP costs have been consistently underestimated.

IP costs are not fixed. They can vary with a number of factors, both in and out of the control of the participants in IP systems. Key among such factors is the purity threshold that defines "identity" for any IP crop. Since thresholds can drastically change IP protocols, they can also change the IP cost structure. As thresholds become more stringent, IP costs tend to increase, typically exponentially. Other factors, such as the size of IP lots and the configuration of physical assets in IP supply chains, may also influence IP costs in significant ways.

As IP markets continue to grow, both direct and indirect IP costs will likely diminish over time. Expanding IP operations will allow learning through which firms could improve their operations and reduce direct IP costs. A larger number of buyers and sellers could lead to reduced search and market coordination costs. Investments could replace older physical assets with newer ones, more suited for IP, lowering indirect IP costs. Even standardization of traceability requirements and testing protocols could reduce costs associated with risks and liabilities and other relevant transaction costs. These and other improvements, however, will take time as firms, markets and institutions are expected to adjust slowly. Large, lumpy investments with few alternative uses and low salvage value, such as those needed for new or modified on-farm and commercial storage,

transport systems or processing facilities, are expected to take place only very slowly and in the presence of strong market signals.

Concluding Comments

Beyond biotechnology, there is a confluence of factors that provides impetus for the expansion of IP supply chains in the corn industry and, more broadly, the agrifood sector. Consumers seem to view IP and traceable food systems as a way to ensure food safety. In turn, such views tend to influence government regulation in the agrifood sector. The agrifood industry also seems to view IP as a remedy for industry overcapacity as well as an essential support for the growth of food brands and private labels. Under such broad interest, IP markets will likely continue to expand.

Added costs are an important obstacle to fast growth in IP. Indeed, for the U.S. corn industry to capitalize on the value added by biotechnology and capture the value that resides in emerging market segments, it must learn how to manage IP costs. In the past, efficiency gains in the corn supply chain have come from optimizing individual components of the supply chain through technical innovation and scale increases. In the future, efficiency gains might come from perfecting how such individual components work together in tightly coordinated IP delivery systems.

New Product Developments

Developments in enzyme technology have allowed a significant expansion in the product portfolio of the corn wet milling industry. Corn refiners' expertise in the areas of fermentation, microbiology and carbohydrate chemistry has enabled the industry to branch into markets traditionally served by chemical manufacturers and firms specializing in food additives.

The following paragraphs provide details on several of the most recent developments in products produced by the corn refining industry.

Starch Developments

Cyclodextrins

Cyclodextrins are obtained from starch that is enzymatically modified to produce a round, hollow structure. Because of this unique property, cyclodextrins can be used to carry active ingredients such as drugs, fragrances, flavors, vitamins and industrial chemicals in a wide variety of formulations. The ring-shaped structure of cyclodextrins offers protection for ingredients that can degrade or evaporate with exposure to light, heat or air.

The scientific community has known about cyclodextrins for over 100 years, but production costs and limited application opportunities hindered development of this product. The introduction of the enzyme cyclodextrin glycosyltransferase in the late 1980s allowed corn refiners to pursue the development of cyclodextrins. Since then, cyclodextrins and their uses have been researched extensively. There are now several types of cyclodextrins that can be used to meet specific needs for industrial, pharmaceutical and food applications.

There are three basic types of cyclodextrins, alpha, beta and gamma cyclodextrin. The structure of each type contains six, seven or eight glucose molecules respectively. The number of glucose molecules is associated with the size of the cavity for each type of cyclodextrin. The various cavity sizes allow for greater application flexibility since ingredients with different

Exports of Products From Corn 2001

Product	2001	Units	Value
Corn meal	110,989,054	Kilograms	$31,302,915
Corn starch	97,386,794	Kilograms	$40,606,945
Corn oil, crude	217,682,053	Kilograms	$102,038,422
Corn oil, once refined	10,528,123	Kilograms	$4,842,587
Corn oil, fully refined	212,843,607	Kilograms	$107,378,792
Glucose (dextrose)	61,403,925	Kilograms	$27,885,206
Glucose syrup not containing fructose or containing in the dry state less than 20% fructose	129,781,193	Kilograms	$43,190,562
Glucose syrup with 20-50% fructose	28,164,170	Kilograms	$8,265,534
Chemically pure fructose	52,713,771	Kilograms	$37,060,037
Fructose syrup with 50%+ fructose	166,431,984	Kilograms	$48,522,976
Fructose solids containing more than 50% fructose	16,385,957	Kilograms	$25,728,771
Bran, sharps and other residues	79,490	Metric tons	$7,847,148
Corn gluten feed	4,485,645	Metric tons	$354,466,377
Corn gluten meal	817,348	Metric tons	$249,580,819
Other residues of starch manufacturing	14,064	Metric tons	$2,008,933
Corn oil cake	18,398,068	Kilograms	$1,723,312
Dextrins	21,166,044	Kilograms	$16,630,164
Modified starches derived from corn starch	75,363,326	Kilograms	$53,196,531

Source: U.S. Department of Commerce

molecular sizes can be effectively complexed with the cyclodextrin. Small molecules with four or fewer carbon atoms bind best with alpha cyclodextrin and large molecules bind best with gamma cyclodextrin.

The various cyclodextrins also have different solubility characteristics. Gamma cyclodextrin is the most soluble in water. Alpha cyclodextrin is the second most soluble in water and beta cyclodextrin is the least soluble of the three. The rate of solubility can be affected by the ingredient being carried by the cyclodextrin. Some ingredients will form very insoluble complexes and others form highly soluble complexes.

Hydroxypropyl beta cyclodextrin is a modified form of beta cyclodextrin. It is made by adding propylene oxide to some of the hydroxyl groups of beta cyclodextrin. This modification results in a host with greater solubility and is used in applications where faster dissolution rates are needed.

Increased stability, water solubility, reduction in odor and controlled release are among the many application benefits of cyclodextrins. Cyclodextrins can be found in many products, including fabric softeners, paper towels, skin creams and toothpaste. They can be used to detoxify waste materials in herbicides, insecticides and other agricultural chemicals. Cyclodextrins are also used to increase tackiness and stickiness in adhesives and coatings.

Resistant Starch

Resistant starch is impervious to the effects of digestive enzymes and is not digested in the small intestine, which allows it to function like dietary fiber. Resistant starch is made from starch that has been modified with debranching enzymes such as pullulanase or isoamylase and subsequent chemical modification with inorganic salts. Development of resistant starch by corn refiners began in the early 1990s. Since then, the product and manufacturing process have been refined and improved.

Traditional fiber sources, such as wheat bran, can cause problems in food manufacturing because they have a high water uptake. Such fiber sources can also contain oils or fats that can limit the shelf life of foods in which they are used. Resistant starch holds significantly less water than traditional dietary fibers. It does not compete for the water needed by other ingredients and allows for easier processing because it does not contribute to stickiness. Resistant starch is made up of small crystalline particles or granules, allowing it to be intimately incorporated into food matrices.

Foods made with resistant starch can make label claims such as "Good source of high fiber." This benefit as well as excellent expansion and low moisture retention qualities, make resistant starch an appealing ingredient for snack food manufacturers. It has a low calorie profile and can be used as a bulking agent in reduced sugar or reduced fat food formulations. Products ranging from bread to crackers to muffins have better taste, mouth feel and appearance when resistant starch is used in place of traditional fiber sources. In most applications, it does not alter the taste, texture or appearance of the food.

The use of resistant starch can be advantageous for those with special dietary needs. Resistant starch has a low insulin secretion response, which has advantages for diabetics. Patients requiring special texture modified meals often lack sufficient amounts of dietary fiber. Resistant starch can be used to add fiber without changing the taste and texture of the meals or, importantly, adding bulk.

Sweeteners

Erythritol

Erythritol is a low calorie sugar alcohol that is approximately 70 percent as sweet as sucrose. It occurs naturally in a wide variety of fruits and vegetables. Corn refiners manufacture erythritol by fermentation of glucose with the fungus Moniliella pollinis. Erythritol is a white crystalline powder that is odorless. It can be used in a variety of processed foods, baked products, confectionery, beverages and pharmaceuticals.

Erythritol can be made through chemical synthesis, but the method is expensive, the yield is low and other side products are produced. Development of erythritol by corn refiners began in the early 1980s. The commercial fermentation process has drastically reduced the manufacturing cost of erythritol and allowed greater usage in the food and pharmaceutical industries. Erythritol has been used extensively in Japan since 1990. In the U.S., its use is not as wide spread, but the market continues to develop. Erythritol is self-affirmed as a generally recognized as safe (GRAS) food ingredient, which the Food and Drug Administration (FDA) recognized in March 1997.

Erythritol can be added to foods and beverages to provide sweetness, as well as enhance their taste and texture. With a caloric value of 0.2 calories per gram, erythritol is primarily used as a bulk sweetener in reduced calorie foods. When used in combination with intense sweeteners, erythritol can enhance the sweetness of both ingredients, add mouth feel, body and mask unwanted off-tastes. It is also non-cariogenic.

Erythritol has a small molecular size which cannot be metabolized by the human enzymatic system. It has a very high digestive tolerance. Since erythritol does not influence blood glucose or insulin levels, it may be safely used to replace sucrose in foods formulated specifically for people with diabetes.

Erythritol has a very low solubility rate. This characteristic is important in confectionery applications where the crystalline structure of sucrose is essential. Thus, erythritol may be used in tablets, lozenges, chewing gum and coatings where it also contributes to an extended shelf life of the products.

Erythritol is stable in high temperatures, which allows flexibility in various processes used in food manufacturing such as pasteurization, UHT treatment and hot pack. It has a high negative heat of solution and thus provides a strong cooling effect, which is advantageous in products like mints, chewing gum and toothpaste.

Trehalose

Trehalose is a reduced calorie sweetener that is produced from starch through a series of enzymatic conversions. It is a chemically stable, non-reducing disaccharide. Trehalose occurs naturally in foods such as honey, mushrooms, lobster and shrimp. It is about 45 percent as sweet as sucrose and is non-cariogenic. Trehalose can be used as a component of sweeteners, seasonings, preserved and frozen foods and soft drinks, It can also be used as a moisture retainer in cosmetics and a preservative in pharmaceutical products.

Because it had to be extracted from yeast and other fungi, trehalose was cost prohibitive to the food industry, and its uses were limited to the stabilization of proteins and biological systems in pharmaceutical applications and in cosmetics. Development of a low-cost production process of trehalose from starch began in the mid-1990s in Japan. Trehalose manufactured in the U.S. has only become commercially available this year. Trehalose is self-affirmed as a GRAS food ingredient, which FDA recognized in October 2000.

Trehalose may function as a coloring adjunct, flavor enhancer, humectant, nutritive sweetener, stabilizer and thickener, synergist or texturizer. As a non-reducing sugar, trehalose does not react with amino acids or proteins causing Maillard browning. It is clear in solution and does not distort the natural color of products in which it is used. Trehalose is stable under low pH conditions. It is also heat stable.

Trehalose can be used to enhance flavor, texture and color in dried vegetable and fruit products. It can also be used to extend the shelf life of processed foods where browning is a concern. Trehalose can be used as a carrier for spray dried ingredients. The flavor profile and texture of various confectionery products can be improved with the addition of trehalose.

Trehalose has the ability to protect and preserve cell structure in foods. This characteristic can help maintain the texture, flavor and color of frozen foods during freezing and thawing. Dried milk and egg products can also benefit from this characteristic. When rehydrated, these products have textures and flavors more like fresh milk and eggs.

In chewing gum, the addition of trehalose can extend the overall flavor release because its flavor persists slightly longer than sucrose and has a lower solubility rate.

Trehalose has been shown to elicit a very low insulin response and provides sustained energy; as such, it may be useful in foods for diabetics.

As with the traditional products of the corn wet milling industry, these newer products will likely go through numerous product enhancements. As their markets develop, new applications and uses will be discovered. It is certain that the corn refining industry will further expand its product range as the industry continues to be revolutionized by advances in enzyme and fermentation technology.

Corn for Grain: Yield and Production

State	Area Harvested Thousand Acres			Yield Bushel Per Acre			Production Thousand Bushels		
	1999	2000	2001	1999	2000	2001	1999	2000	2001
AL	200	165	150	103.0	65.0	107.0	20,600	10,725	16,050
AZ	30	33	28	195.0	196.0	208.0	5,850	6,468	5,824
AR	100	175	185	130.0	130.0	145.0	13,000	22,750	26,825
CA	185	205	160	170.0	170.0	170.0	31,450	34,850	27,200
CO	1,120	1,150	1,070	142.0	126.0	140.0	159,040	144,900	149,800
DE	154	155	162	89.0	162.0	146.0	13,706	25,110	23,652
FL	40	25	26	93.0	75.0	87.0	3,720	1,875	2,262
GA	300	240	220	103.0	107.0	134.0	30,900	25,680	29,480
ID	55	57	45	155.0	160.0	150.0	8,525	9,120	6,750
IL	10,650	11,050	10,850	140.0	151.0	152.0	1,491,000	1,668,550	1,649,200
IN	5,670	5,550	5,670	132.0	146.0	156.0	748,440	810,300	884,520
IA	11,800	12,000	11,400	149.0	144.0	146.0	1,758,200	1,728,000	1,664,400
KS	2,980	3,170	3,050	141.0	130.0	127.0	420,180	412,100	387,350
KY	1,180	1,230	1,100	105.0	130.0	142.0	123,900	159,900	156,200
LA	330	370	307	121.0	116.0	148.0	39,930	42,920	45,436
MD	360	405	410	93.0	155.0	136.0	33,480	62,775	55,760
MI	1,950	1,950	1,900	130.0	124.0	105.0	253,500	241,800	199,500
MN	6,600	6,650	6,200	150.0	145.0	130.0	990,000	964,250	806,000
MS	310	365	385	117.0	100.0	130.0	36,270	36,500	50,050
MO	2,550	2,770	2,600	97.0	143.0	133.0	247,350	396,110	345,800
MT	18	16	13	110.0	140.0	148.0	1,980	2,240	1,924
NE	8,300	8,050	7,750	139.0	126.0	147.0	1,153,700	1,014,300	1,139,250
NJ	60	75	66	37.0	134.0	112.0	2,220	10,050	7,392
NM	83	66	46	180.0	160.0	180.0	14,940	10,560	8,280
NY	590	450	540	101.0	98.0	105.0	59,590	44,100	56,700
NC	640	640	625	80.0	116.0	125.0	51,200	74,240	78,125
ND	655	930	705	117.0	112.0	115.0	76,635	104,160	81,075
OH	3,200	3,300	3,170	126.0	147.0	138.0	403,200	485,100	437,460
OK	280	240	210	145.0	140.0	125.0	40,600	33,600	26,250
OR	30	27	18	175.0	180.0	140.0	5,250	4,860	2,520
PA	880	1,080	990	70.0	127.0	98.0	61,600	137,160	97,020
SC	275	280	240	70.0	65.0	108.0	19,250	18,200	25,920
SD	3,250	3,800	3,400	113.0	112.0	109.0	367,250	425,600	370,600
TN	570	580	620	102.0	114.0	132.0	58,140	66,120	81,840
TX	1,770	1,900	1,420	129.0	124.0	118.0	228,330	235,600	167,560
UT	20	18	15	143.0	144.0	142.0	2,860	2,592	2,130
VA	280	330	330	78.0	146.0	123.0	21,840	48,180	40,590
WA	100	100	55	180.0	185.0	190.0	18,000	18,500	10,450
WV	20	35	26	65.0	130.0	120.0	1,300	4,550	3,120
WI	2,850	2,750	2,600	143.0	132.0	127.0	407,550	363,000	330,200
WY	52	58	51	118.0	132.0	125.0	6,136	7,656	6,375
US	70,487	72,440	68,808	133.8	136.9	138.2	9,430,612	9,915,051	9,506,840

CT, ME, MA, NH, RI, VT Not estimated
Source: USDA - National Agricultural Statistics Service