CHAPTER THREE

SUGAR AND SUGARCANE

Sugar

The product marketed as "sugar" is a saccharide (a form of carbohydrate) in pure crystalline form. It is variously called granulated sugar, crystalline sugar, or centrifugal sugar (because the crystals are removed from the uncrystallized molasses by centrifugation). Saccharides (sugars) are the simplest carbohydrates synthesized in nature and consist of various arrangements of the atoms carbon, hydrogen, and oxygen. The more common saccharides are sucrose, glucose, fructose, and dextrose. Saccharides are classified according to the number of distinct sugar molecules that form the compound: disaccharides, trisaccharides, etc. (Streitwieser and Heathcock 1981). Common table sugar (sucrose) is a disaccharide composed of the monosaccharides fructose and glucose. Its chemical formula, $C_{12}H_{22}O_{11}$, is represented in Figure 3.1. Because molecules of sucrose in "sugar" are identical, the source of the sugar — sugarcane or sugar beets — is irrelevant to the food industry. As will be discussed in chapter six, it is, however very important to the granulated sugar industry.

Sugarcane has been used as a sweetener for millennia and today refined sugar is used in copious quantities to supplement the natural sugar (fructose) found in fruits and vegetables. Sugar has been isolated from all parts of plants: from the stem of plants such as sugarcane, sorghum, sweet palm, maple, and maize (the source of high-fructose corn syrup [HFCS]); from the roots of the plants such as sugar beet and sweet potato; from any number of fruits such as the fig and the grape ("must"); and even from the flower itself, as the sweet *mahua* of India. Plant exudates are also a source of sugar, the *manna* of biblical fame being the more famous (Deerr 1949, Mathewson 2000).

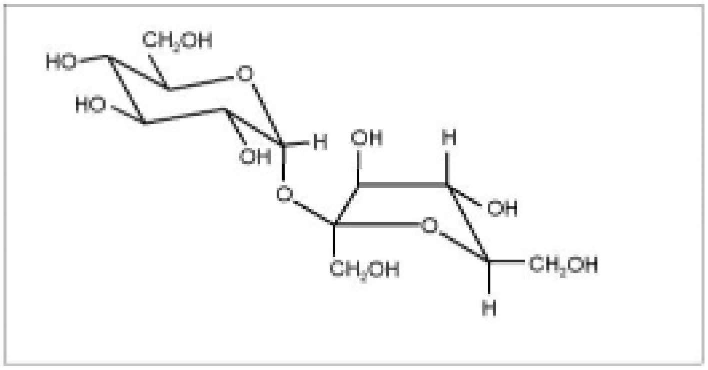


Figure 3.1. Chemical Structure of the Sucrose Molecule. Regardless of its source --either sugar beets or sugarcane -- the molecules of sucrose are identical. Redrawn from Andrew Streitwieser, Jr. and Clayton H. Heathcock, *Introduction to Organic Chemistry* (New York, 1981), 925.

The Sugarcane Plant

Sugarcane, like wheat, rice, corn and other grains, is of the grass family, Gramineae, characterized by segmented stems, blade-like leaves, and reproduction by seed (Barnes 1974). Sugarcane is a tropical plant; it has no adaptation to survive freezing and it is dependent on abundant sunlight for healthy growth. As in all plants, the growth of sugarcane results from the conversion of radiant energy from the sun into plant fibers and sugars (Figure 3.2). Tropical plants, sugarcane has a specific photosynthetic mechanism for fixing carbon into plant sugars. In this adaptation, the first product of photosynthesis is a four-carbon sugar (C_4) (rather than a three-carbon sugar) that is fixed in specialized cells in the conductive tissue (stem) of the plant (Cox and Moore 1985). In sugarcane, the concentration of sugar is exceptionally high, making the plant especially desirable to humans.

The carbon gain per day from photosynthesis varies with latitude as well as cloud cover. Latitude determines the intenseness of solar radiation on a horizontal surface and cloud cover determines the amount of radiation that reaches the surface. Cloud cover, in turn, is affected by

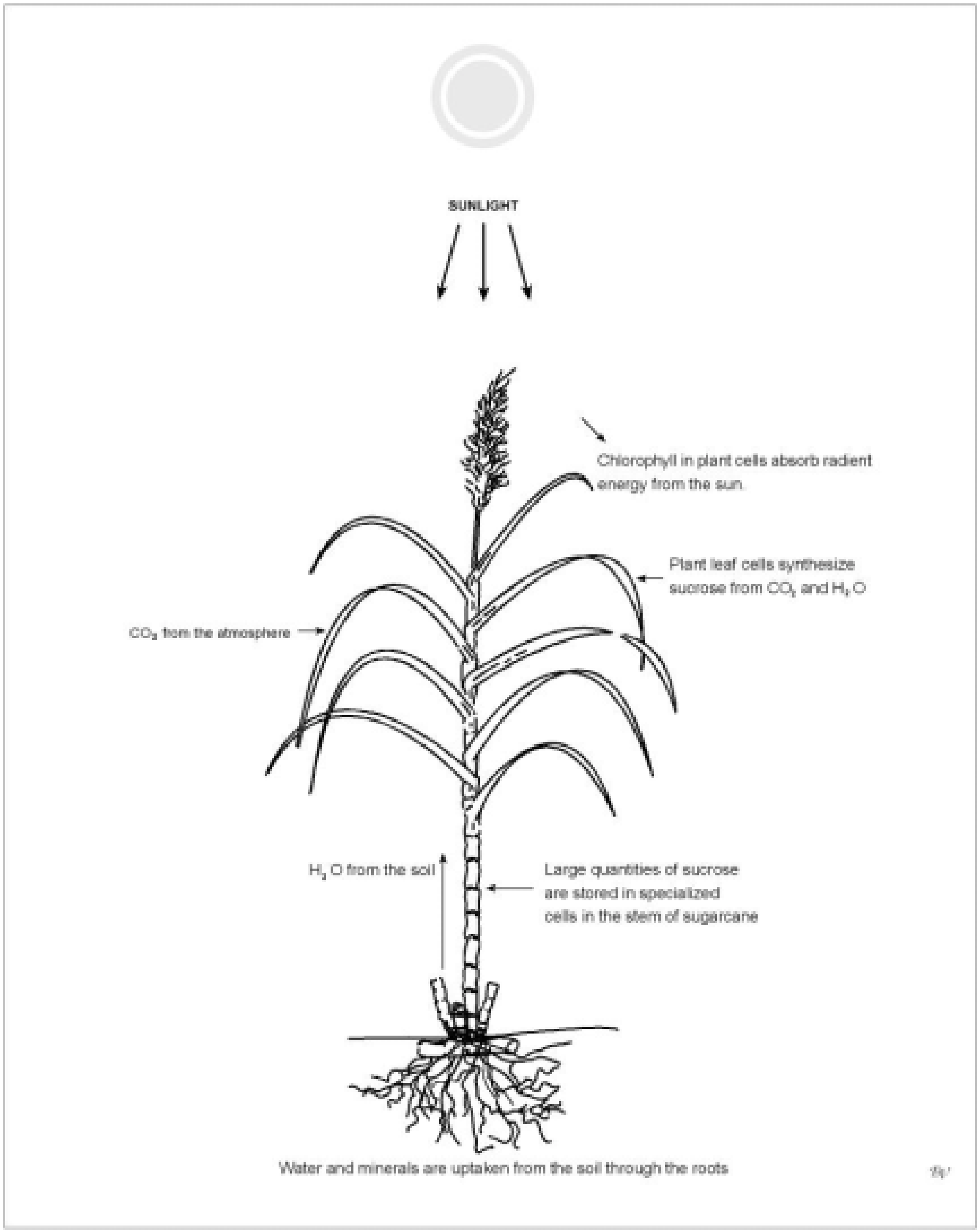


Figure 3.2. Insolation and Photosynthesis. Plants convert solar energy to chemical energy through photosynthesis. The efficiency of each species is determined by its adaptation to the challenges of a particular location, including variety in temperature, soils, and solar radiation.

air currents and the arrangement of continents and oceans. The average solar insolation at any given location is, therefore, a function of latitude and its location relative to continental and ocean configurations. Figure 3.3 identifies areas of the earth's surface that receive the highest solar insolation.

The C_4 plants thrive best under conditions of high solar insolation and high temperature associated with the lower latitudes. Figure 3.4 illustrates the increased efficiencies of C_4 plants at lower latitudes as well as their reduced efficiencies at higher latitudes. The 40th parallel represents the outermost limit of optimum solar radiation for C_4 plants (Cox and Moore 1985). The present global distribution of sugarcane (Figure 3.5) reflects these associations. Because of insolation and temperature requirements, sugarcane cultivation in the Louisiana latitude is at a singular disadvantage.

Like other Gramineae, sugarcane has a wide distribution. Through time the Gramineae became an important food source for humans. Maintaining supplies of this seed continues to engage large segments of the human population. The sugarcane plant itself is of the genus *Saccharum*. Its early domestication is probably due to the ease with which it can be grown and reproduced. The *Saccharum* has five extant species: two wild (*S. spontanium* and *S. robustum*) and three cultivated (*S. officinarum, S. barberi,* and *S. sinense*) (Barnes 1974). More recent plant taxonomy includes two additional species within the genus: *S. bengalenese* and *S. arundinaceum* (McCann 1990). Sugarcane nomenclature is complex (and confusing) due to the long history of domestication in differing parts of the world where various names have been used for the same plant. Table 3.1, aptly titled "Sorting Saccharum Names," lists the stabilized names of extant sugarcane plants and the authorities to which the name is attributed.

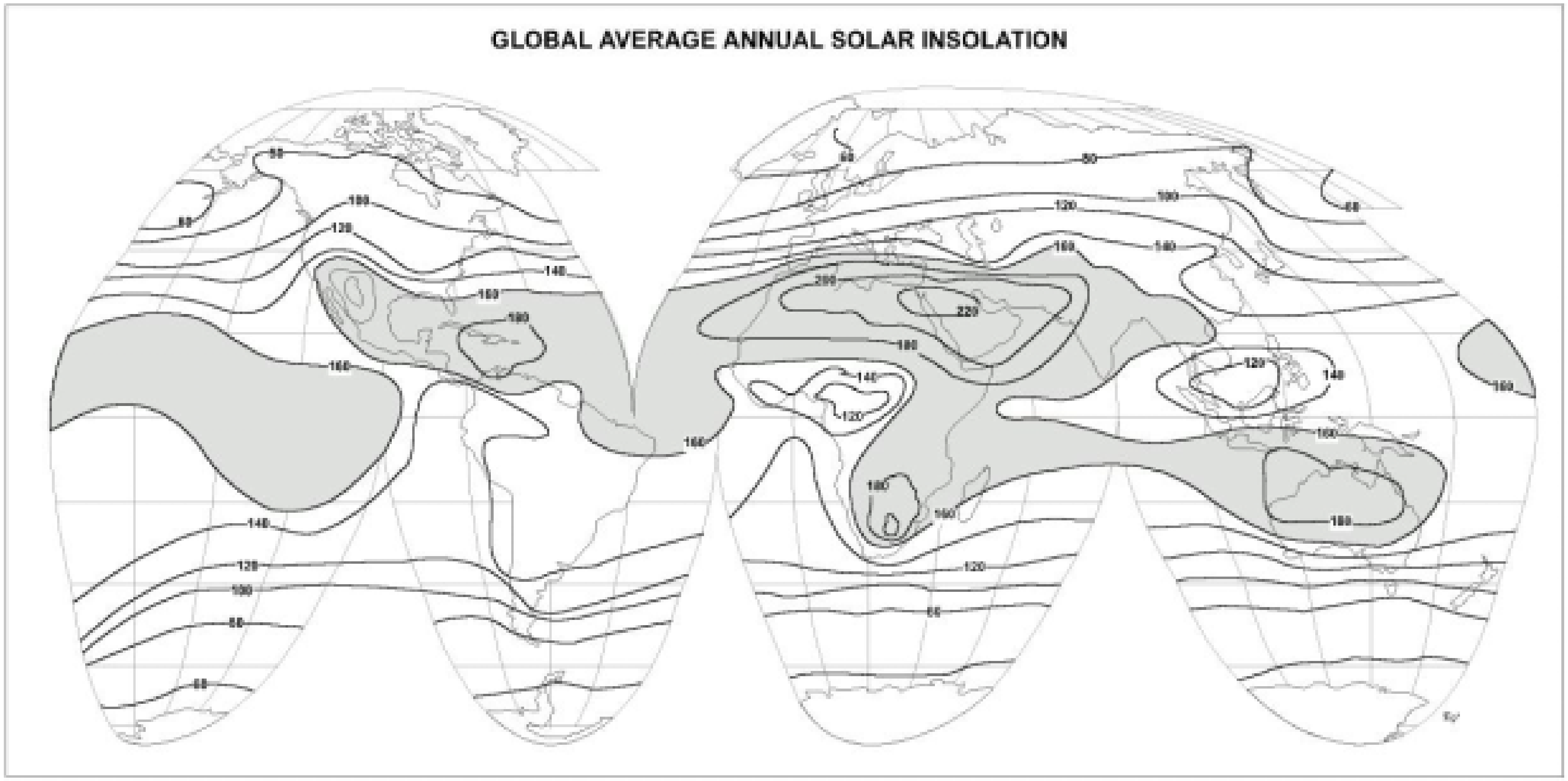


Figure 3.3. Global Average Annual Solar Insolation. The units indicated on the isolines are kilolangleys per year. A langley is a measure of solar radiation equivalent to one calorie per square centimeter of surface. A minimum of 160 kilolangleys per year is necessary for optimum sugarcane maturation. Redrawn from John E. Oliver and John J. Hidore, *Climatology: An Introduction* (London, 1984), 34.

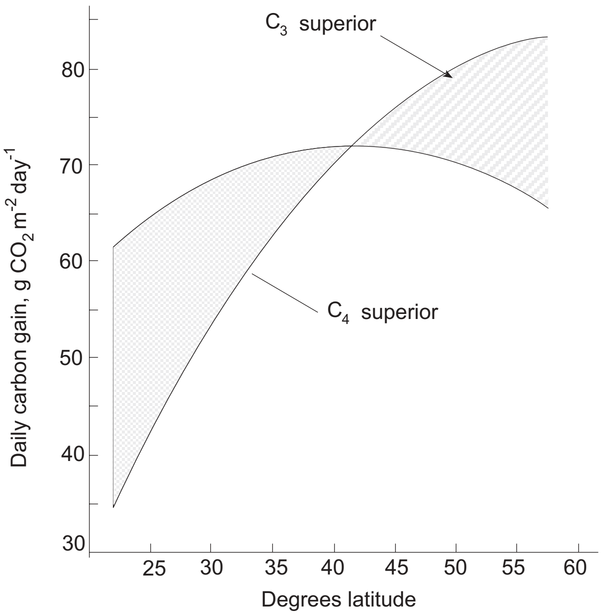


Figure 3.4. Predicted Levels of Photosynthesis for C_3 and C_4 Plants at 40° Latitude. Source: C. Barry Cox and Peter D. Moore, *Biogeography* (London, 1985), 37. Biomass acumulation advantage diminishes with distance from the equator for C_4 plants.

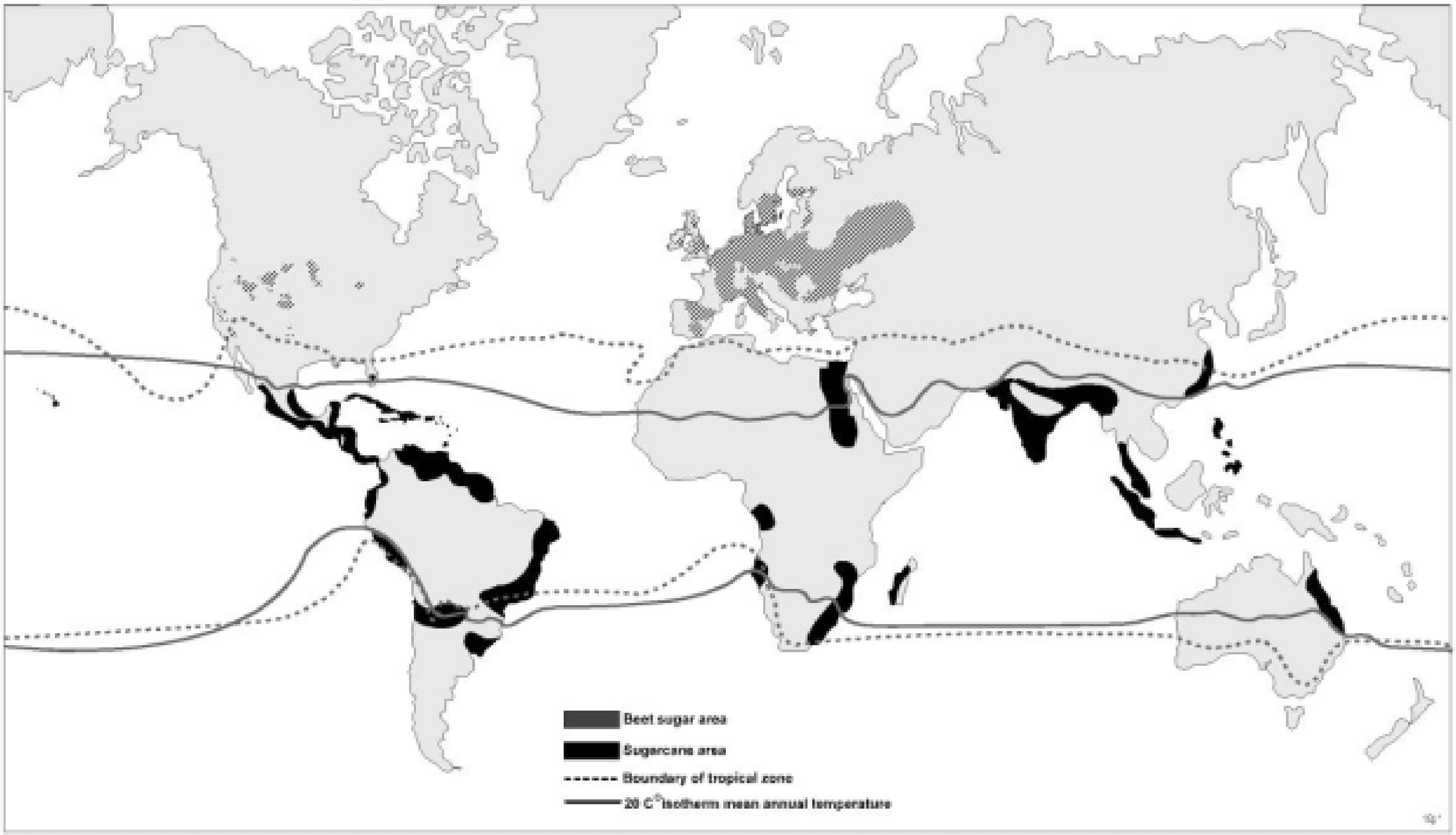


Figure 3.5. Global Distribution of Sugar Beet and Sugarcane Production. Redrawn from Helmut Blume, *Geography of Sugar Cane* (Berlin,1985), 22.

Table 3.1. Sorting Saccharum Names

Saccharum aegyptiacum Willd. ->
Saccharum arenicola Ohwi -> Saccharum spontaneum L. subsp. spontaneum
Saccharum arundinaceum Retz.
Saccharum barberi Jeswiet
Saccharum bengalense Retz.
Saccharatum biflorum Forssk. -> Saccharum spontaneum L. subsp. aegyptiacum (Willd.)Hack.
Saccharum ciliare Andersson -> Saccharum bengalense Retz.
Saccharum edule Hassk. -> Saccharum spontaneum L. var. edulis (Hassk.) K. Schum. & Lauterb.
Saccharatum exaltatum Roxb. -> Saccharum arundinaceum Retz.
Saccharum fallax Balansa
Saccharum fallax Balansa var. aristatum Balansa
Saccharum floridulum Labill. -> Miscanthus floridulus (Labill.) Warb. (GRIN,Wang)
Saccharatum hybridum hort. -> Saccharum officinarum L.
Saccharum japonicum Thunb. (Wang) -> Miscanthus floridulus (Labill.) Warb. (GRIN,Wang)
Saccharum japonicum Thunb. (GRIN) -> Miscanthus sinensis Andersson (GRIN,Wang)
Saccharum munja Roxb. -> Saccharum bengalense Retz.
Saccharum narenga (Nees ex Steud.) Wall. ex Hack. (GRIN)
Saccharum officinale Salisb. -> Saccharum officinarum L.
Saccharum officinarum L.
Saccharum officinarum L. var. violaceum Pers.
Saccharum paniceum Lam. -> Pogonatherum paniceum (Lam.) Hack. <- not yet entered in our own database
Saccharum pophyrocoma (Hance ex Trimen) Bor -> Narenga porphyrocoma (Hance ex Trimen) Bor -> Saccharum narenga (Nees ex Steud.) Wall. ex Hack. (GRIN)
Saccharum robustum E.W. Brandes & Jeswiet ex Grassl
Saccharum rufipilum Steud.
Saccharum sara Roxb. -> Saccharum bengalense Retz.
Saccharum sinense Roxb.
Saccharum spontaneum L.
Saccharum spontaneum L. subsp. aegyptiacum (Willd.) Hack.
Saccharum spontaneum L. subsp. spontaneum
Saccharum spontaneum L. var. arenicola (Ohwi) Ohwi -> Saccharum spontaneum L.subsp. spontaneum
Saccharum spontaneum L. var. edulis (Hassk.) K. Schum. & Lauterb.
Saccharum tinctorium Steud. -> Miscanthus tinctorius (Steud.) Hack.
Saccharatum violaceum Tussac -> Saccharum officinarum L.

Source: Multilingual Multiscript Plant Name Database, 2003.

Batavia, a variety planted in Louisiana in the early nineteenth century, was also called Crystaline, Transparent, Cheribon, and Preanger cane (Deerr 1949). Mutant forms of Batavia were variously called purple, yellow, or striped (as suggested by the stalk or leaf pattern and color). Deerr (1949, 22) comments that at his writing at least 1800 varieties were grown, though he acknowledged that different names probably referred to the same variety. Uba, a sugarcane from Brazil (later called “ribbon” cane) rescued the Louisiana industry from its disastrous collapse due to mosaic disease in the 1920s. Through his extensive experimentation, Deere found Uba to be originally from Natal Province in South Africa, the name possibly derived from the corruption of "Durban" on a shipping label. He found that Pansahi, Chinea, Agaul, and Merthi of India — all summarily knows as Kavengerie — are also identical to the Uba cane (Deere 1949).

The confusion in early sugarcane nomenclature has been eliminated by a universal adherence to a standardized naming system. New varieties are identified by name of the breeding station and the number of the experimental plant. The variety presently invigorating the Louisiana industry is LCP-85-384. "L" designates the LSU breeding station in Houma, and "CP," that in Canal Pointe, Florida. Other varieties have similarly identifying prefixes: : "BH" indicates Barbados Hybrid, "CH," Cuba Hybrid; "CL," Clewiston, Florida; "POJ," Proefstation Oost Java, "Co" Coimbatore, Madras, etc.

Through time numerous varieties of sugarcane species have been isolated for sugar extraction. Today, hybrids of the species *S. officinarum* are the preferred breeding stock of the commercial sugar industry. On-going hybridization and genetic engineering (in which genetic materials (chromosomes) are manipulated at the cellular level) continue to enlarge the number of varieties available to the sugar industry (Gravois 2001).

Diffusion of Sugarcane

The species, *S. officinarum*, the basis of all industrial cane sugar production today, is also among the oldest cultivars domesticated by humans (Barnes 1974, Blume 1985, Galloway 1987). Confusion in the naming of sugarcane varieties makes tracing sugarcane diffusion a daunting task. American botanist E. W. Brandes, the current authority on the origins and distribution of sugarcane, places the emergence of the *S. officinarum* as a species in New Guinea about 10,000 years ago (Barnes 1974). Barnes bases this assignment on linguistic as well entomologic evidence in which an obligate association was demonstrated among a parasitic fly, its host beetle, and *S. officinarum*, indicating that the three evolved in close proximity to each other (Brandes and Sartoris 1936).[1] Additional botanic and cytological research confirms that domestication of the species occurred as early 6000 BC (Galloway 1987).

From its origin in New Guinea, the sugarcane plant has experienced a wide dispersion as it accompanied humans in their various migrations. Brandes (in the 1936 publication with Sartoris) identifies three phases in the diffusion of the indigenous Papuan plant: 1) the 8000 BC eastward movement to the Solomon, Hebrides, and New Caledonia islands; 2) the 6000 BC westward movement to Indonesia, the Philippines, and India; and 3) the 800-1000 AD eastward movements to the Marquises, Society Islands, other parts of Oceania, and, finally, the Hawaiian Islands (Figure 3.6). In the latter case, ample linguistic and folkloric evidence confirms the presence of the plant in the islands from the tenth century AD. The 325 BC movement into the Mediterranean region by Alexander the Great, continued a westward diffusion that eventually brought sugarcane to Brazil, the Caribbean, and finally to Louisiana.

Undoubtedly, Arab innovations in irrigation (particularly the quanat system) played a large part in making the arid Mediterranean region suitable for sugarcane growth. Sugar extraction processes spread with the plant as the industry was extended into Egypt, East and North Africa, southern Spain, Cypress, and Sicily where it persisted longest before Spain and Portugal transferred the industry westward into the Atlantic (Galloway 1989, Barnes 1974).

[1] Deere (1949, 21), however, suggests that the wild species, *S. spontanium*, was carried to India and China where the subsequent domestic species, *S. barberi* (after the botanist, C. A. Barber) and *S. sinense* were isolated. Further hybridization then gave rise to *S. officinarum*.

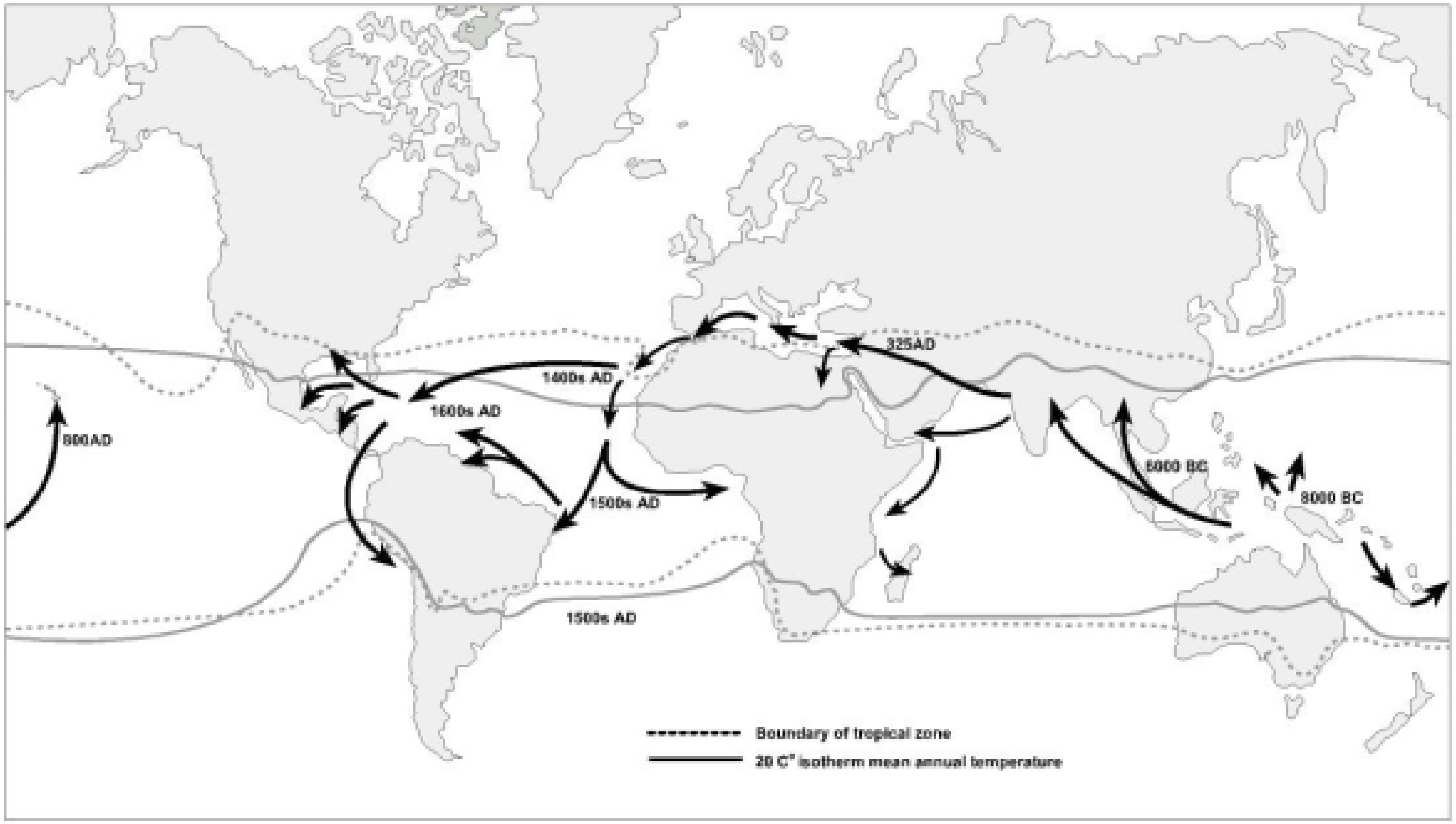


Figure 3.6. Global Diffusion of Sugarcane. Redrawn from Helmut Blume, *Geography of Sugar Cane* (Berlin,1985), 22.

The varieties brought westward in the fourth century BC and subsequently grown in Persia, Arabia, and Egypt formed the basis of the Mediterranean industry until another Indian variety, Puri, was introduced in the fifteenth century. Puri was the stock transferred to Madeira, the Canaries, Cape Verde Islands, São Tomé, and parts of West Africa and, in 1493, by Columbus to the Americas.[2] Puri cane — later called "Creole" cane — was planted throughout Brazil and the Caribbean until the mid-eighteenth century when varieties imported from the Old World began to replace it (Deerr 1949, Galloway 1989).

The continued productivity of the Creole cane after centuries of growth in the Americas was remarkable, given that the warm and humid climate necessary for its growth also encourages competition from pest and disease organisms. Plants of the Gramineae family (wheat, rice, rye) are usually reproduced from the germination of seed. Sugarcane, however, is reproduced vegetatively by placing portions of mature stalk ("sets") into the cultivated ground. The subsequent growth from the sets is, therefore, continued growth of the original plant. With no exogenous genetic contribution (as occurs in the formation of seed from the pollinated flower) the sugarcane plant "weakens" through time, manifesting less resistance to disease and producing less sugar.

By the mid-eighteenth century yields from Creole cane began to drop. Fortunately for the flagging Caribbean industry, Europeans were traveling the world in the "great voyages of discovery." Naturalists onboard the chartered ships collected domesticated cultivars (as well as exotic plants and animals) which they moved about the world in processes that greatly

[2] Because of the wide and early distribution of sugarcane, a pre-Columbian presence in the New World has sometimes been suggested. But, as presented in chapter one, expanding a sugar supply was a significant motivation for colonizing the New World tropics, so a history of early distribution in the favorable American tropics should be of no surprise.

accelerated the diffusion of cultivated plants. The flagging sugarcane industry of the Americas benefited from these relocations. Bougainville brought a resilient and highly productive cultivar from Réunion (Île de Bourbon) to Saint Domingue where it thrived in the Caribbean climate (Galloway 1987). The introduced variety was initially called Otaheite (Tahiti), but later renamed "Bourbon" or "Royal" cane. Captain Bligh brought Otoheite to St. Vincent from where it was moved to Jamaica to become the basis of that enormously productive industry. The Dutch also brought Otaheite (as well as other varieties) to their colonies in St. Eustatius, Curaçao, and Surinam (Deerr 1949). Movements of Otaheite continued throughout the sugar islands, replacing the flagging Creole cane and enabling the Caribbean industry to continue its prodigious output into the twentieth century. Most significance to this discussion, the 1795 de Boré granulation, credited with changing the course of the sugar industry in Louisiana, was from a crop of Otaheite newly brought to Louisiana from Saint Domingue (Blume 1984, Galloway 1987).

Barnes (1974) gives evidence of cane breeding in Mauritius as early as 1780. Later, more significant varietal contributions resulted from the work of John R. Bovell who, in 1888, rediscovered that sugar cane could produce fertile seed. The cane breeding industry Bovell initiated was centered in Barbados, coordinated with Kew Gardens in London, and eventually integrated with stations worldwide (Galloway 1996).

Louisiana sugar planters recognized early the importance of cane breeding to create disease-resistant and productive cultivars. To this end they formed the Louisiana Sugar Planters Association and encouraged the introduction of scientific methodology in both sugarcane cultivation and sugar manufacture (Heitman 1987). Their efforts to modernize were rewarded in 1896 when the LSU Sugar Station was established at Audubon Park in New Orleans to focus on the breeding of sugarcane varieties specific to the Louisiana industry. In 1923 the station was relocated to Houma where collaboration among the USDA, the American Sugar Cane League, and the LSU Agricultural Center continues today.

Independent as well as collaborative research has characterized the modern sugar industry in the search for new varieties. A 1925 expedition to New Guinea to ascertain the origin of the sugarcane plant was a joint effort of E. W. Brandes of the USDA, C. E. Pemberton of the Philippines, and Dr. Jeswiet of Java — all significant contributors to the modern sugar industry (Deerr 1949). The principal sugarcane breeding stations today are the USDA Sugarcane Station at Canal Point, Florida, and the Indian Sugarcane Breeding Institute at Coimbatore, Madras. [3] These stations serve as major repositories for sugarcane germ plasm as well as centers for crossing, selection and evaluation of new varieties.

Sugarcane Planting and Harvest

Like other grasses, sugarcane will yield flower and seed at maturation. The genetic combinations resulting from seed germination, however, are not always desirable and cannot be reproduced consistently. (Additionally, sugar extraction efficiencies are greater if the sugarcane is harvested before it has "gone to seed.") Instead of planting seed, sugarcane is reproduced from sections of stalk containing nodes (called "sets") (Figure 3.7) that are laid in furrows and covered with soil. Roots and young shoots emerge from the nodes within several weeks. In Louisiana planting usually occurs in late October to allow the tender shoots time to mature

[3] A variety developed at Coimbatore, Co 205, proved to be a remarkable success in North India, particularly in Punjab, where it produced 50 percent greater yield than the indigenous varieties under cultivation. This was followed by other hybrids derived from the three species, *S. officinarum*, *S. barberi*, and *S. spontaneum*. Three of these varieties, Co 285, Co 312, and Co 313, also significantly improved local yields and formed the basis of further breeding work not only in India but also in many sugarcane growing countries. The variety, Co 419, contributed significantly to improved output in Barbados, Jamaica, British Guyana, Sudan, Kenya, Uganda, and Tanzania.

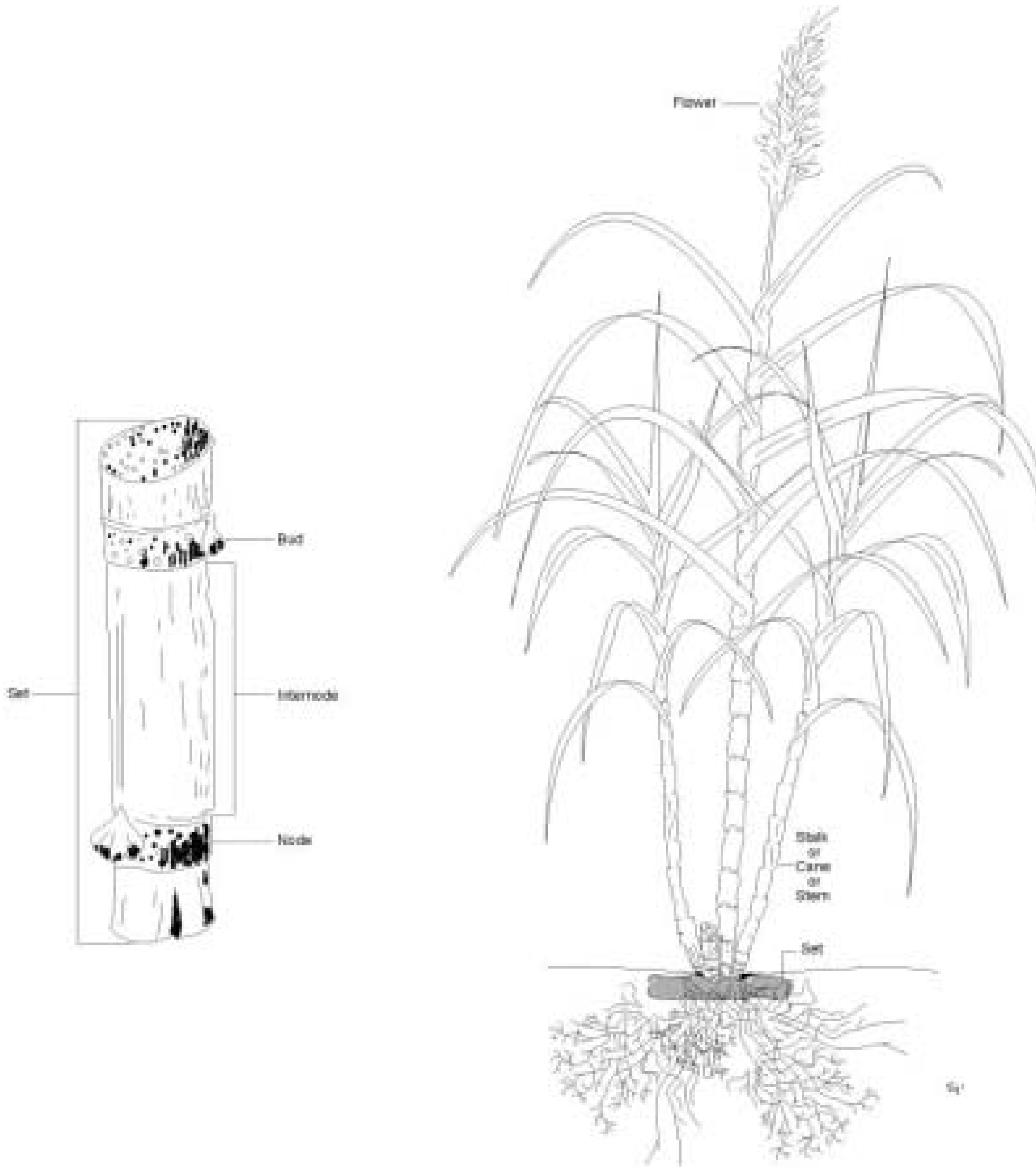


Figure 3.7. orphology of the Sugarplane Plant.

somewhat before a possible frost. At least eight months' growth is necessary for the stalk to accumulate adequate sugar for recovery (Gravois 2001). Figure 3.8 illustrates the wide variety of planting and harvesting seasons found throughout the sugar-producing countries. Those with the longest growing season obviously benefit from the highest sugar yields.

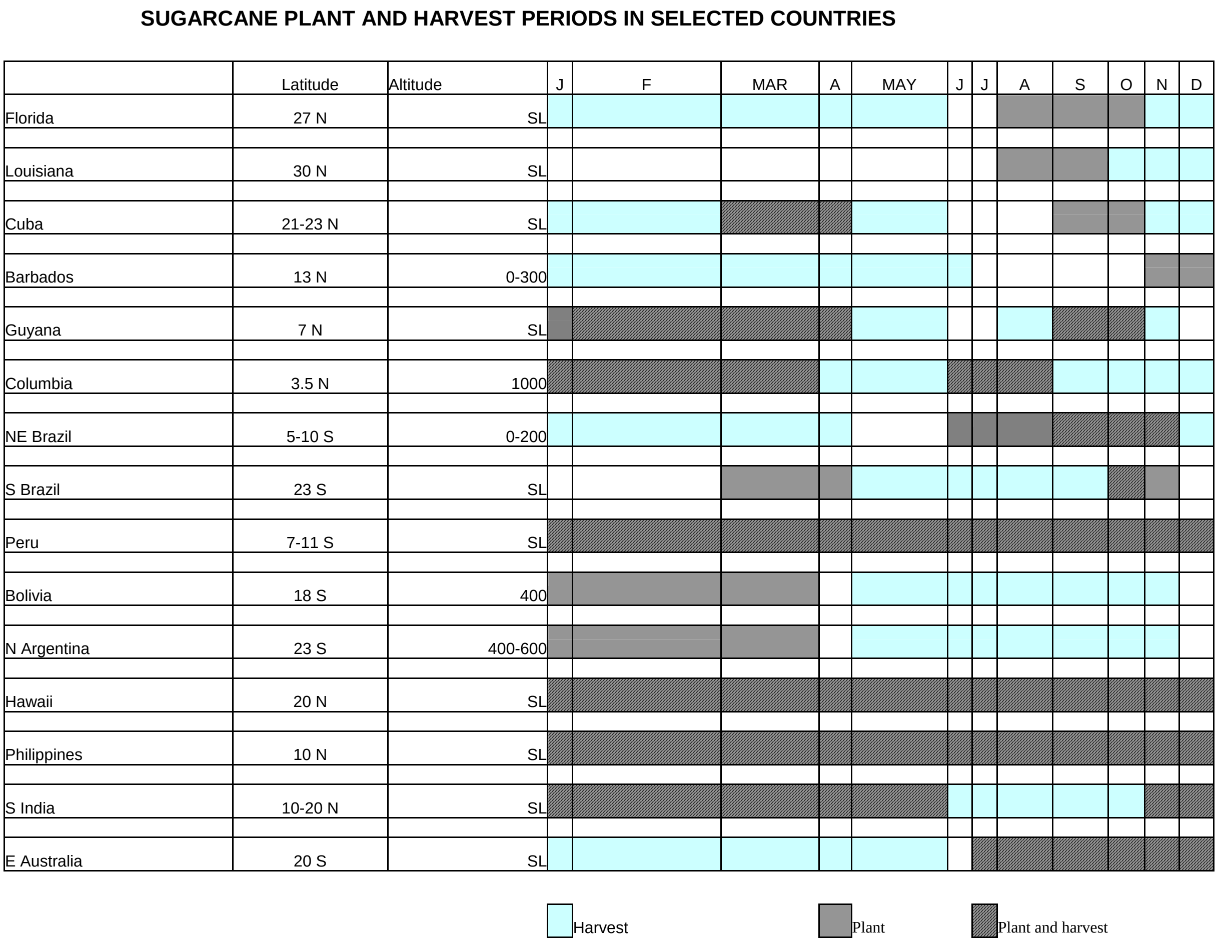


Figure 3.8. Sugarcane Plant and Harvest Period in Selected Countries. Modified after Helmut Blume, *Geography of Sugar Cane* (Berlin, 1985), 68.

Sugarcane harvest involves cutting the emergent stem (or stalk) at the ground. The roots are left in the ground and allowed to regrow or “ratoon.” The first crop that emerges from the planted sets is called “plant cane.” The subsequent crops are variously termed “first ratoon” (also “first stubble”), “second ratoon” (“second stubble”) etc. Sugar concentration drops with successive ratoon crops so after two to three crops (historically) the old roots are excavated and a fresh “plant cane” crop is installed to begin the cycle anew (Figure 3.9). Production efficiencies in ratoon crops have been increased with newer varieties. The variety favored in Louisiana

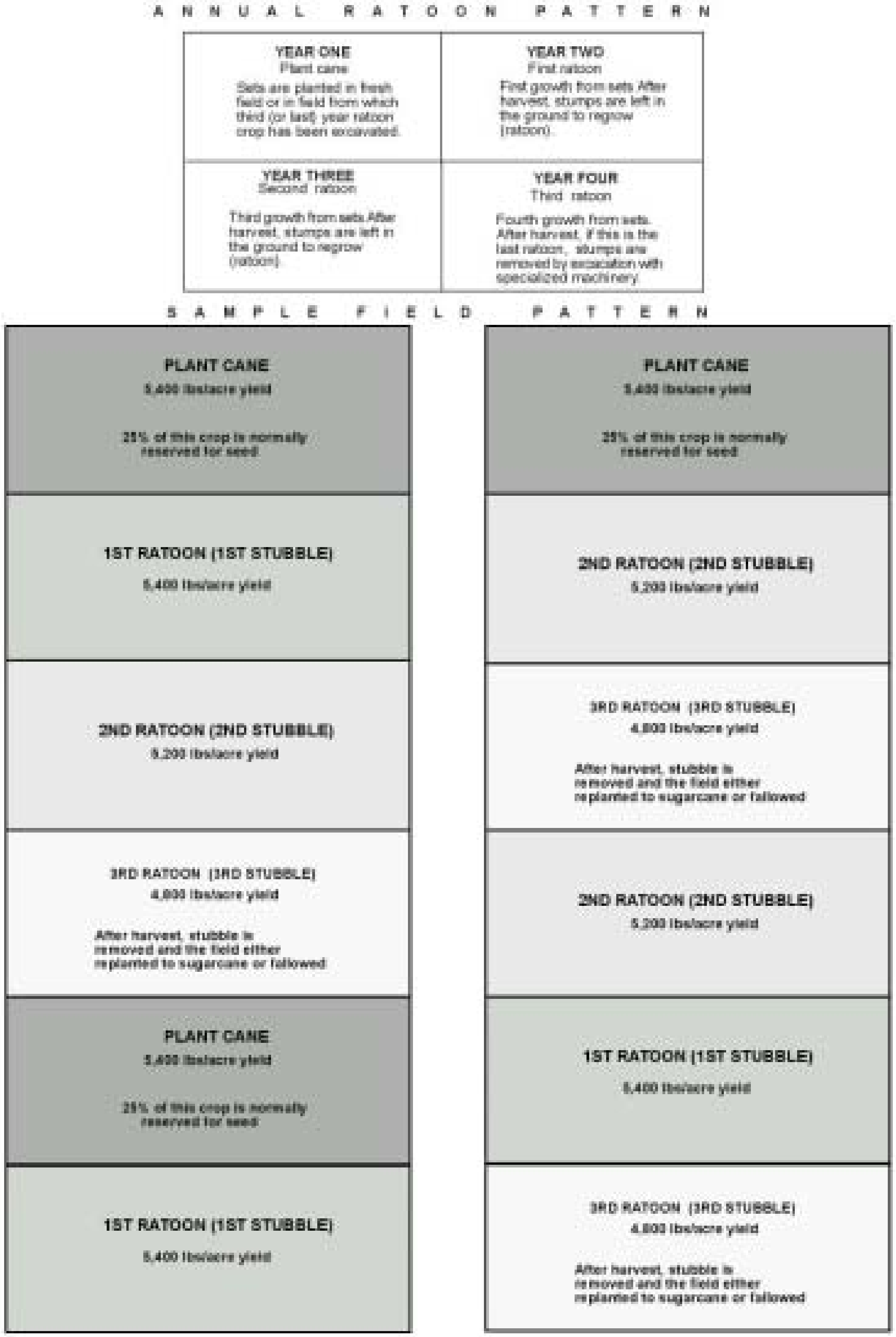


Figure 3.9. Sugarcane Ratoon Cycle. Twenty percent of plant cane is normally reserved for seed. The remainder, along with the stubble crops, is sent to the mill for sugar extraction, hence the designation "sugarcane for sugar" in data sets. In Louisiana, Variety LCP85-384 has enabled a fifth, and sometimes sixth, ratoon of adequate yield. Yields indicated here are for 1997 as quoted in Lonnie Champagen and ichael Salassi (Baton Rouge 1997), 8.

today, LCP 85-384, has produced as many as five ratoon crops of acceptable sugar concentrations (Gravois and Bischoff 2001). This long ratoon cycle is welcomed because it reduces the cost of clearing away an old crop and replanting a fresh field. Additionally, LCP 85-384 has greater cold tolerances and has increased yields as much as 20 percent since its introduction in 1998 (Gravois and Bischoff 2001).

In the subtropics sugarcane harvest ideally occurs before the first frost. When the sugarcane plant is subject to freeze (or harvest) photosynthesis immediately stops and the sucrose begins to change to dextrose and levulose, saccharides that do not readily crystallize by conventional processes. It is therefore important to harvest before a freeze and begin juice reduction (boiling) immediately after the canes are cut. In an earlier era, the planter decided when to begin the harvest, weighing his desire for maximum yield against the possibility of the loss of his entire crop in early freeze. Once cutting began, the “grinding” season was one of frenzied activity in which the cut cane was transported to the mill and juice reduction begun as quickly as possible. Today, harvest begins on a predetermined date for each farmer, set according to a pre-season contract with the mill. The mill’s schedule, in turn, is determined (mostly) by its daily grinding capacity and the arrangement and size of the surrounding sugarcane fields. The cut cane is transported by truck (sometimes by rail) to centralized mills where the crop is processed with speed and efficiency unimaginable by earlier planters.

Sugar Manufacture

Granulated (crystalline) sugar has been made by humans for millennia (Galloway 1987, Barnes 1974, Deere 1949). Rudimentary boiling techniques practiced in India eventually led to the “invention” of crystalline sugar (Deerr 1949). Evidence of earliest sugar manufacture[4] is scanty but, as with diffusion of the plant, linguistic evidence puts the first appearance of crystallization techniques in northern India at about 375 BC (Barnes 1974). Galloway (1989) cites references to “stone honey” that suggest China had crystallization techniques as early as 2000 BC. Brandes (1936) and Galloway (1989) both agree on the fourth century for the arrival of sugar manufacture in Persia.

Unlike mills that process wheat or rice, a sugar “mill” both extracts juice from the canes and manufactures crystalline sugar. A sugarhouse (“boiling house” or “sugar factory”) is, therefore, an integral part of a sugar mill. In Louisiana, before rapid transportation was available, each planter had his own mill on site. The urgency to cut and process sugarcane descended on all planters simultaneously and only by coordinating his own cutting and milling could a planter assure success. Once harvest began, the furnaces kept the cauldrons boiling night and day and the sugar-making process was not interrupted lightly (Sitterson 1953a, Prichard 1927). A bottleneck at any point in the production process could have expensive consequences. Labor disruption or mechanical failure of the mill could stop the flow of juice. Fuel shortage could stop the boiling process. Production efficiencies, therefore, required an unusual amount of skill and vigilance on the part of the planter.

Though the modern sugar mill and those of the seventeenth century bear little resemblance, the function of the two facilities differs only in complexity and efficiency. The earliest mills of the Caribbean and Louisiana continued a technology first developed in India and

[4] The process of reducing the cane syrup to the point of crystallization, while referred to as the “manufacture” of sugar is, in fact, only a process of extraction. The sucrose solution is reduced (water is removed) until the sugar assumes its characteristic solid, crystalline form. There is no assemblage of molecules (or product) as is usually indicated by the term “manufacture.”

improved by the Arabs. This consisted of wooden rollers in a set of three through which the canes were fed manually (Figure 3.10). For centuries animal or water power turned the mills. Wind was used where favorable air currents prevailed but, for the most part, no significant improvement in the milling process occurred until the nineteenth century when the steam engine introduced dramatic increases in extraction efficiency. Iron and steel casings strengthened the rollers and steel bearings and gears reduced mechanical failures (Fraginals 1976). The modern mill continues the three-roller innovation of the Arabs (Figure 3.11). It is electricity-powered and consists of multiple sets of metal rollers that achieve juice extraction approaching 85 percent efficiency (Reheder 1999) — in marked contrast to the estimated 20 percent efficiency of the older mills (Fraginals 1976).

Figure 3.10. Animal-Powered Three-Roller Sugar Mill. The three-roller mill was an Arab improvement on the Indian vertical, two-roller mill. This innovation was used for centuries in the Mediterranean, the East Atlantic sugar islands, Brazil, and the Caribbean. Source: Noel Deerr, *The History of Sugar* (London, 1949), Plate 27, facing p. 230.

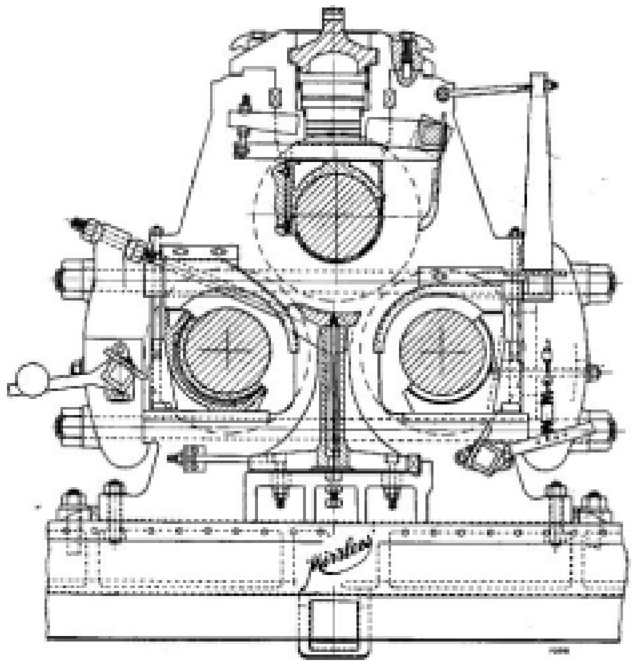


Figure 3.11. Early Twentieth-Century Three-Roller Mill. This diagram of the three roller-mill as produced in the early twentieth century, shows the continuation of Arab technology that introduced a third roller to the earlier Indian two-roller design and thereby achieved greater extraction efficiency. Today's modern mills still use the three-roller arrangement in multiple sets. Source: Noel Deerr, *The History of Sugar*, Vol. 2 (London, 1950), 543.

The early reduction techniques used in the Caribbean as well as Louisiana consisted of a series of open-air kettles in which the syrup was transferred as viscosity increased. In this "Jamaican train," the first kettle, called the *grande*, held 70 to 100 gallons of juice. The second was called the *flambeau*, the third the *sirop*, and the fourth the *teche* or *batterie* (Figure 3.12).[5] The "strike" (*teche*) is the moment crystallization begins. Occasionally, the sugarmaster initiated crystallization by throwing in a handful of sugar to serve as crystal "seed." Once crystallization began, the thickening mass was poured into a wooden trough or "cooler" where it was beaten

[5] The kettle in which De Boré's historic granulation occurred is on permanent display in front of School of Chemical Engineering at Louisiana State University in Baton Rouge.

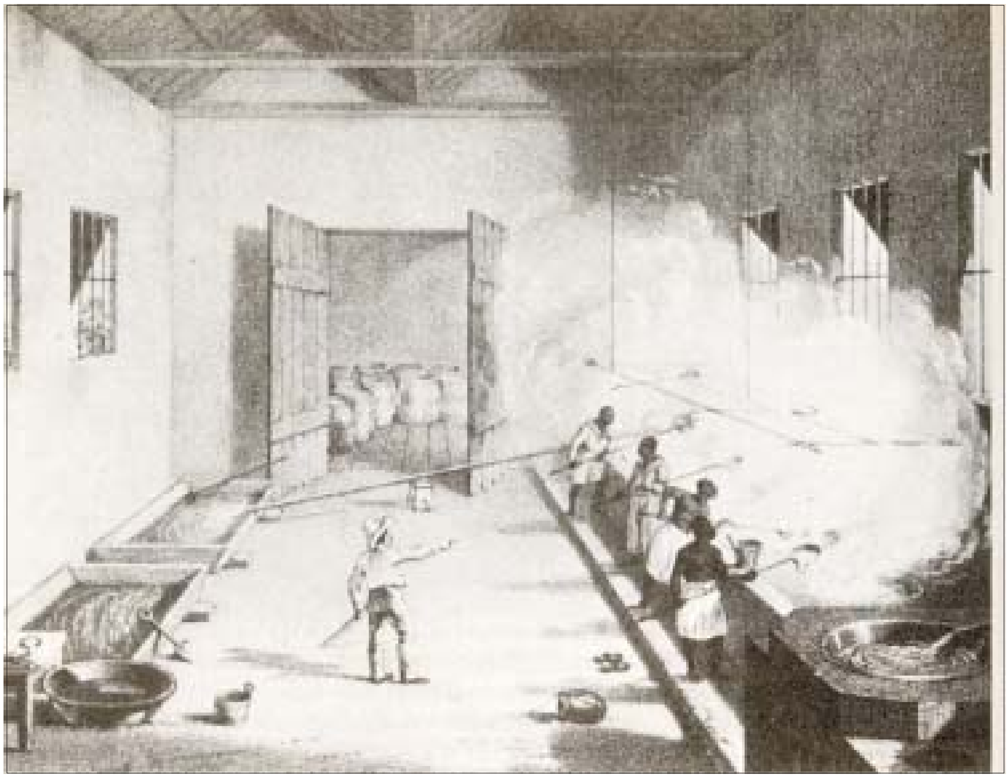


Figure 3.12. Inside an Eighteenth-Century Sugar House. Slaves are ladeling the syrup from right to left in a series of kettles arranged in the "Jamacian train." The *grande* is in the right foreground. The wooden trough for crystallization is in the left background and a ramp for moving the massecuite (mixture of syrup and sugar crystals) is shown connecting it to the *teche, the boiling kettle in which crystallization occurs.* Crystallized raw sugar is shown in the trough in the left foreground. Source: Noel Deerr, *The History of Sugar* (London, 1950), Plate 24, opposite p.451.

with wooden paddles to encourage further crystallization. The thick magma (called "massecuite") was then poured into large casks, positioned in elevated draining rooms, and the uncrystallized syrup caught in cisterns positioned below the casks. Improvements on the Jamaican train continued into the nineteenth century as foundries used available metals to increase the size and efficiency of the train (Deerr 1949, Fraginals 1976) (Figure 3.13).

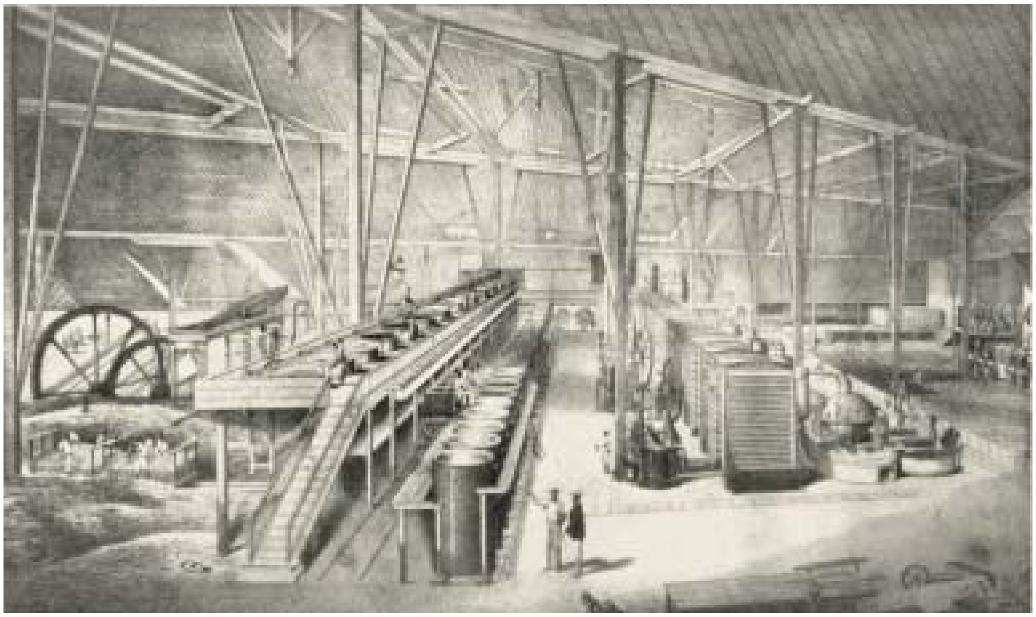


Figure 3.13. Inside a Nineteenth-Century Sugarhouse. The wheels of the mill are seen to the far left. The rows of boiling kettles in the center are an elaboration of the Jamacian train. The filtering cisterns and vacuum pans for final crystallization are to the right. From Geoffrey Fairrie, sugar (Liverpool, 1925), Plate 59, opposite page 158.

In an earlier era, the thickening mass was poured into conical molds (a Venetian innovation) that had a hole at the smaller end for molasses drainage (Figure 3.14). This processes was called “purging” and it preceded “claying,” a primitive refining method that produced “clayed” or whitened sugars. After the rise of off-site refining, the resulting raw sugar was transported to a distant location where it was re-melted, further purified, then recrystallized.

The process of removing undesirable products (purification) continued basically unchanged from the early centuries until modern chemical and mechanical introductions of the mid-nineteenth century. As boiling began, flocculants (agents that induce precipitation) were added to bond with impurities and the solid debris was removed with strainers or sieves. The resulting solution was then boiled until crystallization occurred (Fraginals 1976, Deerr 1949).

Figure 3.14. Fifteenth-Century Venetian Draining Cone and Sugar Loaves. The massecuite was placed in a cone-shaped mold and the draining molasses was collected in a vessel positioned below the mold. The resulting sugar "loaves" are shown on the adjacent table. Drawn from a photograph in Fernand Braudel, *Civilization and Capitalism 15th-18th* Century. Vol. 1 (New York, 1992), 225.

In the eighteenth century flocculants were made from strongly alkaline plants such as the jobo, ceiba or almácigo tree (Fraginals 1976). By the late eighteenth century lime was increasingly used as a flocculent for juice purification. Technical improvements in purification and crystallization were slow to come. The introduction of scientific instrumentation began with the Baumé hydrometer (also called the “saccharimeter”) in 1799 (Heitman 1987). This instrument allowed the sugar master to monitor increasing density and better anticipate crystallization. Subsequent application of modern chemical and mechanical engineering has resulted in the efficient modern mill where sugar recovery rates approach 31 tons per acre, almost 14 percent of the gross weight of the sugarcane (USDA 2001).

Sugar Refining

Earliest refining technology consisted of the claying method in which raw sugar was purified in its draining cone. In the claying process hydrated clay was applied to the top of the cone and within 30 to 40 days the draining water carried away any excess molasses and associated impurities. After drying in the sun, the sugar "loaf" was removed from the mold and cut according to grade, from "white" near the clay-end to "brown" or "muscavado" near the end farthest from the clay. As many as 16 grades were gotten from one loaf (Fraginals 1976, 34). Granulated sugar was manufactured and traded in this characteristic shape until the modern era.

Typical sugar loaves can be seen in the representation of Napoleon in Figure 3.15. The habit of granulated sugar to retain the shape of its draining mold encouraged some of the first applications of the confectionary craft that arose with the availability of "clayed" sugars. The form as well as taste of sugar was prized. Elaborate geometric shapes and images of animals and flowers characterized many gifts of sugar. The record must surely still belong to the king of Portugal who, in 1517, sent to the pope a life-sized sugar effigy, one of each of his twelve cardinals *and* 365 six-feet tall sugar candles (Deerr 1949).

The quality of early manufactured sugar ranged from failed crystallization, yielding only molasses, to pristine white sugar that had been subjected to some form of refining. (As a precursor of rum, however, molasses was never without a market.) By the late seventeenth century a variety of sugars were available in Europe. The most prized was *cassonade*, a "choice, white, dry, fine-grained, violet scented" (Braudel 1982 [1979], 191) sugar from Brazil and

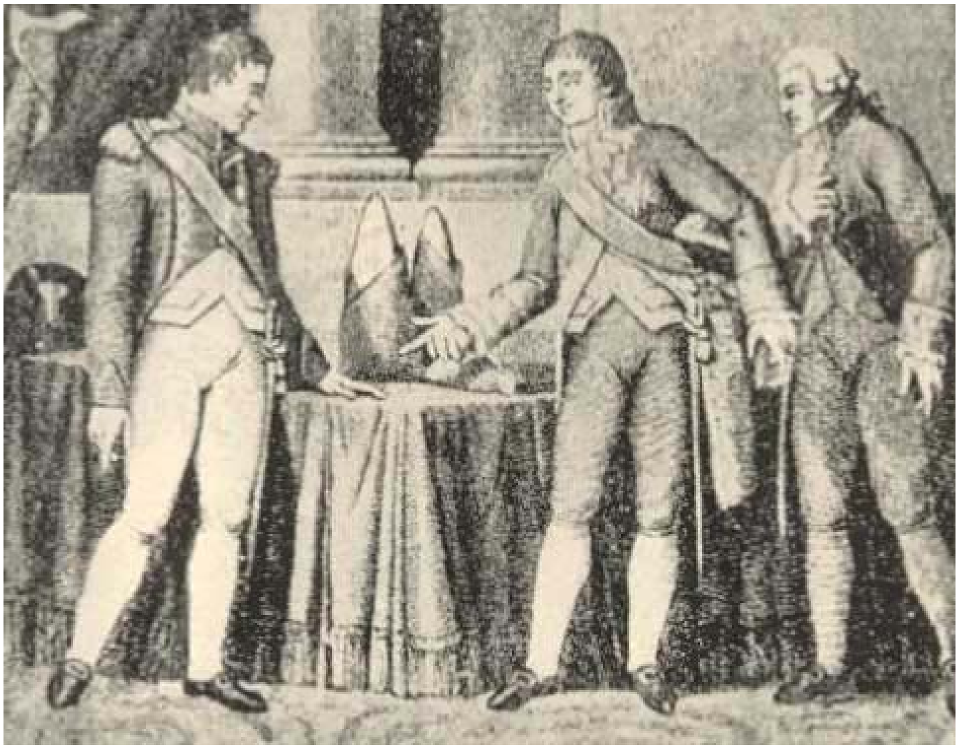


Figure 3.15. Napoleon and Delessert, Sugar loaves can be seen on the table in this photograph of an early nineteenth-century painting of Napoleon and his interior minister. Source: Noel Deerr, *The History of Sugar*, Vol. 2, (London, 1950), Plate 28, facing p. 475.

several of the sugar islands. Next in preference were the sugars from the east Atlantic islands and the Mediterranean: royal sugar, then semi-royal, candy sugar, and finally, Cyprus sugar, a reddish-tinted sugar made in the old Venetian mills of the Cornero family. Sugar from the West Indies fell into four major categories: 1) *muscavado* (raw), 2) *cassonade gris* (also called *sucre passé*), 3) *cassonade blanche* (also called clayed or *sucre terré*), and 4) *sucre raffiné.* The Dutch established a numeric classification of sugar based on color and granulation still in use today. "Twenty-five" indicated a sugar of ideal color and fine granulation while "one" indicated a dark, poorly crystallized sugar. The raw sugar price commonly quoted today on the London and New

York sugar and cocoa exchanges still references this Dutch Standard (DS). DS11 and DS14 are medium-grade sugars commonly marketed today as "raw sugar."

Undoubtedly most of the early whitened sugars were made by claying. At some point the refining process expanded to involve melting of the raw sugar, introduction of more flocculants to remove remaining dissolved impurities, and recrystallization. Early refining techniques were heavily guarded secrets and each "house" was associated with a certain quality of sugar. Various clarifying agents were used in the refining process but the principal agent used for centuries was albumin from egg white or animal blood. Four to five tons of refined sugar required 70-80 egg whites or two gallons of blood to clarify (Deerr 1949). These were added to the melted sugar and the resulting scum continuously scooped off or the solution strained through cloth until it was clear. The variability of success encouraged experimentation with different clarifiers.

Techniques in evidence after 1830 used a German method in which lime was added and carbon dioxide bubbled through the resulting mixture (Fairrie 1925). The liquid was "washed" by percolation through a series of filters made of bone-black (animal charcoal). Upon reduction this clarified syrup yielded fine, white crystals that has come to be the standard for refined sugar.[6] refining techniques became more complex, refining facilities gradually shifted to more convenient locations, usually closer to fuel, refining supplies, and the final market. The Cornero family of the fifteenth century first capitalized on the efficiency of centralized factories for refining raw sugar (Deerr 1949, 451). As the sugar trade spread throughout the Mediterranean, their refineries sprang up in Cyprus, Venice, the Papal States, and Bologna where, as early as

[6] Today's popular "brown" sugar is made from an additional round of syrup thickening in which the syrup is allowed to darken from the heat. The crystals from this process are coated with synthetic levulose. The hydroscopic quality of levulose causes brown sugar to remain moist. Combined with the darkened sugar, it gives a taste much desired for selected dishes.

1470, there was a Society of Sugar Refiners (Deerr 1949). Early sugar refining, however, was a voracious consumer of wood, and the availability of this fuel dictated the location of the early refineries.

The most significant innovations in the sugar industry were those that affected fuel consumption. Until well into the twentieth century, wood was the chief source of fuel, both to boil the syrups and run the mills. The introduction of the steam-power added fuel demands of the mill to those of the boiling house. Brazilian, Caribbean and Louisiana industries emerged during a time when wood was used both as a building material and as fuel and the use of wood in the sugar industry compounded the pressure on wood supplies. The industry not only removed trees to prepare fields for cultivation, but continued the removal in an ever-enlarging periphery to keep the kettles boiling.

Louisiana plantation records provide ample testimony to the planters' concern for fuel and the enormous quantities used in making sugar (Follett 1997). Moody (1974) cites one Louisiana record in which the planter used 940 cords for the boiling house and 450 cords for the steam mill in the production of 5020 hogsheads[7] of sugar (Moody 1976, 47). A crude estimation of the volume of wood yielded by one tree of one foot girth and 30 feet height, allowing an equal volume is branches, is approximately 60 cubic feet. At 128 cubic feet per cord, two trees were needed to make one cord of wood. A planter using 1400 cords of wood in a season to produce 5000 hogsheads of sugar (at the average rate of one cord of wood to produce 3.50 hogsheads would consume 2800 trees — an enormous strain on forest resources.

[7] The hogshead was a West Indies measure of weight equal to 889 kilograms or 7/8 of a ton. It originated as a volumetric measure of the quantity of sugar that could be held in the wooden casks and subsequently varied from 1000 to 1500 pounds (Follett 1997, 397).

The high fuel demand associated with the sugar industry undoubtedly contributed to the exhaustion of the Mediterranean sugar industry by the fifteenth century (as well as the deforestation that transformed that semi-arid environment into the treeless region it is today). Depletion of forest reserves was a limiting factor in continued sugar production in the islands of the East Atlantic (Deerr 1949). The voracious use of wood in the Caribbean spurred the import of foodstuffs and building materials as lands were cleared for the production of sugar at the expense of all other activity.[8]

The separation of sugar manufacture and sugar refining was inevitable in the sugar islands as wood for the furnaces became scarce. Sugar manufacture necessarily occurred near the fields, but raw sugar could be moved a great distance without significant deterioration. The Dutch were first to capture the refining opportunity and by 1580 Dutch refineries in Antwerp processed raw sugar brought from Madeira and the Canaries. By 1640 the Dutch (then in Amsterdam) refined most of the raw sugar brought to Europe from both the English and French colonies (Braudel 1982 [1979]). The English Navigation Acts and the French Exchange later curbed the Dutch refining monopoly but did not destroy the Dutch refining industry. By 1780, only a decade before the dramatic decline of the sugar industry of the Americas, the Dutch operated 170 refineries in Amsterdam ((Braudel 1982 [1979]).

Colbert himself invested in French refineries to encourage French control of their sugar industry. By 1683 France was refining raw sugar from its sugar islands. Refineries sprang up in

[8] The clearing of the land, however, apart from the problematic loss of fuelwood, was otherwise viewed as a benefit though hunting success was diminished by the destruction of wild-life habitat. Antipathy towards naturally vegetated areas was expressed early by the French. Of an abbey in France built in the lowlands of a large parcel granted to the church, Braudel gives us this comment. " . . . a terrible wilderness in the forest of Saint-Gobain, a foetid marsh, a sterile and uncultivated land, the haunt of fever and wild beasts" (Braudel 1988 [1986], 141).

coastal cities from Dunkirk to Marseilles. The most efficient were in Rouen where eight refineries could process 2,250 tons of raw sugar per year (Deerr 1949, 457).. By 1700 the export of refined sugar was the most important revenue source for France. In the 1763 Treaty of Paris, France forfeited all of Louisiana to retain her source of sugar. After the 1791 slave insurrection and collapse of her enormous industry in Saint Domingue, continental French sugar refining diminished dramatically, but French interest in sugar was continued as Napoleon vigorously promoted a beet industry (to the consternation of French farmers) (Figure 3.16) to offset loss of the West Indies supply. This launched the beet sugar industry which spread through Europe and subsequently stimulated the Louisiana cane sugar industry as beet processing technology was applied to sugarcane[9] (Heitman 1987). The beet sugar industry enlarged quickly under Napoleon's policies, was abruptly curtailed with the post-war arrivals of West Indies sugar, but again regained prominence by the 1830s (Heitman 1987, Galloway 1989).

Early sugar refining extended into Germany and was actively promoted through government intervention. In 1676 Leopold I of Hungary embargoed Dutch sugar in an argument still used by advocates a domestic sugar industry today: "this [import of refined sugar] injures the home trade and affords much money to hostile foreigners" (quoted in Deerr 1949, 455). By 1750 Hamburg's 350 refineries processed 49,000 tons of raw sugar from English and French colonies (Deerr 1949, 456). In an "early example of protected state-aided industrialism,"

[9] Heitman (1987) attributes the technique for the extraction of sugar from the sugarbeet to experiments of German chemists in 1747. Fairrie (1925), on the other hand, traces the invention of the process to a French refugee living in Prussia in 1797. In the process, sugar beets are cut into thin slices (cossets) which are immersed in water. The sugar then moves by osmosis into the water. Specific osmotic membranes limit the passage of impurities and the resultant solution is readily crystallized into refined-quality sugar.

Figure 3.16. France's Ambivalence towards Napoleon's Beet Sugar Project. The lack of enthusiasm with which French farmers received the Napoleonic mandate to grow sugar beets is illustrated in this early nineteenth-century cartoon:"Suck, baby, suck. Your father says it's sugar." Source: Jeffrey Fairrie, *Sugar* (Liverpool, 1925), Plate 15, opposite page 24.

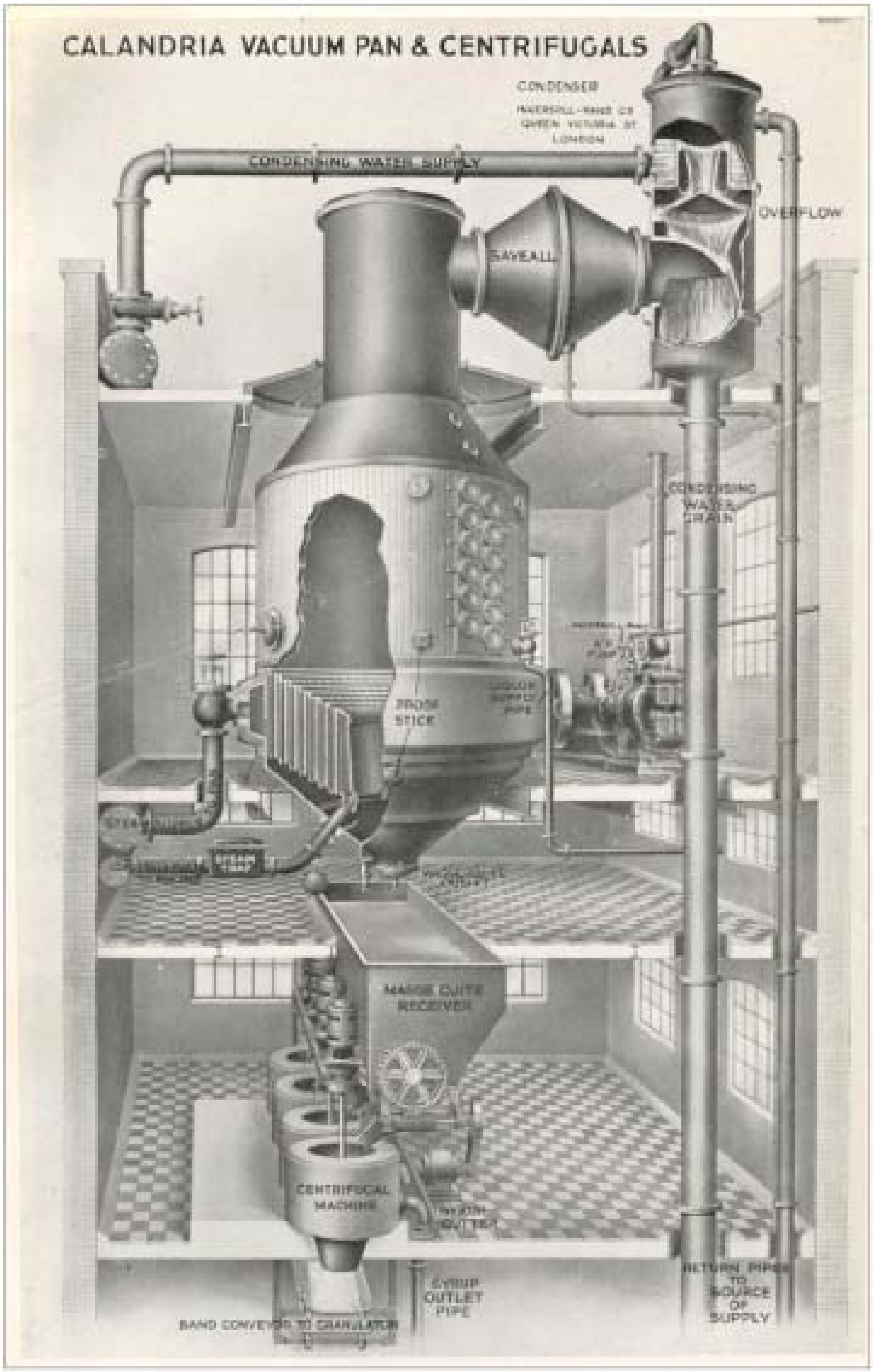
Frederick the Great both controlled and subsidized all sugar refining in Germany (Deerr 1949, 455). German innovation in sugar refining led the industry until well into the twentieth century (Heitman 1987).

England also had early interest in sugar refining. By 1544 it had domestic refineries in London and Liverpool. The numbers increased dramatically as the Navigation Acts halted the import of Dutch refined sugar. A 1753 inventory lists 120 refineries in England: 80 in London, 20 in Bristol, and others in Chester, Liverpool, Lancaster, Whitehaven, Newcastle, Hull, and Southampton, and several in Scotland (Deerr 1949, 458). London refining techniques were improved by German "sugar Bakers" whose skill in purifying the loaves was concealed from the

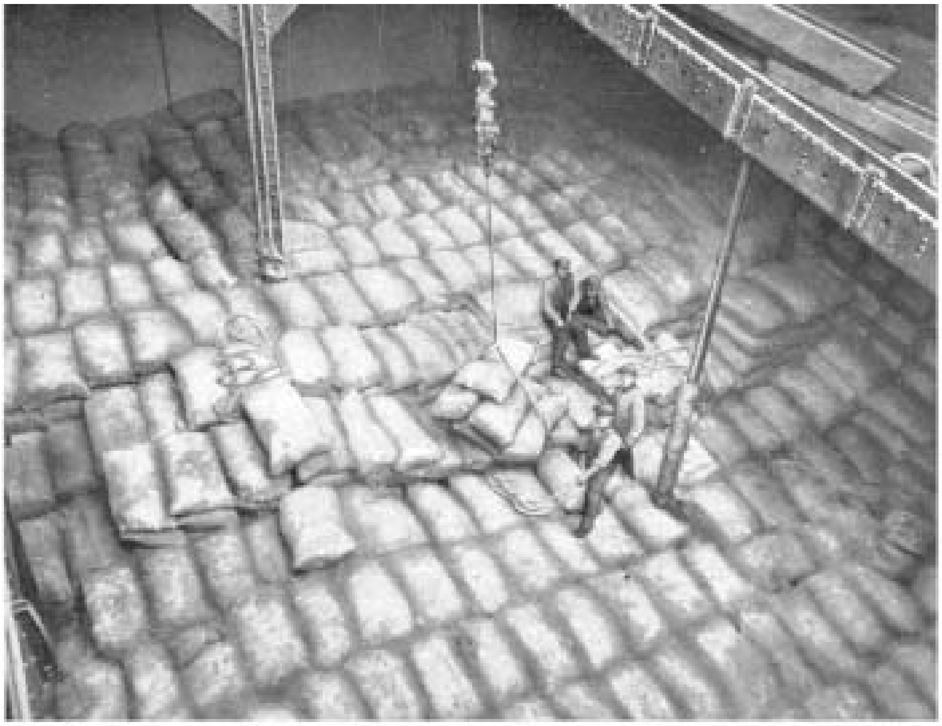
British refiner owners. As late as 1925, the charcoal filter room of the British refinery was still referred to as the “secret room” (Fairrie 1925, 150). In an early manifestation of the tensions that persist today between sugar production and sugar refining interests, sugar refining was prohibited in the English colonies early in the nineteenth century (Braudel 1992 [1979]). English planters complained bitterly of their disadvantage through transportation losses due to molasses leakage. A keg of raw sugar frequently arrived in England ten pounds short of its disembarkation weight, the molasses having seeped through the cracks of the casks. The ensuing struggle between planters and refiners lasted until 1845 when the tariffs on refined sugar were eliminated (Deerr 1949, 467).

The French, meanwhile, permitted colonial planters to continue local refining. French “clayed” sugars from the West Indies remained popular in France and innovation in refining techniques continued among the West Indies French planters until the collapse of the French industry. This tradition of combined production and refining was transferred with French planters to Louisiana when they relocated following the Saint Domingue revolution of 1791 and accounts for the “plantation sugar” (refined-quality sugar) produced by early Louisiana planters (Deerr 1949).

Refining facilities decreased in number as they increased in size and efficiency. By 1882 British refineries numbered only 34. These received sugar by steamer from English colonies both in the Caribbean and India. As foundries improved the size and precision of machinery, the modern refinery took form (Figure 3.17). Figure 3.18 illustrates the intensive labor involved in transfer of raw sugar prior to the bulk handling and transport of today (Figure 3.19). By 1948 only three refineries remained in England and today, British refining occurs in a single facility controlled by Tate and Lyle, Ltd., an amalgam formed in 1921 from the merger of Abraham Lyle and



3.17. Early Twentieth-Century Refining Machinery. The large circular structure is the Calandria vacuum pan for boiling the syrup. The massecuite (sugar and syrup mixture) receiver and centrifual machines are below. From Geoffrey Fairrie, *Sugar* (Liverpool, 1925), Plate 44, opposite p. 96.



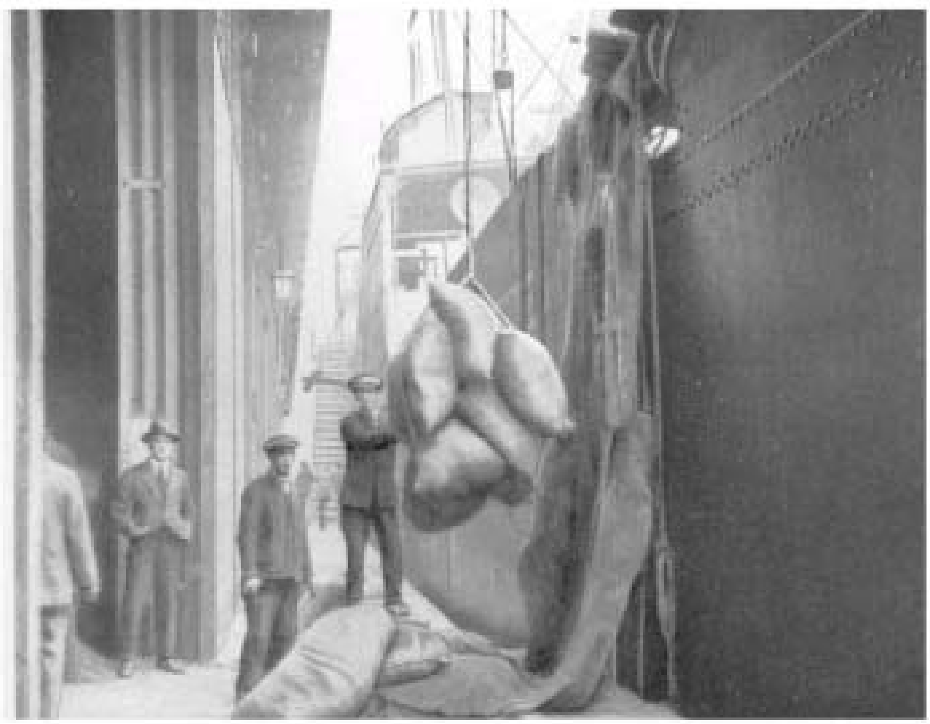


Figure 3.18. Sacks of Raw Sugar Inside a Steamer and at a Liverpool Dock, 1906. By the twentieth-century the cloth sack had replaced the wooden cask for the transport of raw sugar, but the loading and unloading remained labor intensive. Today raw sugar is transported in bulk in specially designed ships. From Geoffrey Fairrie, *Sugar (Liverpool, 1925), Plate 28, opposite p. 58.*

Figure 3.19. Bulk Raw Sugar Storage. This scene is within the St James Sugar Cooperative warehouse in St. James, Louisiana. Photo by John Wozniak, Louisiana State University Cooperative Extension. Used by permission.

Sons and Henry Tate and Sons.[10] This refinery in Silverton (outside London) processes over one million tons of raw sugar a year (Chalmin 1990).

Sugar refining in the United States emerged in parallel with European refining. At the time the Louisiana industry emerged, North American colonial refineries numbered 17 (Figure 3.20). These refineries received raw sugar from the British sugar colonies and produced both

[10] Tate and Lyle sugar interests are world-wide. It controls not only a large percent of the world's sugar refining, but sugar packaging, distribution, and the manufacture of numerous sugar-containing products. Tate and Lyle describes itself as "World Leaders in Carbohydrate Ingredients." Their products are sold under seven separate brands and include cereal sweeteners, food starches, industrial starches, ethanol, sugars, Sucralose (a sugar substitute), proteins, molasses, animal feed, and bulk storage (Tate and Lyle 2003).

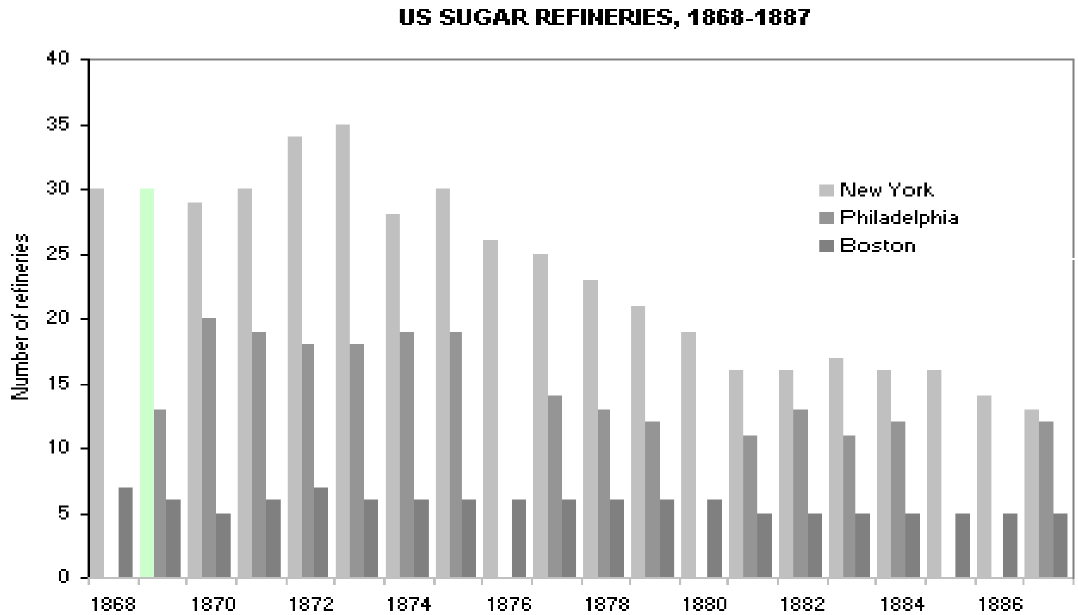


Figure 3.20. U.S. Sugar Refineries, 1868-1887. Source: Alfred Eichner, *The Emergence of Oligopoly* (Baltimore, 1969), 339-342.

refined sugar and rum. After U.S. independence and imposition of the first tariff on sugar in 1789, these New England refiners struggled for access to raw sugar. Duties and quotas continue to limit the entrance of foreign raw sugar into the U.S. Today, the U.S. has eleven cane sugar refineries. As with their English predecessors, American sugar producers and refiners remain at odds. As will be seen in chapter five, domestic producers depend on tariffs to deter the entrance of raw sugar while refiners benefit from foreign raw imports.

Today the production of sugar from sugarcane is an industrial activity conducted separately from farm operations. Once harvested, the sugarcane crop today moves through a complex web of production processes to reach its final products (Figure 3.21). Cane juice, once extracted at the mill, enters a complex production stream that yields refined sugar for human consumption and molasses products for both human consumption and industrial applications.

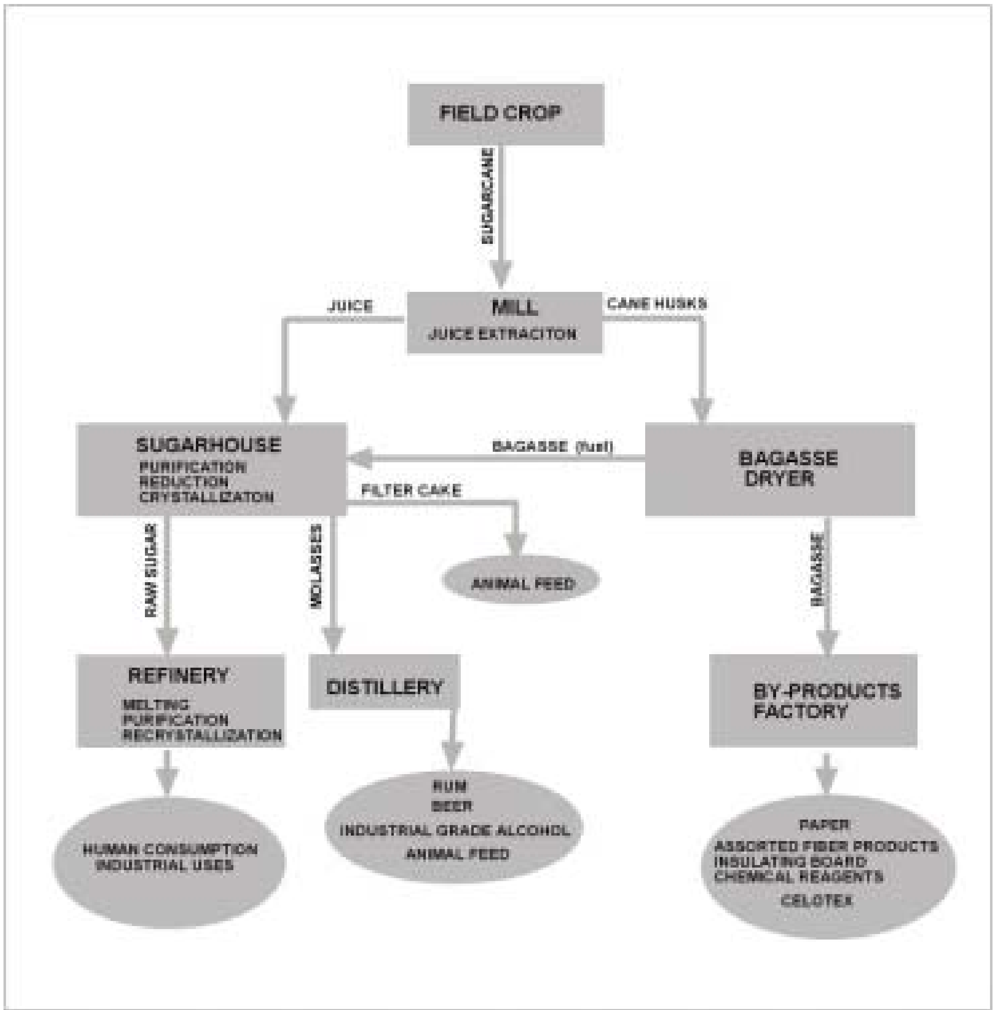


Figure 3.21. Sugarcane Processing and Products.

Cane husks, previously used only for fuel at the mill site, now have a multitude of industrial applications, one of the more important is the manufacture of chemical reagents.