CHAPTER 17

Realistic Industrial Complexes

In some cases, I have gathered more industrial production and waste data than others. These I am classifying as "Realistic Industrial Complexes" and presenting for illustration purposes in this chapter. In Chapter 18, I propose other possible industrial complexes about which little operating data have been amassed. These environmentally balanced industrial complexes (EBICs) are classified as "potential industrial complexes."

In this chapter, six EBICs are depicted as realistic. Some of these I have reported in earlier publications, some have been fortified with additional data, and one has been developed recently.

1. Phosphate fertilizer–ammonium sulfate–cement complex
2. Tannery–slaughterhouse–rendering complex
3. Sugarcane–power–alcohol complex
4. Textile mill complex
5. Pulp and paper mill complex
6. Sugarcane–briquette–fertilizer complex

Fertilizer–Cement Complex

Fertilizer Plant Wastes and Production

It has been reported and generally accepted that phosphate mining in central Florida accounts for about 75% of the U.S. needs and one-third of the world's supply. This alone makes it a vital industry not only to Florida, but also to the United States and the world.

After the rock is extracted, slurried, and separated from the clay and sand by screening and flotation, it is used to produce wet process phosphoric acid. The rock is digested by sulfuric acid to produce a slurry of contaminated gypsum ($CaSO_4.2H_2O$) and phosphoric acid. The gypsum is pumped to holding ponds, where it represents a major disposal problem for the fertilizer industry. Because 4.5–5.0 tons of gypsum are formed during the production of each ton of phosphoric acid, the industry has a formidable volume of phosphogypsum (PG) waste with which to cope.

Any recovery and reuse system for PG will free up reclaimable land for productive purposes by the industry or by other private or public landowners. Further benefits can be derived from the elimination of adverse environmental consequences of leachates from the gypsum heaps. Leachates carry phosphate and other mineral nutrients that could contaminate drinking water supplies and cause algal blooms (red tide) in recreational waters. Direct reuse of PG presents the potential problem of incorporating radioactivity into building or road products. Sulfates also cause cement-contamination problems.

It is quite likely that the direct reuse of this PG within a closed industrial complex in making cement could eliminate all of the aforementioned problems. In addition, it anticipates a lowered production cost for both the fertilizer and the cement plants for reasons already mentioned in Chapter 16.

One other area of waste recovery that should be mentioned is “heat” energy. A phosphate complex generates and must dissipate large amounts of energy as waste heat. The recovery and utilization of much of this energy is a very real success story. Efforts are continuing to recover even more of the “waste” energy from the more difficult to recover sources, and there is no doubt that an even greater percentage of the available “waste heat” will be put to profitable use.

As early as 1968, it was reported that many firms in the United States had innovated processes for manufacturing useful products such as H_2SO_4 and cement from waste gypsum (*Chemical Week* 1968). Nothing would be gained by reporting here the numerous papers that have been published describing the potential or actual use of gypsum in cement making. However, I will report on a few representative ones. The British Sulfur Corporation, Ltd., described the MASAN product transformed from PG by the Brussels-based company Ultra International SA as a useful cement or plaster (*Chemical Week* 1968). It was reported to possess a compressive strength three to four times that of Portland cement (1,100 kg/cm^2 as compared to 300–400 for Portland cement). Moreover, the cost of cement from PG was $10/ton as compared to $30–40/ton for Portland cement at that time.

Ellwood (1969) describes a chemical process for converting PG into hemihydrate powder as a cement strong enough to compete with cement in applications such as sound-proofing dividing walls. Carmichael (1986) reported two Belgium plants that were using the Central-Prayon process for converting PG into the hemihydrate form of $CaSO_4$. The gypsum is then suitable for direct reuse in the plaster industry or as a cement retarder back in the cement plant.

Bhanumathidas and Kalida (1986) reported the conversion of anhydrite I grade of PG to calcine at 950°C to obtain a product similar to Portland cement. They claim that the product “has shown remarkable cementitious behaviors in parallel to those of white Portland cement.”

Clur (1986) claims that the Fedmis (South Africa) fertilizer plant disposes about 25% of its PG production as soil conditioner, cement clinker, and cement retarder. “The quality of the cement compares favorably with that of local limestone-based cements, and is used in all classes of building construction and civil engineering." Clur (1986) also reports that "the technical problems of producing a good quality cement from phosphogypsum have largely been solved, the future of the process would seem to depend mainly on economic and environmental factors."

Cement Plant Raw Materials and Wastes

Portland cement is made by mixing and calcining calcereous and argillacerous materials in the proper ratio. Table 17.1 summarizes the raw materials consumed in 1972 (Shreve and Brink 1977).

One can observe in Table 17.1 that limestone represents the majority mass of cement raw materials. Replacement of some or all of this calcareous material with phosphogypsum would reduce the production cost of the cement as a result in savings of raw material.

Unit processes involved in cement manufacturing essentially include storage and mixing of raw materials, drying, grinding and crushing, calcining, clinker storage, finishing additives and ball milling, and packing for delivery. Although dry processing is practiced more than wet processing, both are shown in Figure 17.1A and B to provide a visual aid for cement production.

For each 376 barrels of finished cement by the dry process, 1,120,000 BTUs of fuel is required as well as 24.1 kWh of electricity, 30 gallons of water, and 0.17 hours of direct labor. Also required are 498 pounds of limestone, 124 pounds of shale, and 16 pounds of gypsum (Shreve and Brink 1977). I also mention here that as far back as 1945 I developed a wallboard for Johns Manville Corporation. This board was made of asbestos fibers and gypsum formed under high temperature and pressure.

TABLE 17.1
Raw Materials Consumed for Portland Cement in United States 3 (thousands of short tons)

Cement rock	23,799
Limestone	90,003
Marl	2,080
Clay and shale	12,158
Blast furnace slag	759
Gypsum	4,094
Sand and Sandstone	2,774
Iron Materials	839
Miscellaneous	414

Source: Shreve and Brinke (1977).

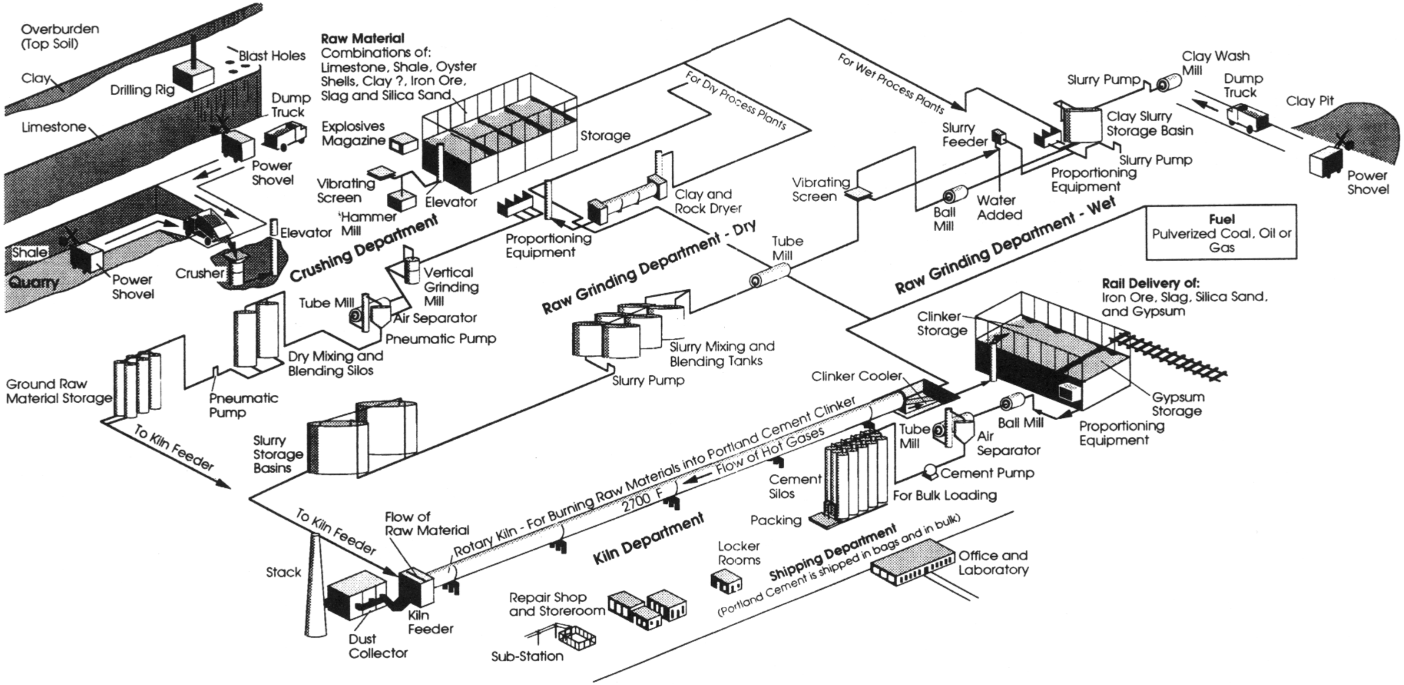
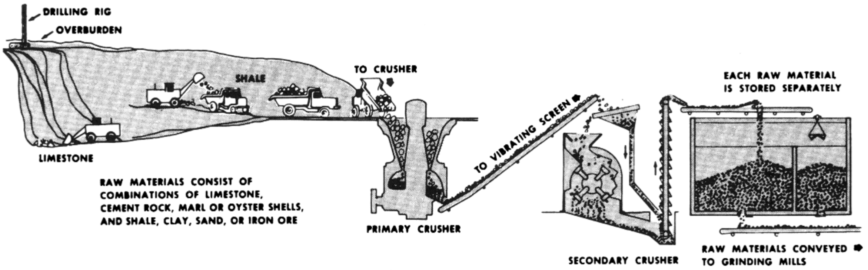
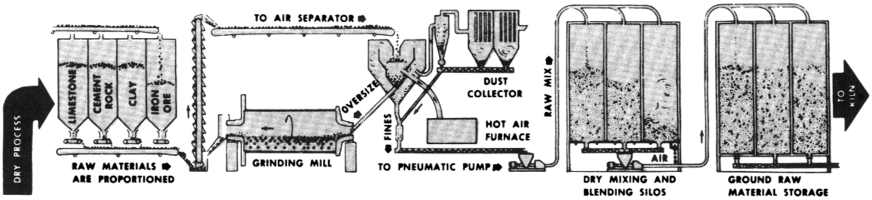


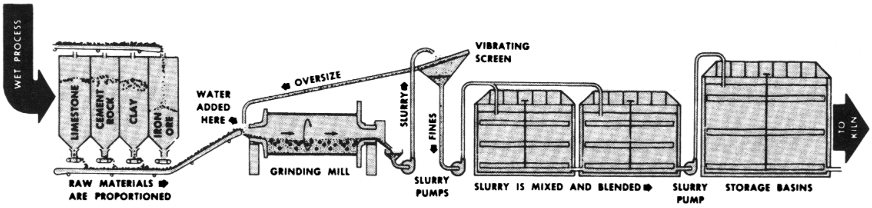
FIGURE 17.1A. Dry and wet processing. Used with permission from John Wiley and Sons.



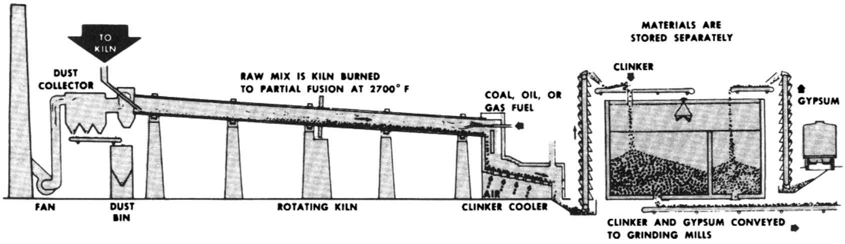
1. **Stone is first reduced to 5-in. size, then to ¾ in., and stored.**



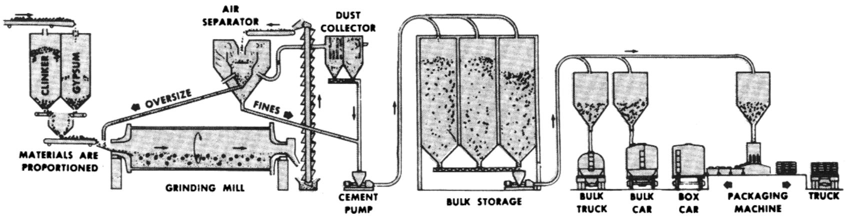
OR **2. Raw materials are ground to powder and blended.**



2. Raw materials are ground, mixed with water to form slurry, and blended.



3. Burning changes raw mix chemically into cement clinker.



4. Clinker with gypsum is ground into portland cement and shipped.

FIGURE 17.1B. Dry and wet processing. Used with permission from John Wiley and Sons.

Statement of Problems and Objectives

The problems are twofold: (1) to lower production costs and (2) to eliminate adverse environmental impacts of industrial plants. These problems are especially severe or extensive when a particular industry is highly competitive, such as fertilizer and cement plants, and when these same plants produce significant wastes that pollute the environment (air, water, and land).

The overall objective was to determine the feasibility of location, building, and operating a two-industry complex, consisting of a phosphate fertilizer and a cement plant, within an EBIC at one site. The ultimate goal of this complex is to lower production costs at both plants while eliminating all adverse environmental impacts.

Further study (such as is presented on an economic basis in Chapter 16, Section two) should analyze and evaluate in depth the practicality of the complex that I presented earlier. Once again this complex as proposed is presented for your review in Figure 17.2A.

More precisely, it is necessary to determine: (1) the optimum size for each manufacturing plant included within the complex; (2) the suitability of the three products (wastes) for recovery and reuse as raw materials for ancillary adjacent plants within the complex (compatibility of plants); (3) the validity of total waste elimination from the two plants involved within the complex; and (4) the cost of production of the prime goods when manufactured at distinctly separated plants and compared to the same when manufactured within the complex (once again, as described in Chapter 16B). For convenience and further examination, this complex is shown in Figure 17.2B.

Next, the main effort concentrated on the extent of the economic gain by using the complex principle. This study included the economic cost of

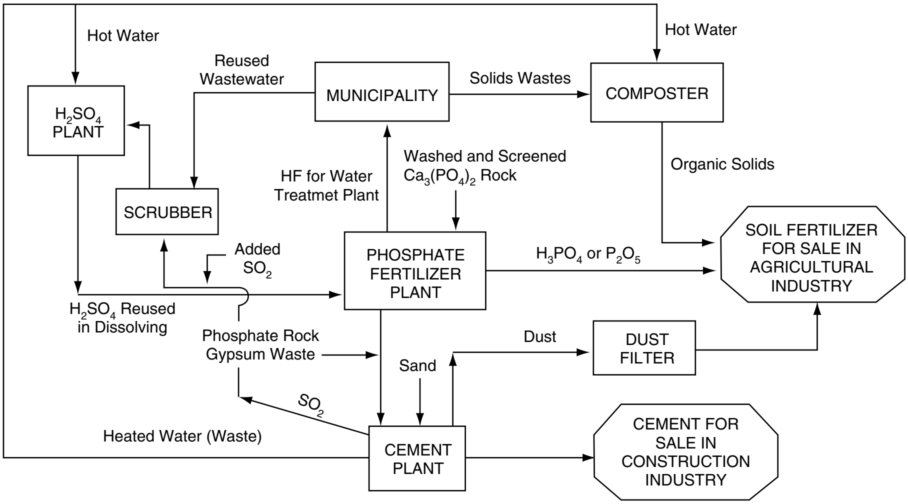


FIGURE 17.2A. Cement–fertilizer–municipal complex.

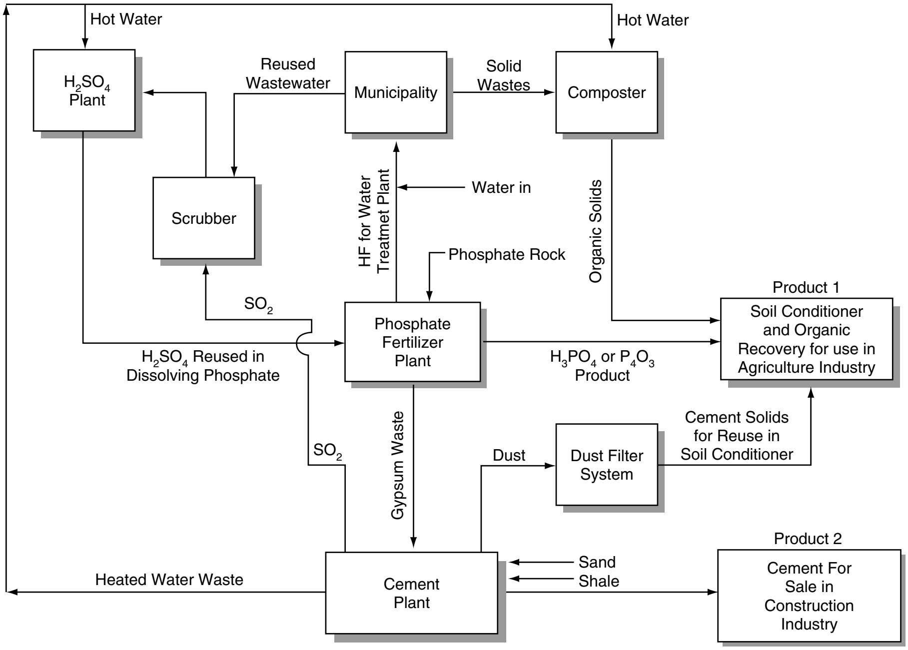


FIGURE 17.2B. Environmentally balanced fertilizer-cement plant complex phase.

environmental damage caused by wastes of all plants involved as part of the production costs.

This concept is not only “a gypsum for cement” idea, but also a totally new balanced industrial complex plan. The question is not whether this innovation is economical, but how much reduction in cost can be obtained by this complex principle when environmental costs are also included and all complex plant wastes are reused including excess heat.

Environmental costs include direct costs of wastewater treatment, indirect costs of environmental damages (to adjacent property owners), and intangible costs of environmental damages to “distant third parties,” that is the public at large. These considerations are valid for both fertilizer and cement plants. The direct costs of fertilizer waste treatment (Fwt) included those for preventing PG piles from reaching groundwater or surface water, storage and preventing escape of mine tailings, air abatement from the production of fertilizer from sulfuric acid reactors, and other forms of waste treatment.

The *indirect costs of fertilizer waste environmental damages* (Fnd) include those for fish kills from pile or pond seepage, groundwater contamination from these seepages, and decontamination of company-owned and adjacent (third-party) property, as well as costs associated with the public relations aspects of these events (commonly referred to as "damage control"). It is much easier to maintain a "good corporate citizen image" than to win back that image after an environmental incident.

The *intangible costs of fertilizer environmental damages* (Frd) include costs such as those for loss in land value due to pollution and decrease in desirability of the property due to public reluctance to locate adjacent to contaminated facilities. Times Beach in Missouri, Love Canal in New York State, and the Stringfellow Acid Pits in southern California are examples to be studied and learned from.

One study (described in Chapter 16) (Krishnam et al. 1996) revealed the following values:

Fwt value of \$15.24/ton of fertilizer
Fnd value of \$1.74/ton of fertilizer
Frd value of \$84.36/ton of fertilizer

When added to the conventional production cost of \$204.02/ton, the real production cost became \$305.36/ton, or about 50% greater than the conventional cost.

Similar analysis of the cement industry led to the following:

Cwt value of \$14.28/ton of cement
Cnd value of \$2.90/ton of cement
Crd value of \$0.03/ton of cement

When added to the conventional product cost of \$50/ton, the production cost becomes \$67.21/ton, or about a 34% increase.

When combining these two plants in the complex described earlier, these environmental costs can be significantly reduced or avoided altogether. The result would be an overall savings resulting from facility complexing of \$154.62/ton of product or 42%. In addition, the costs of mining, transporting (of raw materials), associated transportation spill damage, material handling, and storage are reduced or eliminated using the complexing principle.

Prevention rather than pollution appears more often than not to be the most profitable alternative. In some instances, when the PG is unsuitable for direct reuse in making cement because of its sulfur content, intermediate treatment with ammonia and CO_2 may be necessary. This results in another fertilizer product, $(NH_4)_2SO_4$. Phosphochalk is also produced, which can be used directly in making cement. Such a potential EBIC is presented in Figure 17.3 for a typical 600-ton/day phosphoric acid fertilizer plant.

Two-Tannery Complex

Tannery wastes from upper sole chrome tanning mills contribute to a significant pollution problem in the United States. The wastes are hot, highly alkaline, odorous, highly colored, and contain elevated quantities of dissolved organic matter, biochemical oxygen demand (BOD), total suspended solids, lime, sulfides, and chromium. The

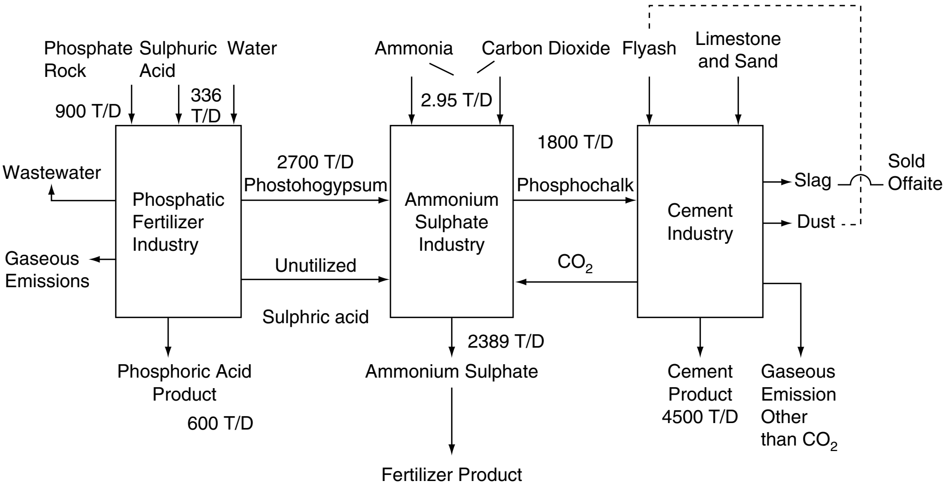


FIGURE 17.3. Schematic diagram of environmentally balanced phosphate–fertilizer–cement industrial complex.

treatment of such wastes has been difficult because of the conflicting pollutional parameters of pH, organic matter, and potential toxic compounds. Most successful treatment plants use some form of biological treatment to reduce the oxygen demand on receiving waters. This necessitates the use of well-designed and operated preliminary treatments to ensure safe and efficient biodegradation. High sludge quantities result from these treatments. Therefore, properly designed and operated tannery waste-treatment systems may be costly to build and operate, whereas the lack of these facilities will cause excessive stream pollution. Placing the tannery in an environmentally optimized industrial complex eliminates both of these negatives. One such complex involves three separate industries and is described next.

The Slaughterhouse–Tannery–Rendering Complex

I have presented two formal papers at technical meetings on this subject (Nemerow 1980a; Nemerow and Dasgupta 1981) and a report (Nemerow 1980b). These represented a first attempt at providing a complete mass balance of reference-validated inputs and outputs of plants within an industrial complex.

The fulcrum industrial plant of this complex is a tannery. Supporting industries include slaughterhouse and rendering plants. The three-industry complex is also expanded to consist of an animal grazing and feedlot facility, as well as a residential area for homes of all personnel working in the complex. As the complex is expanded to include the feedlot and residences and biogas and power plant services, the complex becomes more self-sustaining. Outside service requirements are minimized by the expansion. All power is generated within the complex—in the expanded third-stage version. Excess products of leather, meat, meal, soap, and even electricity are sold to consumers outside the complex. Chemicals, water, cattle, and animal feed are imported to the complex. Wastewater, blood and bone meal, hide and leather trimmings, cattle dung, and residential solid wastes are recovered and reused within (internally) the expanded complex. The complex can be constructed as shown in the first stage, second stage, or fully expanded to the third stage (Figure 17.4). Criteria for decision making will be based on area requirements and individual local objectives.

Stage 1

This is the first of the three-stage industrial complex, which is balanced internally so that little or no adverse environmental impact results from any of the industrial plants' production activities. Each subsequent stage represents a totally balanced and individual industrial complex. This first stage consists of a three-industry plant complex: (1) a slaughterhouse, (2) a tannery, and (3) a rendering plant (Nemerow 1980b).

Stage 2

The second of the three-stage industrial complex is also balanced internally so that little or no adverse environmental impact results from any of the industrial plants' production activities. It differs from the first stage in that it provides a more complete and self-sufficient complex. It also provides more reuse potential for the three industrial effluents than the first stage. In addition, it provides living space in the complex for employees of the industrial plants and feedlot and grazing area for raising the animals to the required weight. Whenever feasible, the second-stage complex is recommended in preference to the first stage only (Nemerow 1980b).

Stage 3

The third stage of the three-stage industrial complex enlarges the smaller complex and is more balanced internally so that little or no adverse environmental impact results from any of the industrial plants' productive activities. Agriculture and municipal residence services are provided in this phase of the complex. Residential solid wastes from both industrial and municipal facilities are fermented to methane gas, which is used subsequently to produce electrical energy for use in the complex. Waste sludge from the fermenter is incinerated to produce additional electrical energy for use in the complex. The schematic arrangement of the third phase of the complex is shown along with the mass balances of each unit in Figure 17.4. External raw materials and manufactured products for external sale are given in Table 17.2.

General Discussion

As we proceed with the three-industry complex by adding stages, some potential problems arise. For example, when we add stage 2 to the complex, we compute that a cattle grazing and feedlot area of 620 acres is required for the 135,000 cattle. This vast acreage may be difficult to obtain. In addition, 1,350/tons/day of feed must be supplied from internal and external sources.

In the third stage of the complex, we are proposing to produce methane gas from solid waste residues. This gas will subsequently be used for power production.

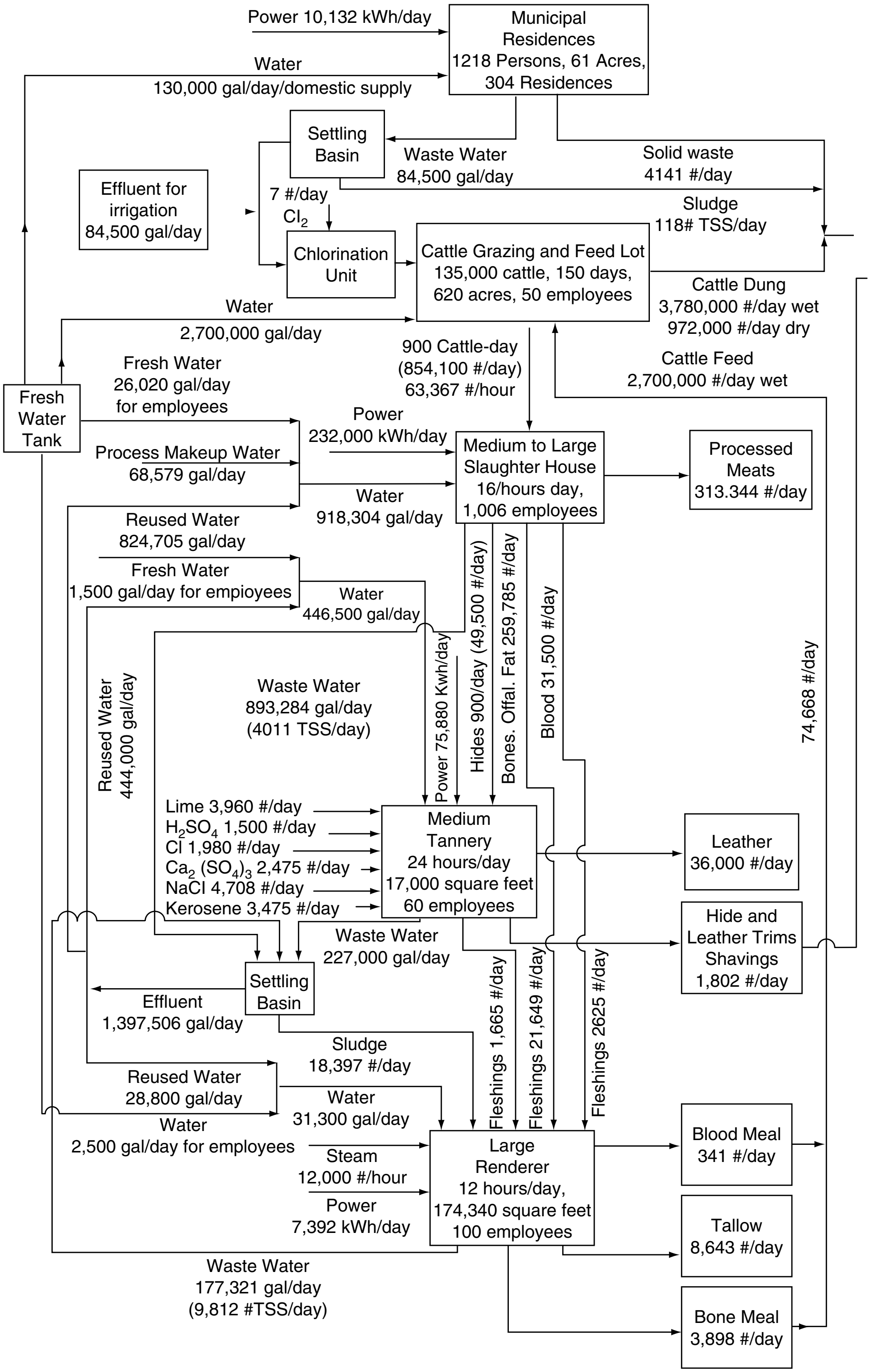


FIGURE 17.4A. Three-industry complex: tannery–slaughterhouse–rendering.

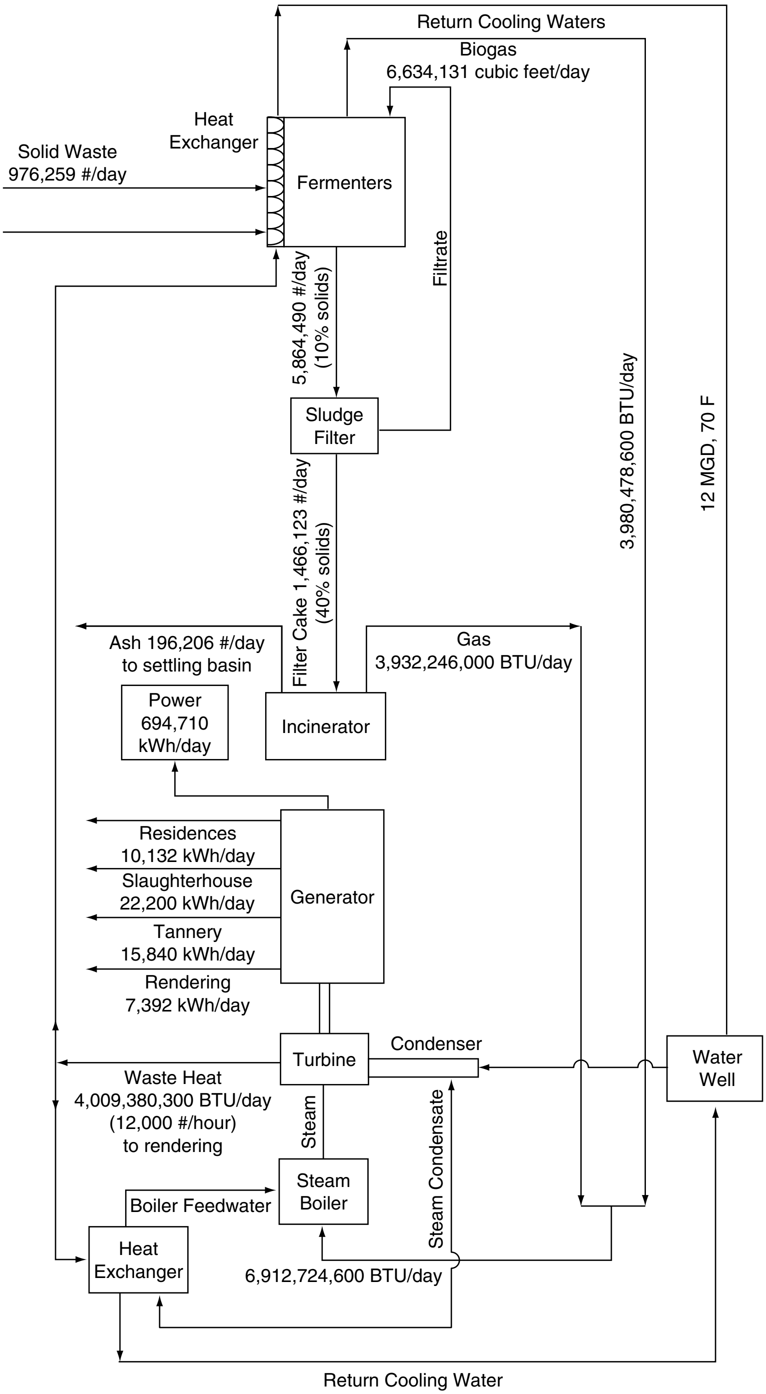


FIGURE 17.4B. Three-industry complex: slaughterhouse–tannery–rendering.

TABLE 17.2
External Raw Materials and Manufactured Products in Three-Industry Complex (Stage 3)

Raw Material Required from Outside the Complex		***Manufactured Products for Outside Sale***	
Material	*Amount*	*Material*	*Amount*
1. Fresh Makeup water	2,927,599 gal/d	1. Meat products	513.341 #/d
1A. Well water (one time only)	12 mgd	2. Tanned leather	36,000 sq.ft/d
2. Calves	900/d (150 days)	3. Tallow	79,740 #/d
	540,00 #/d	4. Energy	694,710 kwh/d
3. Chemicals	495 #/d Na_2S 3960 #/d $Ca(OH)_2$ 1500 #/d H_2SO_4 2475 gal/d kerosene 1980 #/d oil or wax 2475 #/d $Cr_2(SO_4)_3$ 4208 #/d NaCl 7 #/d Cl_2		
4. Cattlefeed	2,625,000 #/d		

Source: Nemerow and Dasgupta (1981), p. 209.

An excess of power within the complex results from this sequence of operations. An alternative to exporting power for sale outside the complex would be the production of other valuable intermediate products such as alcohol from the ferments. This can be determined from market conditions at the time of establishment of the complex.

This three-stage complex analysis is the deepest study of the new concept. As shown in Table 17.2, the managers of the three-stage complex still must import four basic materials: water, calves, chemicals, and cattle feed. About 3 million gallons of water, 2.6 million pounds of feed, 900 cattle, and about 6 tons of chemicals are needed each and every production day. This complex also will produce for external sale about 250 tons of meat, 36,000 ft^2 of leather, 40 tons of tallow, and almost 700,000 kW of energy each production day. Although complete economic analysis of such a system has not been made, it appears at least self-sustaining and probably will show a considerable net profit. The implications of such complexes are obvious. However, if the complex is able to produce a profit and protect the environment from any degradation, its major goals will have been achieved.

Conclusion

A three-stage environmentally balanced complex has been designed. Mass balances of all plant inputs and outputs have been computed based on the most recent published industrial data. From an analytical standpoint, an industrial complex consisting of a slaughterhouse, tannery, and rendering plant is technically feasible. This complex is also technically feasible when expanded to include animal grazing and feedlots, as well as municipal residences (second stage). The expanded version (third stage) of the complex is more self-sustaining as far as reused products and electrical energy generation are concerned.

Sugarcane Complexes

The Cane Sugar Industry

The cane sugar manufacturing industry is essential to the production of many varieties of foods. In the United States, there are about 6,400 sugarcane plantations, 94 sugar mills, and 24 sugar refineries, mostly located in Florida, Louisiana, and Hawaii.

Because of recent dietary recommendations, alternative sweeteners have entered the market. Competition from the lower prices of other sweeteners has caused a reduction in refined sugar prices. This is true even though there has been a deficit in sugar produced in the United States. Florida, the largest sugar-producing state in the nation, grows about one-fifth of all sugar consumed in the United States. It is imperative to the Florida mills, as well as sugar refineries elsewhere, that production costs be kept to a minimum to keep the industry healthy.

Brief Outline of Sugar Manufacturing Process

In the manufacturing of sugar, the sugarcane stalks are chopped into small pieces by rotary knives, and the cane juice is extracted from these pieces by crushing them through one or more roller mills. The solid residual material from this operation, consisting of fibrous residue of the cane sugar stalks, is termed “bagasse” and is a solid waste of the cane sugar industry. After the juice is extracted from the stalks, it goes to the boiler room where lime is added to precipitate insoluble sugars. The precipitate, in the form of thick slurry, is vacuum-filtered to produce a filter cake often termed “cachaza” and constitutes the second type of solid waste from sugarcane manufacturing operations. Then, the clarified juice is thickened in evaporators, and the resulting syrup containing sugar and molasses is boiled in vacuum pans to form raw sugar crystals. The sugar crystals are separated from molasses by centrifugation, and the molasses is sometimes further evaporated to recover more sugar. The final products are coarse, crystalline brown raw sugar and molasses. The raw sugar is transported for further processing in sugar refineries to produce the various forms of white refined sugar. The bulk of the molasses is used for production of various types of fermentation products and a small portion is used for animal feed. A schematic diagram of a sugar mill operation is shown in Figure 17.5.

The Solid Waste Problem

The two forms of solid wastes generated in the manufacturing of cane sugar are bagasse and cachaza. Every 1,000 tons of processed sugarcane generates about 270 tons of bagasse and 34 tons of cachaza.

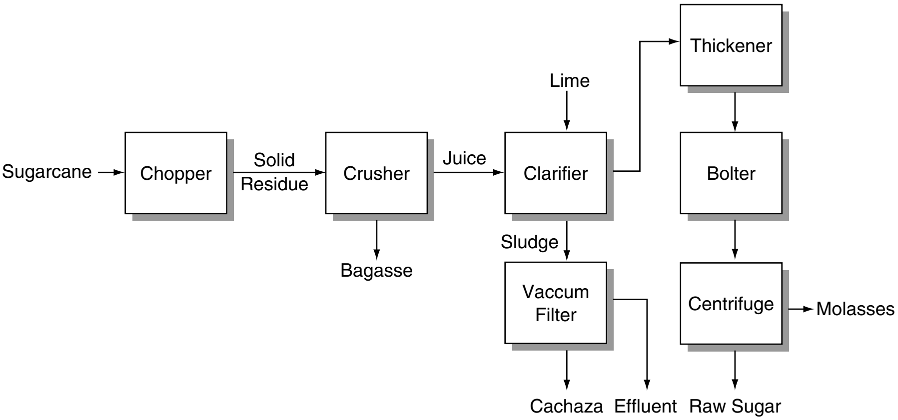


FIGURE 17.5. Raw sugar manufacturer-flow diagram.

The sugar industry is faced with the problem of proper and economical disposal of large quantities of bagasse and cachaza. The most common bagasse disposal method has involved burning as much as possible in boilers operated at sugar mills. Burning bagasse presents problems of its own. It is not a particularly clean fuel, and mills require installation and maintenance of stack scrubbers to clean the emissions. Moreover, utilization of bagasse as a boiler fuel is impaired by the high degree of moisture (45–60%). In addition, its bulkiness requires the construction of special furnaces to operate efficiently.

The other type of solid waste generated, namely cachaza, generally is slurried for disposal by lagooning or disposed as landfill, resulting in land and water pollution. Even if a large portion (usually 70%) of the bagasse generated is burned directly in boilers, a considerable amount of bagasse (30%) remains to be disposed of with the entire quantity of cachaza.

Considering the high cellulose content of bagasse and the organic matter in cachaza, these are potential renewable sources of biomass for biochemical conversion to methane by anaerobic fermentation. In addition, the residual digested sludge can have beneficial uses as fertilizer/soil conditioner.

Environmentally Balanced Industrial Complex Solution

Anaerobic digestion of a 2.4:1 mixture of bagasse to cachaza was demonstrated to be effective in producing methane gas and reducing organic solids (Nemerow and Dasgupta 1984). Despite this development, residual wastes remain to be considered.

An evaluation of the sugarcane refinery based on products and wastes after digestion suggested that a “closed-loop” complex would result in the discharge of little or no final residual wastes. Figure 17.6 presents a schematic diagram of a sugarcane refinery–based

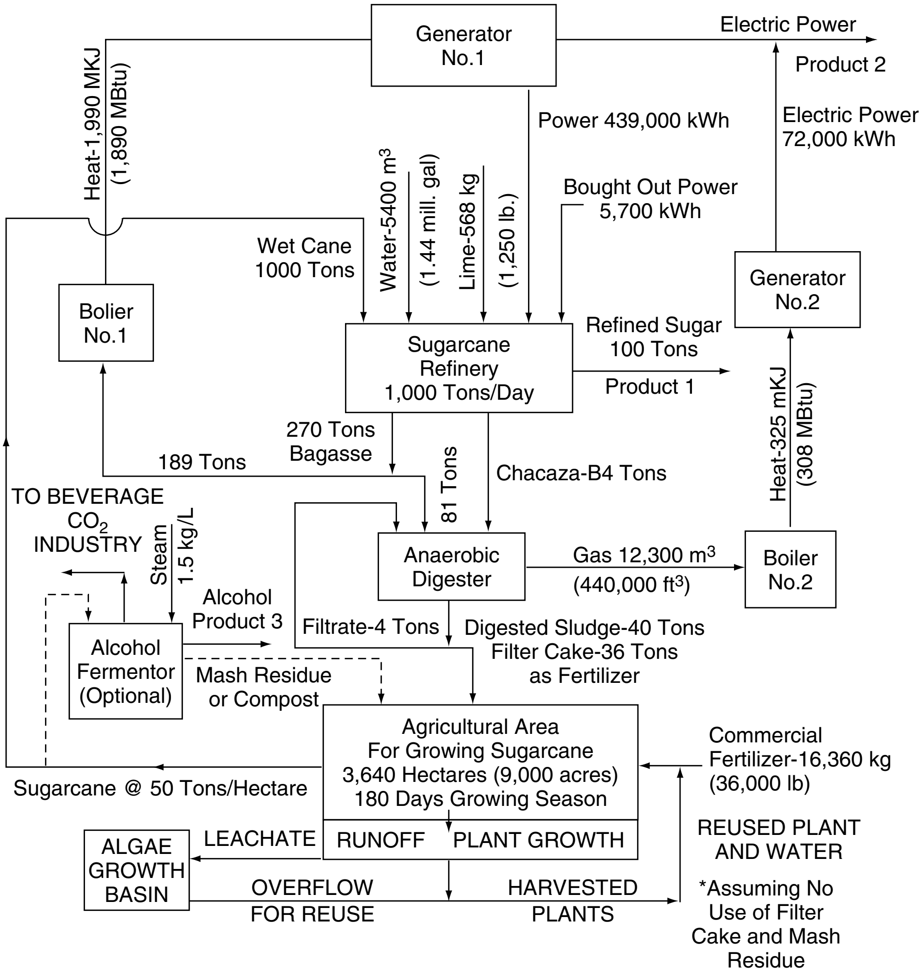


FIGURE 17.6. Sugarcane refinery-based EBIC (sugarcane-power-alcohol complex).

EBIC. For purposes of this evaluation, the mass balances are estimated based on the refining of 1,000 tons of sugarcane, resulting in a generation of about 270 tons of bagasse and 34 tons of cachaza (Nemerow and Dasgupta 1984). In many mills, these wastes are discharged to the environment with a variety of adverse impacts.

Sugarcane–Briquette–Fertilizer Complex

Introduction

Sugarcane is cultivated in tropical and subtropical areas as it requires at least 60 in. of irrigation or rainfall per year. The major producing countries of sugarcane are Brazil, India, and China, as shown in Table 17.3. Their combined total production exceeds half of global production. The composition of sugar cane is shown in Table 17.4.

Sugar Production Process

The sugar production process is very energy intensive, it requires steam and electricity at many stages. Initially, the sugarcane stalks are chopped into smaller pieces by means of a chopper, as shown in Figure 17.7. The chopped stalks then pass through a crusher, which has one or more roller mills for the extraction of the juice. The resulting fibrous residue is called *bagasse,* a solid waste. The juice then passes through a clarifier where lime is added to precipitate the insoluble sugars. The precipitate, a thick slurry, is vacuum filtered to produce filter mud cake (cachaza), another solid waste of the sugarcane industry. The clarified juice is thickened and then heated in a boiler to form raw

TABLE 17.3
World Production

	Area Harvested (ha)	*Yield (tons/ha)*	*Production (tons)*
Brazil	5,303,560	73.83	386,232,000
India	4,300,000	67.44	290,000,000
China	1,328,000	70.71	93,900,000
Thailand	970,000	76.36	74,071,952
Pakistan	1,086,000	47.93	52,055,800
Mexico	639,061	70.61	45,126,500
Colombia	435,000	84.14	36,600,000
Australia	423,000	85.13	36,012,000
Cuba	1,041,200	33.33	34,700,000
USA	403,390	77.29	31,178,130
Philippines	385,000	67.10	25,835,000
Other	4,091,132		244,581,738
Total	**20,405,343**		**1,350,293,120**

TABLE 17.4
Sugarcane Composition

Water	69–75%
Sucrose	8–16%
Reducing sugars (dextrose and levulose)	0.5–2%
Organic matter other than sugar	0.5–1%
Inorganic compounds (phosphates, chlorides, nitrates, silicates, sodium, potassium, etc.)	0.2–0.6%
Nitrogenous bodies (albuminoids, amides, amino acids, ammonia, etc.)	0.5–1%
Ash	0.3–0.8%

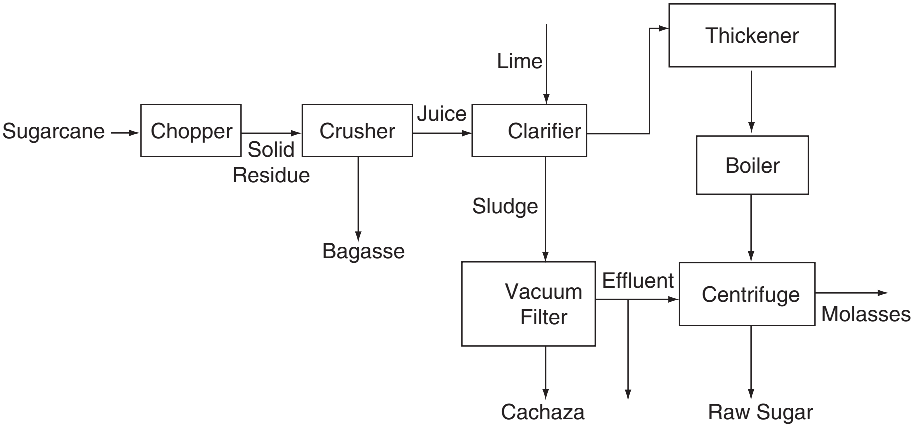


FIGURE 17.7. Sugarcane production.

sugar crystals. These crystals are a mixture of sugar and molasses. The sugar is separated from the molasses by centrifugation. The raw sugar is transported to sugar refineries and the molasses is used in the production of animal feed.

Solid Wastes of Sugarcane Industry

As seen in the cane sugar manufacturing process, there are three byproducts, namely, bagasse, filter mud cake, and molasses. Molasses is widely reused for animal feed in ethanol production or in other molasses-based products and, thus, is not considered an environmental waste. Bagasse and cachaza have limited applications and their disposal causes environmental problems; therefore, they are the main solid wastes in the cane sugar industry.

Every 1,000 tons of processed sugarcane generates 270 tons of bagasse and 34 tons of cachaza (Nemerow 1995). Proper and economical disposal of these solid wastes is a major problem to the sugarcane industry because of their significant quantities and adverse effects on the environment.

Bagasse

Historically, bagasse was burned in boilers at the sugar mill without any treatment as a boiler fuel, although it has a high moisture content (45–60%) (Nemerow 1995), which reduces its efficiency. Bagasse has a gross calorific value of 19,250 kJ/kg at zero moisture and 9,950 kJ/kg at 48% moisture. The net calorific value at 48% moisture is around 8,000 kJ/kg (Deepchand 2001).

Direct burning of bagasse is not an efficient disposal method because the emissions are harmful to the environment and requires the installation of filters to clean the smoke. In addition, the bulkiness of bagasse causes it to have low energy value per unit volume and requires the construction of special furnaces for efficient

TABLE 17.5
Chemical and Physical Composition of Bagasse and Mud Cake (4)

Constituent	*Bagasse (%)*	*Mud Cake (%)*
Cellulose	46	8.9
Hemicellulose	24.5	2.4
Lignin	19.9	1.2
Fats and wax carbon	3.5	9.5
	48.7	32.5
Hydrogen	4.9	2.2
Nitrogen	1.3	2.2
Phosphorous	1.1	2.4
Silica	—	7.0
Ash	2.4	14.5
Fiber	40.8	15.0

Source: Dusgupta (1963).

operation. Because of the inefficient burning of bagasse, usually only 70% is burned and the remaining 30% is disposed with cachaza in a landfill or sold at a very low price.

The high cellulose content of bagasse and the high organic content of mud cake qualify them as potential energy sources (Adekeke 2003). The chemical and physical composition of bagasse and mud cake is presented in Table 17.5.

Proposed Solution to Solid Waste Problem in Cane Sugar Industry

Energy consumption throughout the world is gradually increasing. Most of today's energy sources are carbon-based nonrenewable sources. Consumption of these sources needs to be reduced because of their significant negative impacts on the environment. Attention should be focused on the utilization of renewable energy sources. Biomass, organic matter derived from plants, is one of the renewable sources of energy being used in the production of liquid and gaseous fuels such as ethanol, methanol, hydrogen, and biogas. Efficient use of biomass is crucial for higher energy gains. Direct burning is inefficient because the energy value per unit volume is low and maintaining a steady fire becomes problematic because of difficulty in controlling the combustion process. In addition, collection, transportation, storage, and handling are tedious. One method for the efficient utilization of agricultural residues is their densification into solid fuel pellets called *briquettes*.

Briquette Quality Considerations

Briquette quality aspects are combustion, environmental concern, durability, and stability. C*ombustion* is the energy value from the solid fuel as well as ease of the briquette getting ignited. *Environmental concern,* the level of toxic emissions during burning; *durability and stability,* how long the briquette can remain in its compact solid form for its intended purpose. Properties of the agricultural waste used and the efficiency of the briquetting process determine briquette quality. Other parameters against which briquette quality is measured include calorific value, compressive strength, porosity, and density.

Bagasse Briquetting

Adverse Environmental Impacts

In sugar mills that do not preserve the environment, 70% of the resulting bagasse is inefficiently burned in boilers to generate steam, which is reused in the sugar production process. A proportion of the ash from bagasse burning is lost to the surrounding air as fly-ash, thus polluting the environment. Consequently, sugar mills are required to install costly stack scrubbers to clean emissions. The remaining 30% of bagasse is mixed with cachaza and disposed nearby. Figure 17.8 illustrates the current situation in sugar mills; the values of the Komombo sugar cane factory in Aswan, Egypt, are used for illustration.

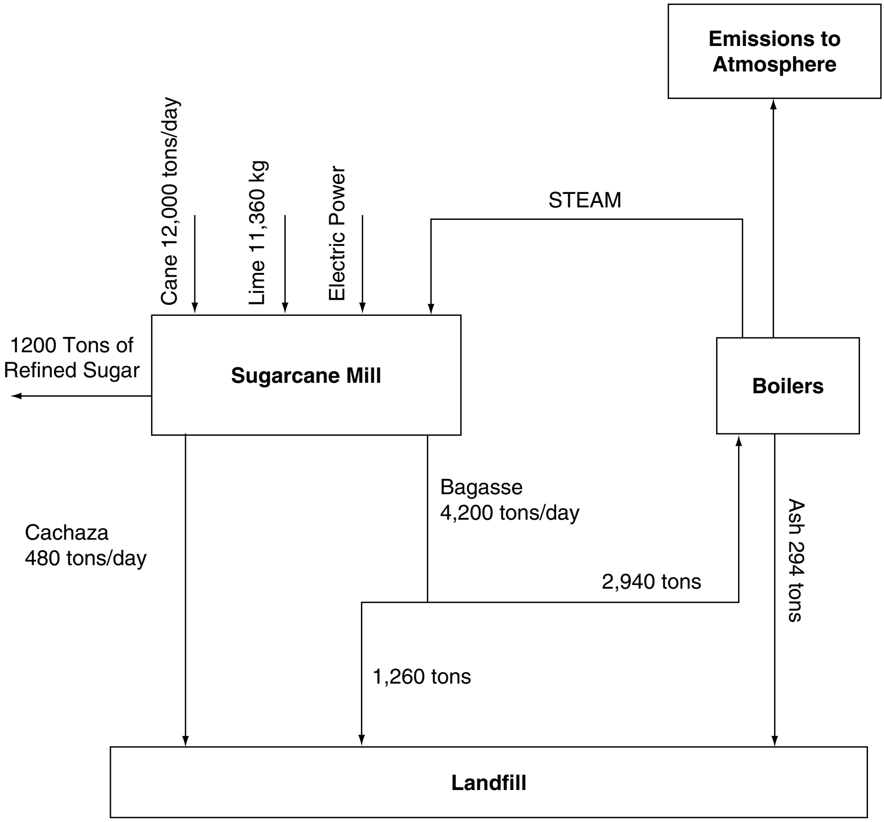


FIGURE 17.8. Current sugar-mill situation.

The previously described system is an inefficient system that needs to be modified. Two modifications are suggested as follows: introducing a briquetting unit for the bagasse and cachaza and developing an EBIC in which the briquetting unit is combined with the sugar mill at a single site. Briquetting of bagasse and cachaza has many advantages; however, more advantages will arise when both types of production are combined into a complex.

Advantages of Briquetting Unit

- When briquettes are burned in boilers, the compact form allows the ash to precipitate, thereby significantly reducing emissions. The precipitating ash, which is very rich in nutrients, can be retrieved and used as a fertilizer. Table 17.6 shows the chemical analysis of the ash generated from burning bagasse and cachaza.
- A briquette has a higher combustion efficiency, 80% on average as opposed to bagasse in its loose bulky form, which has a combustion efficiency less than 60% on average. The difference in combustion efficiencies is primarily related to the lower moisture content and improved properties of the briquettes compared to their loose bulky form.
- The amount of briquettes required for generating sufficient heat for the boiler can be determined with accuracy; therefore, increasing efficiency as opposed to using bagasse in loose bulky form.
- The resulting compact form of the briquettes allows them to have high energy per unit volume and high specific weight and makes them easier to store and transport. These properties make them an attractive fuel for home and industry use, so excess briquettes can be sold by the sugar factory.
- The cachaza and excess bagasse that were being disposed will be used in the production of briquettes.

TABLE 17.6
Composition of Ash from Cachaza and Bagasse [Dasgupta 1983]

	Ash of	
Composition	*Cachaza (%)*	*Bagasse (%)*
Organic Matter	9.77	17.13
Total Potassium	9.97	12.5
Total Phosphorus	0.67	1.24
Iron	0.5885	0.181
Manganese	0.0863	0.006
Copper	0.0353	0.0121
Zinc	0.0314	0.009
Calcium	3.6289	0.4133
Magnesium	0.0173	0.0127

Source: Dasgupta (1983).

Briquetting Unit

In bagasse–cachaza briquettes, most of the mixture is bagasse and the cachaza acts as a binder because of its fat and wax content. Several parameters determine briquette quality: residue size, moisture content, cachaza content, and compression temperature and pressure. Experimentation showed that bagasse–cachaza briquettes can be compressed with or without heating (Ishaq 2003). The briquettes from both processes almost have the same calorific value, which is 15,000 kJ/kg; however, they differ in compressive strength. The heat-pressed briquettes have a higher compressive strength, which allows better storage and handling (Ishaq 2003). Because the briquettes will be used as boiler fuel in the sugar mill, production without heat is more economical.

Briquetting at Varied Pressure without Heat

Increasing the pressure increases the density of the briquette; a higher density is desirable as it contributes to a higher energy per unit volume and improved handling and storage characteristics.

Different densities are obtained at different residue sizes; however, high pressure yields briquettes having densities equal to 0.7 g/cm^3 for all residue sizes, which is high enough to give sufficient energy per unit volume. The optimum process conditions are as follows (Ishaq 2003):

- Applied pressure: 100–120 MPa.
- Residue moisture content should range between 9 and 12%.
- Cachaza inclusion should not exceed 10%.

Theory of Complexing Technology

As shown earlier, briquetting is an appropriate method for the utilization of bagasse and cachaza; however, the sugar mill will realize more benefits by combining the briquetting unit in the same site to form an EBIC. The economic production objectives (in addition to the environmental benefits) of developing an EBIC include the following:

- S*aving in transportation costs:* Transportation costs would otherwise be high because of the large amounts of bagasse and cachaza that would have to be transported from the mill to the briquetting unit and back as briquettes.
- *No time delay:* No time will be lost in transporting the bagasse and cachaza to the briquetting unit and back to the mill to be used as boiler fuel. Time efficiency is essential for sugar mills because they operate only during the cane growing and harvesting season, which is usually 5 mo/yr. During this period, sugar mills usually operate 24 hours a day, 7 days a week because of time constraints.
- *High durability and efficiency:* The briquettes will be subjected to less handling such as loading and unloading on/from trucks, which maintains high durability and energy per unit volume for the briquettes.

- *Maintaining moisture content:* There will not be a significant change in moisture content of the briquettes during the period between their production and usage in the mill as boiler fuel.
- *Space utilization:* There will be no need to store the solid wastes until they are transported or store the briquettes when they arrive, thus reducing storage costs and storage areas. The bagasse–cachaza mixtures will be continuously fed to the briquetting unit and the produced briquettes will be used as boiler fuel right away. In the case of excess briquettes, the storage area required will be less than that needed for loose bulky bagasse.

The Environmentally Balanced Industrial Complex

Sugarcane–Briquettes–Fertilizer Plants

For illustrative purposes, the concept of developing an EBIC will be theoretically applied to the Komombo sugar mill in Aswan, Egypt. One potential complex is shown in Figure 17.9. The Komombo sugar mill produces 180,000 tons of refined sugar per year. The mill operates 24 hours a day, 7 days a week during the cane growing and harvesting season, which lasts for 5 months. The average daily production of the mill is 1,200 tons. The resulting amounts of bagasse and cachaza are 4,200 and 480 tons/day, respectively.

In the production of briquettes, the proportion of cachaza should not exceed 10% by weight, so 420 tons/day is used in production of briquettes and 60 tons/day is used in the organic fertilizer. The corresponding number of briquettes produced per day, assuming a briquette weighs 100 g per briquette, is 46.2 million.

Burning of the briquettes generates 55,440 GJ of steam for energy production. The steam can be used to drive turbines to produce low-pressure steam for heating purposes and 175,575 kW of electric power, both of which can be used to supply the refinery; in addition, excess electric power can be sold to the national grid.

Due to burning briquettes in the boilers, 462 tons/day of ash precipitates. The resulting ash is then transported to the organic fertilizer unit to be mixed with the excess cachaza and used in the production of fertilizer. The fertilizer produced is sold to cane growers and other consumers.

First Alternative: Establishing an EBIC for Each Sugar Mill

The complex proposed is illustrated in Figure 17.9, with a theoretical application to the Komombo sugar mill in Aswan. Comparing the complex in Figure 17.9 with the typical sugar mill in Figure 17.8 shows the additional investments necessary for the establishment of the EBIC. Although these investments will require a large capital outlay, the overall benefits will outweigh the large initial investment. A more complete economic analysis of this industrial concept solution is presented later in this chapter.

From a practical standpoint, we have verified that it is feasible to develop an EBIC utilizing the sugarcane mill, the briquetting plant, and a fertilizer plant to allow no liquid or solid wastes to enter the air, water, or land and cause adverse environmental

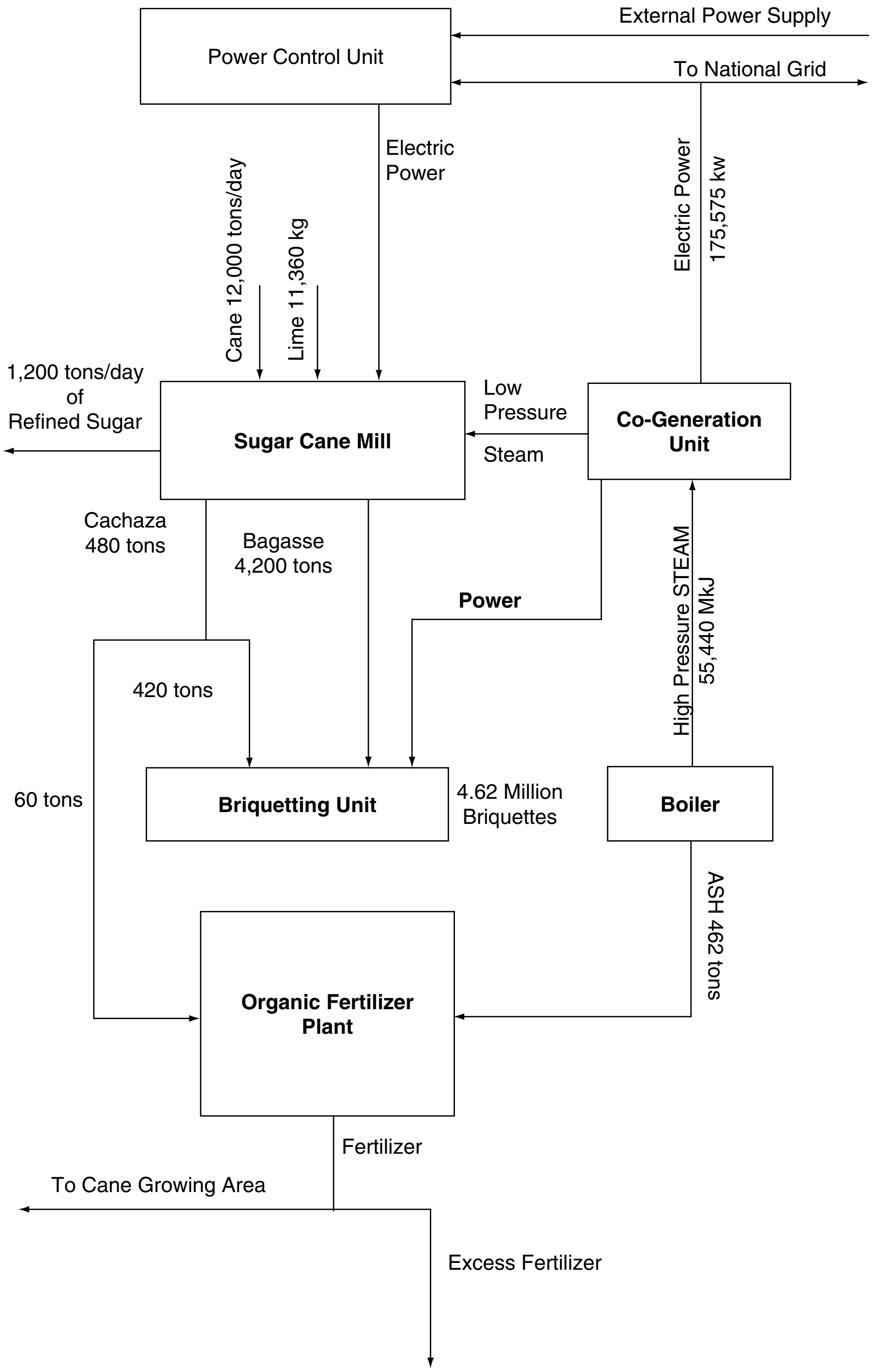


FIGURE 17.9. Environmentally balanced sugarcane complex.

effects. We also show in this book that it is economically feasible as well to develop this EBIC for all plants, especially for the sugarcane mill.

Acknowledgments

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Textile Mill Complex

Plight of Small Textile Mills

The textile industry represents one of the most competitive fields of production worldwide. Each plant attempts to reduce its cost to compete with other similar plants within its region and those in other countries. One answer to competition has been to increase production, sometimes by merging with other plants and sometimes merely by expanding one plant's capacity. Lower unit costs generally result from increased production in accordance with accepted economic principles. However, some mills for one reason or another cannot increase production to reduce costs. These smaller plants are vital to local economies but are finding it difficult to compete with other larger mills.

In addition, these small textile mills are often located on small watercourses where their waste exerts an unusually high pollutional demand on the environment. Pressure is being applied by water pollution control agencies to avoid and avert this pollution. Treatment of these wastes may also increase production costs.

When one couples the economic size and environmental pollution problems with the reality of dwindling supplies of fresh, raw process water, the small textile mill is currently being squeezed either out of business or to disproportionately increase its product cost or both. Larger mills are usually located where process water is more abundant and hence cheaper and where receiving streams or domestic wastewater treatment plants are more able to handle the pollutional load.

The ultimate survival of small textile mills–indeed small water-using industrial plants of all types–depends on solving both economic and the environmental resource problems. This section contains an innovative, potential solution to the plight of these small mills.

Cost of Raw Water

Although process water cost generally represents a minor portion of total manufacturing cost, it is significant because it is becoming an increasing percentage of that cost. Process water is also becoming a scarcer raw material. Little information is published on the actual cost of raw water. In general, municipal water utilities charge from \$0.50 to \$1.50/100 ft^3 (or 1,000 gallons of water). In fact, our survey of textile mills using public water supplies showed that they pay \$0.44–1.43/1,000 gallons.

For a typical small mill finishing woven fabric in a series of complex processes that uses 600,000 gallons/day, its daily cost would be $264–858. Even these charges may be misleading because they occurred only where this amount of water was available for sale, as reported by the mills.

Conventional Wastewater Treatment

Wastewater treatment from small textile finishing mills has been either (1) separate treatment and reuse of dye wastes only or (2) complete treatment of the whole finishing mill waste (Nemerow and Dasgupta 1985). The first has been accomplished mainly by hyperfiltration and/or dye bath reconstitution, while the second has been done mainly by chemical coagulation and/or biological aeration.

Both methods have produced certain amounts of reusable water. However, economic considerations and government environmental regulations play major roles in the decision to produce reusable wastewater. Costs of producing acceptable-quality reusable wastewater to the small mill will need further definition and reduced to a minimum before reuse becomes standard practice, regardless of receiving water quality degradation.

Costs of Conventional Wastewater Treatment

In our search of the literature thus far, we have found that capital and operating costs of small textile mill wastewater treatment depend largely on the type and extensiveness of the treatment used. The capital costs range from as low as $31,500 for simple dye bath reconstitution to as high as $303,000–492,000 for chemical coagulation, filtration, and activated-sludge treatment. Operational costs for similar treatments range from $40,000 to $328,000 per year.

A typical small mill produces about 25,000 lb/day with average capital costs of $500,000 for complete treatment and annual operating costs of $150,000. This results in capital costs of $20/lb of production per day and annual operating costs of $0.02/lb of production per day (assuming 6 days per week and 50 weeks per year of production). These are very approximate costs for presumed average small mills. The range of true costs may vary greatly from. However, it is apparent that both capital and operating costs to these small mills represent a very significant expenditure.

Minimization of these costs by subtracting them from the benefits of wastewater reuse would constitute a real boon to the small mills.

Alternate Solutions to the Dilemma

There are two potential methods for reducing waste treatment costs of the small textile plant and, at the same time, producing reusable wastewater to replace or replenish the mills' costly water supply. These are (1) industrial complexing and (2) chemical coagulation. Other methods reported in the literature may reduce waste-treatment costs or produce a partial supply of raw water but will not accomplish both of these objectives. For example, dispersed growth aeration as suggested by Nemerow and Dasgupta (1985) will treat the wastewater at reduced costs but will not, by itself, produce acceptable reusable water. Also, Brandon and Porter (1976) hyperfiltered dye wastes through membranes to produce both recyclable water and dyes but failed to treat a sufficient portion of the plants' total waste at a lowered cost to result in satisfactory overall waste treatment. In order to be cost effective for the small textile manufacturer, the solution must satisfy both environmental and production concerns.

Industrial Complexing

Water-consuming and waste-producing textile finishing mills are ideally suited in these industrial complexes. Although wastes may pollute the fragile environment, they may be amenable to reuse by close association with satellite industrial plants, that in turn, produce raw materials for others within the complex.

An ideal illustrative EBIC for small textile finishing mills is shown in Figure 17.10. This complex contains five manufacturing plants producing 12,000 lb of woven fabric

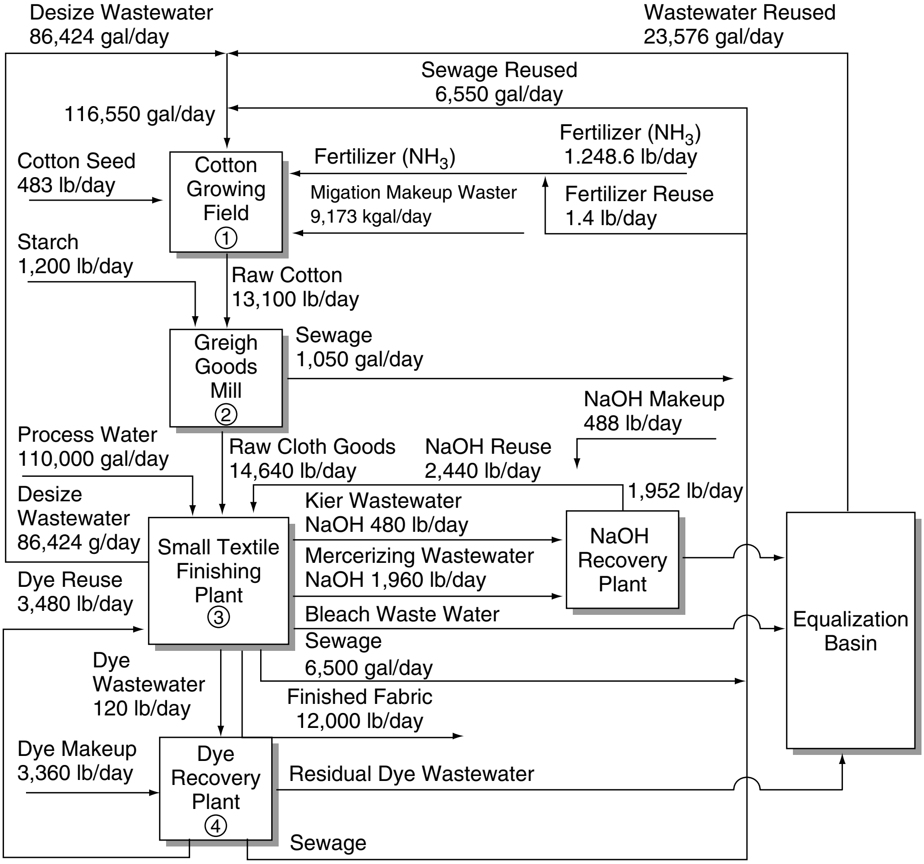

FIGURE 17.10. Diagram of the integrated five-plant industrial complex.

for sale outside the complex and 13,200 lb of cotton, 14,640 lb of greigh goods, 1,952 lb of NaOH, and 120 lb of dyes for reuse within the complex.

In addition, all sewages and wastewaters are reused without treatment within the complex. Of notable interest and importance is the reuse of 86,424 gallons of untreated finishing mill desize waste that contains 732 lb of BOD.

In Table 17.7, a raw material balance justification is given, which compares the raw material quantities and costs for the five separate plants manufacturing at distant locations and manufacturing within the EBIC. From Table 17.7, it is apparent that the cost savings of the industrial complex from a material balance perspective alone is \$6,726 less \$6,093.75 or \$623.25 per day, which represents a savings of \$52.69/1,000 lb of finished cotton fabric.

In addition, environmental costs would have to be considered. Within the industrial complex, we are presuming no external environmental costs are needed. As separate plants operating at distant locations from each other, environmental costs would include both domestic and industrial waste treatment charges as well as any measurable adverse environmental impact costs of the residual effluent wastes. These additional costs are currently being assessed by your author.

From a preliminary study, total environmental savings appear to be greater than \$1,248/day, which represents the average costs of treatment for separate greigh goods and finishing mill wastes. To both savings the savings from transportation of raw cotton and sized woven goods must be added. Presuming transportation cost is \$0.026/lb of cotton transported, we can estimate the additional cost for transportation as \$343.20/day.

Pulp and Paper Mill Complex

The products of pulp and paper mills, the fifth largest in the U.S. economy, are consumed at the annual rate of about 400 lb/person. The pulping of the wood and the formation of the paper product produce wastes containing considerable quantities of sulfates, fine pulp solids, bleaching chemicals, mercaptans, sodium sulfides, carbonates and hydroxides, sizing casein, clay ink, dyes, waxes, grease, oils, and other small fibers. The overall wastes can be high or low in pH, and contain high-color, suspended, colloidal, and dissolved solids and inorganic fibers. Because of its high water consumption and wastewater discharge of 20,000–60,000 gal/ton of product, the wastes contain large total quantities of organic oxygen-demanding matter.

The high water use and wastewater production usually preclude the possibility of joint treatment with municipal sewage. These wastes also create considerable environmental impacts because of their concentrated loads of air, water, and land pollutants. The siting of new pulp and paper mills has become a major endeavor. They must be located near vast quantities of relatively clean water, as well as receiving water resources downwind and at a distance from residential habitation (because of common air pollutants such as SO_2 and mercaptans), usually on a rail line and near major highways for shipping, and near adequate land area for waste treatment and sludge disposal. Such sites are also difficult to find. For these and other reasons previously given,

TABLE 17.7
Raw Material Balance as Part of Total Production Cost

		Mass Balance of Small Textile Complex Raw Material				
Raw Materials, Amount Needed	*Plant Type Amount Needed*	*By the Complex Quantities*	*Cost ($)*	*When Plants Are Separate Quantities*	*Cost ($)*	*Cost/Unit of (1982–1983)*
	Agricultural growing field					
	Irrigation water	9.173mgd	4,036.00	9.29 mgd	4,087.00	$0.44–1.43/1,000 gal
	Cotton seed	483 lb/day	48.30	483 lb/day	48.30	0.10 lb
	Fertilizer	1,248.6 lb/day	81.16	1,250 lb/day	81.25	0.065 lb (1987)
	Greigh goods manufacturing					
Starch sizing		1200 lb/day	180.00	1,200 lb/day	180.00	$0.15
	Textile mill finishing					
NaOH for fabrics		488 lb/day	131.80	2,440 lb/day	658.80	$0.27 lb
Dyes for fabrics		3,360 lb/day	1,512.00	3,480 lb/day	1566.00	0.45 lb
Process water		0.11 mgd	104.50	0.11 mgd	104.50	0.44–1.43/1,000 gal
Total material cost		$6,093.75/day		$6,726/day		

[a] Assume typical small textile finishing plant producing 12,000 lb/day of woven finished cloth product.

I recommend consideration of a pulp and paper mill complex, with little or no adverse environmental effect. Figure 17.11 describes one possible complex centered about an average-sized paper mill producing 1,000 tons of paper product per day

In the first publication (Nemerow et al. 1977), a balanced industrial complex centered about a pulp and paper mill was presented and is produced here as Figure 17.11 for further clarification. Eight separate industrial plants were included as part of this complex, five of which would produce products to be used within the complex.

The Pulp and Paper-Mill Environmental Problem

Pulp and paper-mills are among the top five industrial water users in the United States (Nemerow 1978). They use about two times 10–12 gal/day (Gould 1976). The largest percentage of this water is discharged into the environment as wastewater from pulp washing and paper making or as steam from the drying plant. The pulp and paper industry is also the ninth largest in the United States, accounting for nearly 4% of the value of all manufacturing, producing $7,866 million of our gross national product in 1971 (American Paper Institute 1973). In the cooking and bleaching of the pulp, these mills may also contaminate the air surrounding the plant. Approximately one-half of all weight of the wood entering the pulp mill leaves the mill as product paper. The greatest percentage of the loss in weight ends up as solid material to be disposed of in the environment. Bark, waste pulp, and paper mill fines constitute most of these solids and potentially end up on the land or in the air. Therefore, this industry—because of its great volume of water, wood, and chemical intake per mill—has an adverse impact on the air, water, and land environments. The large quantity of wastes also represents a potential supply of valuable resources for ancillary and compatible industries.

With that in mind, we derived, from our general knowledge and from theory, a pulp and paper-mill industrial complex for further investigation. As mentioned earlier, this complex is depicted in Figure 17.11 and produces 1,000 tons/day of fine paper.

Timber is brought into the complex to the pulp mill (no. 1 in Figure 17.11) where it is converted into pulp for use by the paper mill (no. 2). Major wastes from (no. 1) are bark, which is burned subsequently in the steam plant, and sulfate waste liquor, which is used in three internal complex plants—road binder (no. 3), vanillin (no. 4), and sulfate concentrating (no. 8). Products from no. 3 and 4 can be sold locally or internationally, while those from no. 8 are reused in the complex by no. 1 or by the hardboard manufacturing plant (no. 7). Fine paper product from no. 2 can be sold in the world market. Wastes from no. 2 include heat, fillers, and fines, which can be used internally in the ground-wood pulp mill (no. 5), which also uses a percentage of used newspaper stock.

The pulp product from no. 5 will be used partially in the complex by no. 1 and sold as paperboard externally. The plant (no. 5) produces waste suspended solids, which are used internally by the wrapping paper plant (no. 6 and 7). The products of no. 6 and 7 can be sold regionally. In total, this pulp and paper mill complex produces six products for external sale (fine paper, wrapping paper, hardboard, vanillin, paperboard, and road binder) and four products for internal use (concentrated sulfate, wood pulp, wrapping paper, and ground wood pulp). In addition, all major wastes of suspended

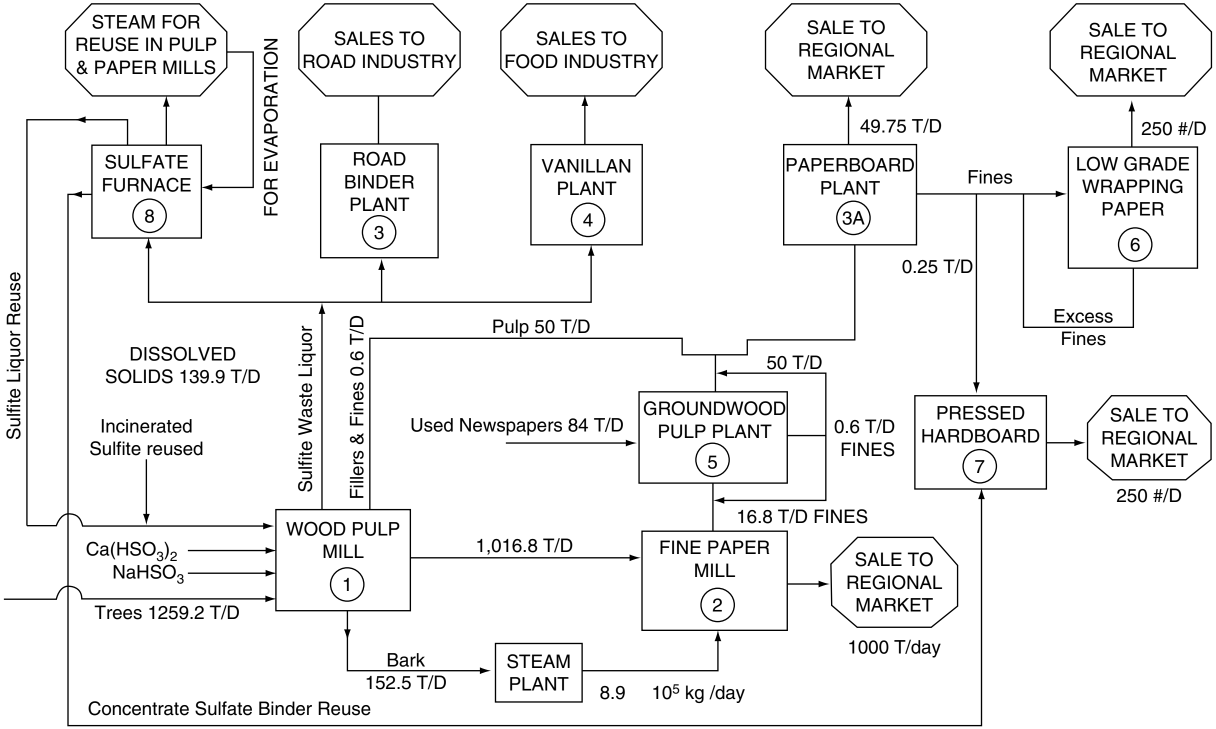

FIGURE 17.11. Pulp and paper mill complex.

solids, cooking liquor, fillers, heat, and bark are reused within the complex in the manufacturing of these products.

Mass Balance of Products

Based on a literature review evolved typical concentrations of recoverable suspended solids in various process effluents were calculated. A mass balance was prepared assuming that the total production of fine paper is 1,000 tons/day. The remaining quantities are calculated based on this production.

Computation of Trees Required at the Complex

Production of fine paper: 1,000 tons/day (907.2 kg/day × 1,000). Fiber losses from the paper mill = 1.68% of production. Therefore, suspended solids going into waste streams from the paper mill = 1.68/100 × 1,000 = 16.8 tons/day (15.24 kg/day × 1,000). Total wood pulp produced per day = 1,000 + 16.8 = 1,016 tons (922.44 kg × 1,000). Quantity of sulfite liquor generated in wood pulp mill = 300 gal/ton, while concentration of dissolved solids in sulfite liquor = 11%.

Thus, dissolved solids going into sulfite liquor = 110,000 × 8.34–6 × 300 × 10 = 275.22 lb/ton (0.1376 kg/kg) of pulp. Total sulfite wastewater dissolved solids produced per day = 275.22 lb/ton × 1,016.8 tons/day × tons/2,000 lb = 139.9 tons/day = 0.00001269 kg/day. On an assumption that the amount of bark produced is generally 15% (by weight) of the pulp production, bark production = 15/100 × 1,016.8 = 152.5 tons/day (138,000 kg/day). Total tonnage of trees used in the complex = 1,016.8 + 139.9 + 152.5 = 1,309.2 tons/day (1,187,000 kg/day).

Ground Wood Pulp Production

Recovery of suspended solids from paper mill = 16.8 tons/day = (15,200 kg/day). Assume that 100 tons (90,720 kg) of ground pulp is required for production every day. Fiber loss in the ground wood pulp plant = 0.6 tons/100 tons of the ground wood pulp (Nemerow 1978) = 0.6/100 = 0.6 tons/day (544.3 kg/day). Total ground wood pulp produced and lost per day = 100 + 0.6 = 100.6 tons/day (91,260 kg/day). Therefore, used newspaper required = 100.6 – 16.8 = 83.6 tons/day (75,840 kg/day assuming 50% of the ground wood pulp is recycled as shown in Figure 17.11 and the remainder is used in the production of paperboard.

Paperboard Production

Loss of fines from ground wood pulp production is about 0.5% of production (15,1978). Let us say that paperboard production = x tons/day and X + 15/100X = 50 tons of pulp/day (54,359 kg/day) and 1.005 X = 50

$$X = 49.75 \text{ tons paperboard/day (45,132 kg/day).}$$

Fines recovered from paperboard waste = 49.75 = 0.25 tons/day (226.79 kg/day). A total of 0.25 tons/day of fines can be used to produce low-grade wrapping paper and pressed hardboard. With no loss of fines and with a 50–50 product production split, 1.25 tons (113.64 kg) of each product can be manufactured.

Sulfite Recovery

The solids concentration of spent sulfite liquor drawn from the digesters may vary from 6 to 16%, with an average value of 11%. These solids may contain as much as 68% lignosulfonic acid, 20% reducing sugars, and 6.7% calcium (Nemerow 1978). Complete evaporation of the sulfite waste liquor produces both a fuel, which can be burned without an additional outside fuel supply, and a salable byproduct such as synthetic vanillin and road binder.

An overall mass balance regarding the production of different quality of papers is given in Figure 17.11. No attempt is made here to correlate the effects of the complete recovery of suspended solids on the reduction of final BOD of the wastewater. Similarly, no detailed information is given about the recycling of the wastewater effluent. However, it is reported in the literature that 90% of the effluent can be recycled wastewater; it must be presumed that a considerable portion of the dissolved and colloidal organic matter is being reincorporated into the various products. This is especially true in the case of the sulfite waste liquor, which is completely reused or recovered and contains the major portion of BOD in the complex.

Energy Management

Integrated production complexes have a significant advantage over conventional plants from the energy management standpoint. Waste heat from one section of the complex can be used as process heat for another section, the concept being minimization of waste heat. The environmental problems associated with waste heat discharged to ecosystems have been well documented. It is accepted that thermal discharges may result in anomalous stratification in the receiving basin, lowering of capacity to hold oxygen, and increased reaction rates and metabolism. These effects vary significantly with the chemical and meteorological conditions associated with the water body. The lethal effects of thermal pollution are sometimes obvious, whereas the sublethal effects on food chains and waste assimilative capacities are not easy to foresee without careful study.

The present industrial complex outlined can reduce waste heat discharged to the hydrosphere and atmosphere. The two significant areas of concern follow:

1. Utilization of solid wastes from the plant to achieve energy efficiency
2. Utilization of low-grade heat from one section in another suitable section

The first area has two possible applications. Bark from the shredding plant is used to provide heat from the steam plant. The estimated bark production for the plant is 152.5 tons/day (138,345 kg/day). Because the heating value of bark varies considerably with the type of tree and aging, an average heating value of 4,000 cal/g is used.

The heat available by combustion of bark is

$$\begin{aligned} &= 152.5 \times 1{,}000 \times 454 \times 4 \text{ kcal} \\ &= 550{,}000{,}000\ (75+54) \text{ kg} = 890{,}000 \text{ kg/day.} \end{aligned}$$

Assuming incoming water temperature at 25°C., the total steam production = 550,000,000/(75+54) kg = 890,000 kg/day.

The second solid waste to energy recovery application lies in evaporation and burning of sulfite liquor. Sulfite liquor is evaporated to enough of a solid content suitable for burning. Difficulties with scaling, corrosion, and fly-ash may result. However, this burning procedure can also be justified because this will eliminate the need to discharge sulfite wastes to the environment.

Utilization of low-grade waste heat from the proposed complex is somewhat difficult, because details of process thermodynamics are needed. Further, research on this concept provides the needed data for such analysis. However, some conceptual comments can be made regarding the proposed complex. Low-grade heat from fine paper mills can be used in the ground wood pulp plant. In cooler regions of the world, waste heat from any of the effluents in the complex could be used for space heating and providing hot water for use by plant personnel.

Economy of Complex or Residual Environmental Impact

Little or no air or water pollution results from this complex. In addition, it is anticipated that no expensive wastewater-treatment plant would be required for the pulp and paper mill complex. This, in itself, represents a savings not only in capital equipment costs, but also in operating or production costs equal to 1–5% of production costs. Additional operating costs will be reduced by the following practices:

1. Reusing burned sulfite waste liquor to replace a portion of calcium or sodium bisulfite cooking liquor
2. Reusing ground wood pulp (50 tons/day) or (43,359 kg/day) to replace a similar weight of trees
3. Burning bark to generate steam for use in the fine paper mill
4. Reusing concentrated sulfite waste liquor in making pressed hardboard
5. Reusing fillers, fines, and heat from the paper mill in making ground wood
6. Reusing ground wood pulp mill fines (0.6 tons/day or 544.31 kg/day) to make additional pulp or paperboard
7. Reusing paperboard mill fines (0.25 tons/day or 226.80 kg/day) to make both low-grade wrapping paper and pressed hardboard
8. The sale of additional products as follows:
    a. Low-grade wrapping paper: 250 lb/day(113.64 kg/day)
    b. Pressed hardboard: 250 lb/day (113.64 kg/day)
    c. Paperboard: 49.75 tons/day (45,132 kg/day)
    d. Vanillin
    e. Road binder
9. Combustion of concentrated liquor for heat recovery and pollution abatement
10. Use of low-grade waste heat for space and water heating

An exact and more detailed economic analysis of this complex will be made in any continuing study. It will be necessary to obtain more precise data on the production requirements of the small service industrial plants in the complex. In the meantime, I propose this analysis as a beginning to what may develop into a revolutionary new system of industrial plant design.

A major producer of the present-day pulp and paper uses the Kraft process. Under normal circumstances, a variety of liquid, solid, and air wastes are created in this process. One possibility for integrating the typical Kraft mill into an EBIC is shown in Figure 17.12.

The approach adopted for developing this complex follows:

1. *Single-system concept of water, power, raw materials, and wastes management:* The operation of utilities system, so critical to the production process, requires efficient performance. Centralized utilities and management allows the achievement of self-containment.
2. *Waste utilization/byproduct recovery:* Industries based on chemicals from the other half of the tree and wastes have been included in the complex. This step

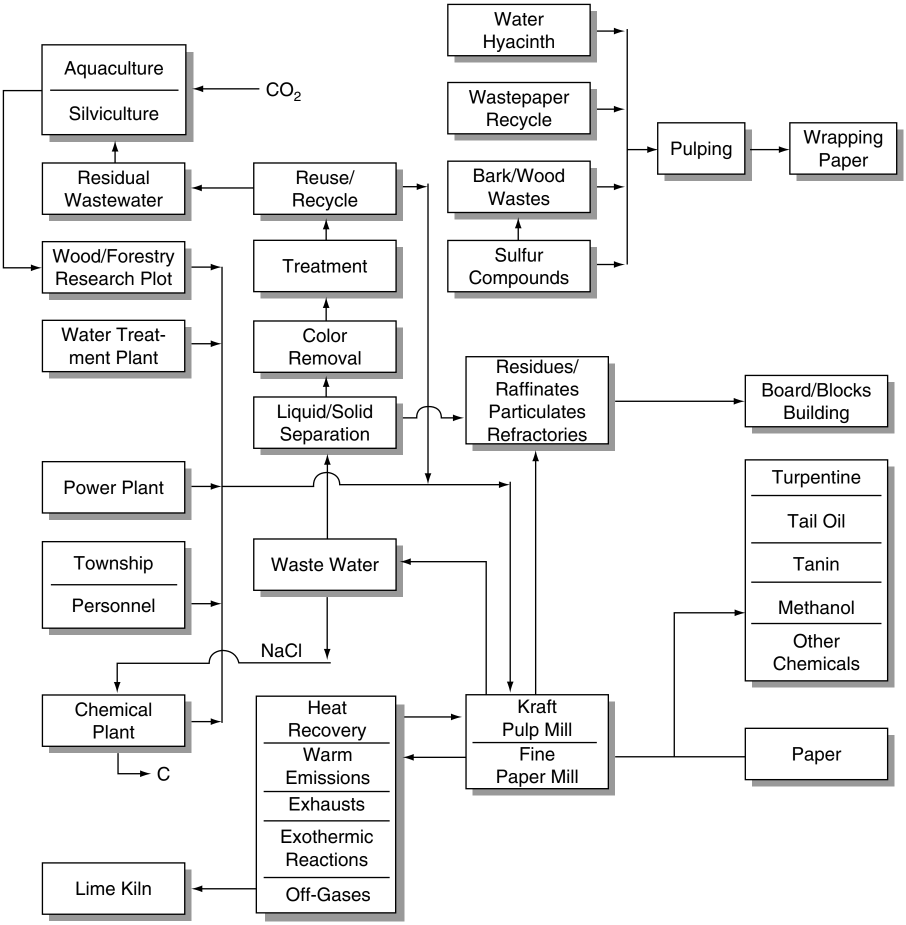

FIGURE 17.12. Paper mill complex.

made of pollution control is of significant merit since it allows twofold benefits of minimizing production and treatment costs.

3. Grouping of other compatible and complementary industrial plants such as chemical, forestry research, aquaculture (water hyacinth), and so on.
4. *Integrated development in stages and overall management of all operations within the complex:* The central starting point is the pulp industry, based on which the complex develops in stages by inclusion of other industries and utilities. The gradual development in this way approaches self-sustainment.

Although complete analysis with respect to criteria for acceptability has not been made, primary technoeconomic considerations make this complex extremely attractive. As resources become increasingly scarce and environmental regulations become more stringent, multiple benefits will be more than apparent.

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