CHAPTER 18

Potential Industrial Complexes

INTRODUCTION

There are many possible examples of potential industrial complexes that may accomplish the objectives set forth in Chapter 15. I list some here and provide brief descriptions of their configuration mostly in schematic ways. The reader may also be aware of others may also meet requirements for workable environmentally balanced industrial complexes (EBICs). Those in this chapter do not contain mass balances or any other detailed operating data. As the latter become available, I intend to transfer these to Chapter 17 in updated editions. Those already in Chapter 17 will be updated and, hopefully, include actual production and operation data, efficiencies, and problems, if they exist.

I am not so presumptuous as to assert positively that the complexes in this chapter are (or ever will be) feasible. I present them here only to stimulate your thinking about these possibilities. If, in fact, it turns out that these potential complexes actually become reality, then I can look back and take some comfort in the fact that practice sometimes results from theory. If, on the other hand, they never become reality, I hope they at least provided you with the incentive to innovate. The principle of industrial complexing is an art of (1) finding a troubled waste-producing industry and (2) matching it with another industry that can alleviate the trouble by consuming its contaminating waste. Once you develop the technique of mastering this principle, you will have used successfully the concept of EBIC.

In Chapter 20, I include some examples of complexes that were not designed as EBICs originally but that developed over time from “industrial estates.”

The following are some of the potential EBICs known to the author and proposed at this time:

A Wood–Papermill Complex
B Steel Mill–Coke and Gas and Fertilizer Plants
C Finished Metals–Plastic Plant Complex
D Organic Chemical–Wood Processing Plant Complex
E Wastewaters–Power Plant Complex

F	Steel Mill–Fertilizer–Cement Plants Complex
G	Coal Power Plant–Cement–Concrete Block Plant Complex
H	Plastic Plant Complex
I	Cement–Lime–Power Plant Complex
J	Wood–Lumber Mill Complex
K	Power Plant–Agriculture Complex
L	Cannery–Agriculture Complex
M	Nuclear Power–Glass Block Complex
N	Animal Feedlot–Plant Food Complex
O	Coke (Steel Mill)–Tar–Benzol Plant Complex
P	Wood–Ethanol Plant Complex
Q	Water, Electricity, Chlorine, Lye Plant Complex
R	Aluminum, Electricity, Red Brick Plant Complex
S	Corn Growing, Alcohol Producing Plants Complex
T	Restaurant, Paint Manufacturing Complex
U	Oil Drilling Offshore–Seashore Recreation
V	Metal Plants–Dry Cleaning Plants Complex
W	Electrical Storing and/or Converting Voltage Wax Manufacturing Complex
X	Nuclear Power Plant, Waste Reprocessing, Cannery Complex
Y	Electric Power, Drinking Water Plant Complex
Z	Vegetable Pickling Cannery, Inorganic Chemical and Chlorine Plant Complex
AA	Sugar, Ethanol, Gasoline Plants Complex
BB	Reclaimed Cell Phones, Cement Plant and Concrete Products Complex
CC	Sugarcane–Fuel Briquettes Complex
DD	Hog Production–Animal Feed–Energy Production Complex
EE	Seawater Desalination Plant–Boric Acid Plant Complex
FF	Animal Feedlot–Power Plant–Fertilizer Complex
GG	Used Plastic–Textile Manufacturing Complex
HH	Lumber–Textile–Corn-Growing–Alcohol-Producing Complex

A. Wood–Paper Mill Complex

A “natural” complex exists with a lumber mill that manufactures lumber from trees, a chipboard mill that uses the waste sawdust and bark to produce paperboard, and a fine paper mill that uses the paper pulp to make fine paper. Each of these three plants discharges wastes along with the valuable products it manufactures. These wastes can be reused as raw materials by another of the complex’s plants to convert into its product. These systems are shown schematically in Figure 18.1.

In this figure, sawdust, wood chips, and bark solid wastes from the lumber mill are reused directly in the chipboard mill instead of being incinerated or landfilled to cause environmental degradation and costs. The wood pulp mill’s waste sulfite liquor is concentrated and reused back in the pulp mill instead of causing immense pollution on

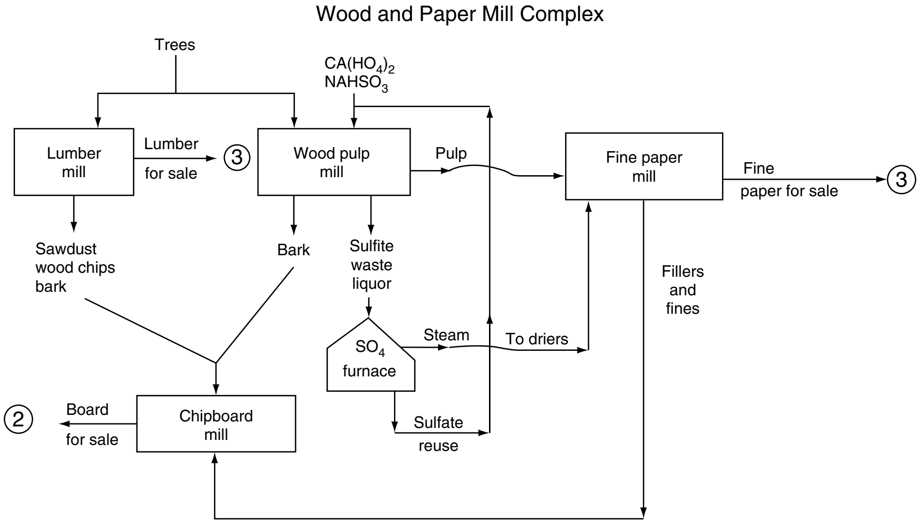


FIGURE 18.1. Wood–Paper Mill complex.

surrounding waterways. Its steam is also captured and reused by the paper mill to aid in drying the fine paper.

Three major products evolve from this complex: lumber for external sale, chipboard for external sale, and fine paper also for external sale. No wastes from these three plants would leave the complex to impose environmental costs on society.

Wood represents an excellent and renewable resource that is not only very valuable but also very preserving if reused. The waste that exists in this industry is enormous. Myerly et al. (1981) suggested that biomass such as cellulose must be handled like any other valuable product: everything must be sold except the sound of the tree falling.

Austin in 1984 admits that underuse of the wastes from wood production comes from the complexity of wood itself and lack of integration of chemical, pulp, and lumber companies. He adds to those the disinterest of processing companies in producing and selling byproducts, lack of chemical knowledge or interest, and the dilute form in which many of the byproducts are available. But he counters with the fact that because environmental laws have made the stream dumping of pulp mill waste products impossible, some real interest in waste use has developed, but most such envisioned uses are as a fuel.

Austin also notes that because one of the major problems in wood use is its collection and transportation out of difficult terrain to the place in which it is desired, use of waste wood is particularly attractive at lumber and pulp mills, where these chores are already done. This agreement makes our proposed complex even more substantiated.

B. Steel Mill–Coke and Gas–Fertilizer Plants Complex

Another “ideal” marriage of compatible industrial plants includes a steel mill with its ancillary coke and gas plant, as well as an ammonia fertilizer plant. With this mix of plants, the waste pickle liquor, $FeSO_4$ from the steel mill, is reacted with ammonia gas waste from the coke plant to make ammonium sulfate, another fertilizer component in the fertilizer plant. Such a combination produces steel, coke, and ammonium sulfate for external complex sale. When these plants operate in separate locations, they also produce extremely pollutional pickle liquor and ammonia gas wastes.

It takes 2.5 tons of raw materials (coal, iron ore, scrap, limestone) to produce 1 ton of liquid steel (Nemerow 1976). Of these raw materials, 1 ton ends up as liquid steel and 0.385 tons as slag (2.5–1.385) leaving 1.115 tons of residual air, water, and solid wastes, assuming that all of the slag is normally ground and reused in road building and/or landfill.

If we assume that all of these wastes in air, water, and solids, except for the coke plant, end up as solid wastes after collection, this amounts to 0.923 tons of solid contaminants resulting from the production of 1 ton of liquid steel. More solid wastes of an unpredictable quantity must be added to this in the finishing of steel unless 100% of the waste is returned to the furnaces as scrap. At least 50% and usually 75% of the solid matter is iron.

In addition, the waste ammonia gas from the coke plant is reacted with steam and caustic soda to remove the contaminant phenol. The resulting sodium phenolate is recovered and sold to a chemical company (either within or outside the complex), which purifies the phenol for use as a raw material, usually for the manufacturing of plastics or wood preservatives. The coke plant ammonia gas waste can also be reacted with sulfuric acid to produce additional ammonium sulfate fertilizer product.

Thus, in this complex, two potentially contaminating wastes—pickling liquor ferric sulfate and coke gas plant ammonia—are recovered as ammonium sulfate and sodium phenolate for subsequent sale to and use by fertilizer and chemical plants, respectively. No waste will leave the complex to enter the surrounding environment. A schematic diagram of this potential EBIC is shown in Figure 18.2.

The air emissions from model coke plants have been given by Codd (1973) and reported by Nemerow (1976). It is repeated here as Table 18.1 to give a fair idea of what to expect from coke plant wastes.

I recommended as far back as 1976 that the production of iron and steel results in the discharge of numerous contaminants but need not be constrained by environmental factors because the control technology is known and abatement costs are relatively insignificant when related to other production costs. I continued that these plants should be located primarily but not solely in developing countries at sites that minimize the sum of the production costs, including environmental control costs. I believe I recognized 25 years ago that developing countries represented the ideal place for industrial complexes. This is where we could expect new plants and new construction in the wet industries to take place.

I further recommended then that the plants could be located in integrated industrial complexes to minimize these production costs while minimizing the total environmental damage costs and maximizing production values. I did qualify my recommendations of

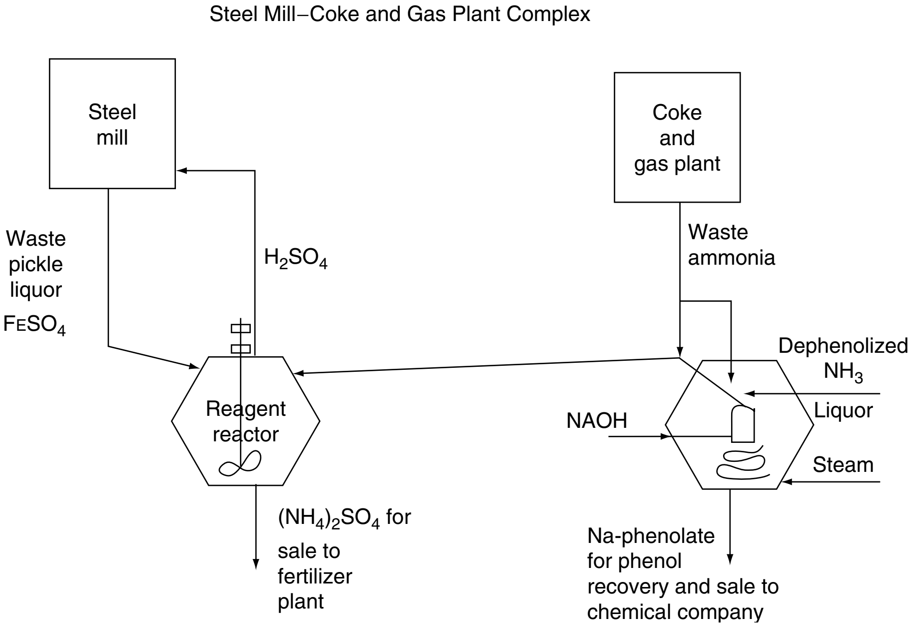


FIGURE 18.2. Steel mill–coke and gas plant complex.

TABLE 18.1
Air Emissions from Model Coke Plants

Pollutant	*Emission Level (kg/ton dry coke)*
Coke and Coke dust	2.0
Coke oven gas	0.7 (approximately 0.4 vol % of total gas made-300 m^3/ton coke)
SO_2	0.63
H_2S	0.12
Phenols	0.13
Aromatics	0.21
HCn	0.07
NH_3	0.14
Pyridine bases	0.02

1976 by stating that considerable research, evaluation, and pilot experimentation are necessary to optimize these industrial complexes (which may contain a different mix of industries for each site in each country). Further, wherever possible steel product should be manufactured by the direct reduction, electric arc furnace, continuous casting sequence of production for minimizing environmental damage.

C. Finished Metals–Plastic Plant Complex

One unusual combination of plants that offers a potential balanced complex consists of a metal parts plant and a plastic production plant.

After metal parts are plated and protected from corrosion with a coating of grease, they are shipped or transferred to a “finished metals parts” plant. Here the grease is removed and the part further fabricated into a finished product. A commonly used solvent is trichloroethylene (TCE), a highly toxic organic compound. When released to the environment, it often exceeds both air- and water-quality standards, thus contaminating groundwater and receiving streams as depicted schematically in Figure 18.3.

At the same time, a polyvinyl plastic manufacturing plant uses as a raw material vinyl chloride monomer to produce polyvinyl chloride (PVC). Various suspension agents and catalysts are added to the monomers. Polymerization takes place in a heated reactor tank, as shown schematically also in Figure 18.3. The polymerized mass is then centrifuged and sold to the plastic industry as PVC. Hot wash wastewaters and centrifugates from this polymerization process, when released to the environment, contaminate groundwater and receiving streams, once again shown in Figure 18.3.

When these two plants are located adjacent to each other in an EBIC (Figure 18.4), it is possible to maintain clean groundwater and rivers. In this case, all that is needed to make this possible is an anaerobic digester reactor to receive the waste TCE and convert it to vinyl chloride, which is then used as raw material for the plastics plant. The metal parts plant’s sewage is used as seed for the digester reactor, the polymer plant’s sewage is used as seed for the digester reactor, and the polymer plant’s centrifugate and TCE are used as feed for the digester reactor.

Hot water from the digester is used to heat the polymerization tank and returned to the digester in a closed system. No waste from either plant is discharged to the air,

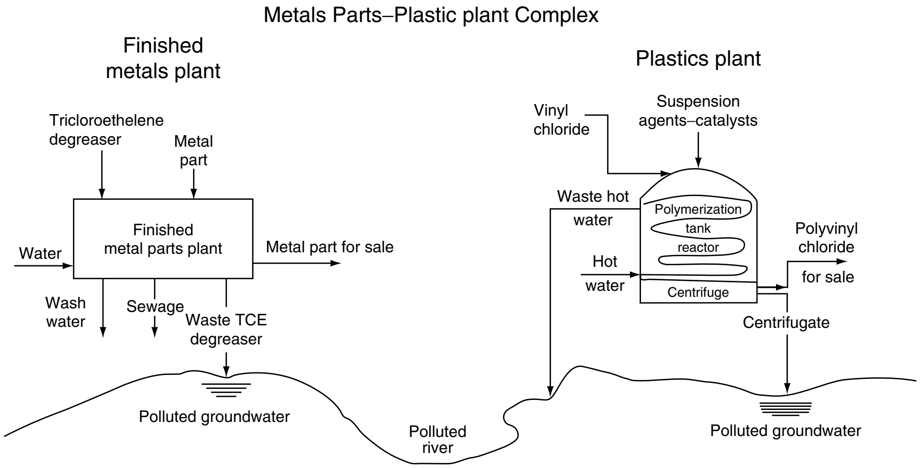


FIGURE 18.3. Metal parts–plastic plant complex.

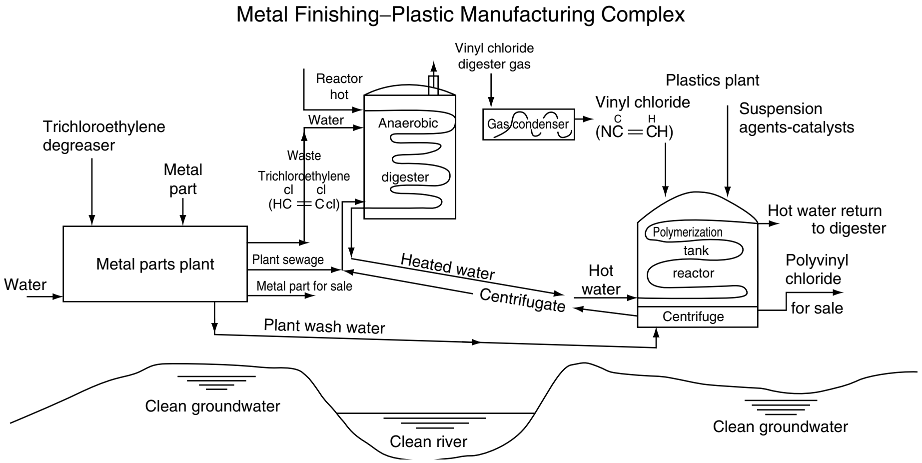


FIGURE 18.4. Metal finishing–plastic manufacturing complex.

ground, or river, as depicted in Figure 18.4. By placing the schematic of Figure 18.3 directly over Figure 18.4, one can observe the value and efficiency of using an EBIC to produce clean metal parts and PVC for external sale.

Of course, not all plastic manufacturing plants produce only PVC. Other plastic manufacturing plants might not fit into this particular environmental complex. Because of this, some facts are presented here about plastic plants in general. The common basic raw materials for plastics are petrochemicals, coal, carbohydrates such as wood or cotton, and gas and saltwater.

Each plastic possesses properties that warrant its manufacture above all others. In general, they are all tough, water and corrosion resistant, many colored, and rather easily manufactured. They started to be produced in 1868 (cellulose nitrate) and continued with different ones through the middle of the twentieth century. The vinyls, which we use as an example in this complex, were started in about 1927.

Shreve (1984) presents an interesting breakdown of plastics into three groups: thermosetting resins, thermoplastic resins, and polymer resins.

D. Organic Chemical–Wood Processing Plant Complex

It is common practice among some organic chemical manufacturing plants to begin with a purchased raw material such as benzene and alter it by reactions to produce other organics such as chlorinated phenols. One typical product is polychlorinated biphenol (PCP). Wastes from the manufacturing of PCP may include mainly phenolic compounds from the original raw material, as well as formaldehyde, hydrochloric acid, and various other organic compounds. Wastes are, therefore, high in phenols and biochemical oxygen demand (BOD) and low in pH. They contaminate the groundwater and receiving streams by contributing odorous matter and oxygen-depleting organic matter and cause potential toxicity to fish and fauna, as depicted schematically in Figure 18.5.

At the same time, wood-preserving plants use creosote and pentachlorophenol to impregnate telephone poles, fence posts, railroad ties, and lumber of all types to preserve them against degradation when put into service. These plants produce, in addition to the aforementioned products, various phenolic wastes, which, when entering the environment, contaminate groundwater and flowing streams. These effects are also shown schematically in Figure 18.5.

The conditioning of wood and its impregnation with preservative vary in materials, procedures, and mainly chemicals. The specific variation depends on the requirement for the use of the final product. In Table 18.2, I have prepared a description of the processes involved in both conditioning and impregnation of the wood. Also included in this table are the wastes resulting from the process, the character of the wastes, and their recommended treatment (if treatment rather than industrial complexing with an organic chemical plant is used).

In a potential EBIC containing both plants adjacent to the other, no wastes reach the groundwater or receiving stream. Phenolic wastes from the wood-preserving plant are extracted, the phenols are returned to the organic chemical plant as supplemental raw material, and the remaining organics are incinerated. Waste heat in the form of steam from the incinerator is reused in the wood-processing plant for curing wood. Polychlorinated biphenols in the organic chemical plants' waste are fed directly into the wood-preserving plant to supplement product PCP raw material for wood preserving.

An EBIC showing complete reuse of all wastes by both plants resulting in an uncontaminated water environment is shown in Figure 18.6. Here, waste phenols and acids from the chemical plant are used as feed supplements for the wood-preserving plant, as is a portion of the PCP product. The wood-preserving plant sends its wastes to

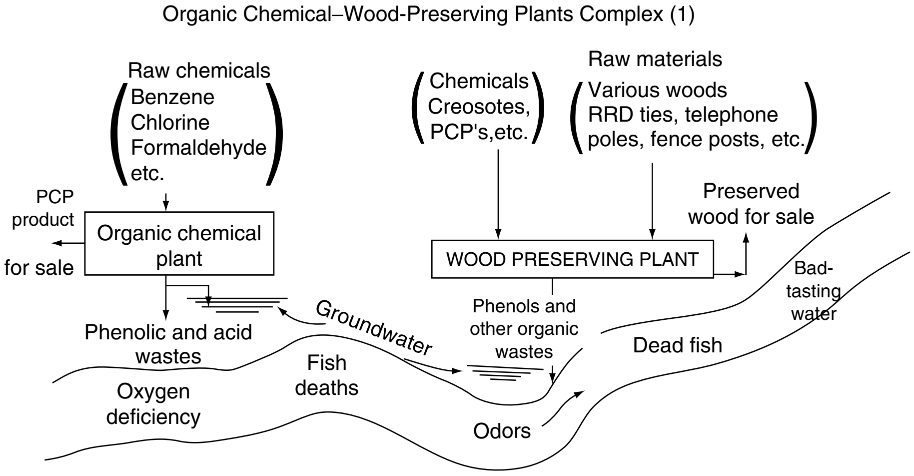


FIGURE 18.5. Organic chemical–wood-preserving plants complex.

TABLE 18.2
Wood-Preserving Processes

Wood Conditioning	*Wood Impregnation with Preservative*
To reduce moisture and increase permeability	To provide toxicity to all forms of wood destroyers
Drying usually by air seasoning, sometimes by kiln seasoning	A. With or without air pressure, always with pressure-closed tanks B. Sometimes without pressure and superficial application of oils
Conditioning usually by steaming under pressure	A. Waterborne preservatives use surface retention primarily
Green Wood	
Products	B. Oil-borne (creosotes) use deep penetration (pentachlorophenols),
Wastes resulting mainly steam condensates crankcase oil drainings boiler blowdowns	mainly separated vacuum or pressure water condensates from retorts and drippings from withdrawn treated wood and charge
Wastes character lignous and cellulosic, sugar organic matter	$ZnCl_2$, As, Cu, Cr, F, and B from use of waterborne preservatives, phenols, coal tar, creosote, petroleum, aldehydes, PCP, and copper naphthenate from use of oil-borne preservatives toxicity, refractory-
Objectionable qualities and recommended treatment Color, odor, and oxygen demand keep out of ground biological treatment concentrate and burn	nature, color, odor, acid pH keep out of ground collect all unusable waste contain all in impermeable facility for reuse,incineration for exportation for recovery or disposal

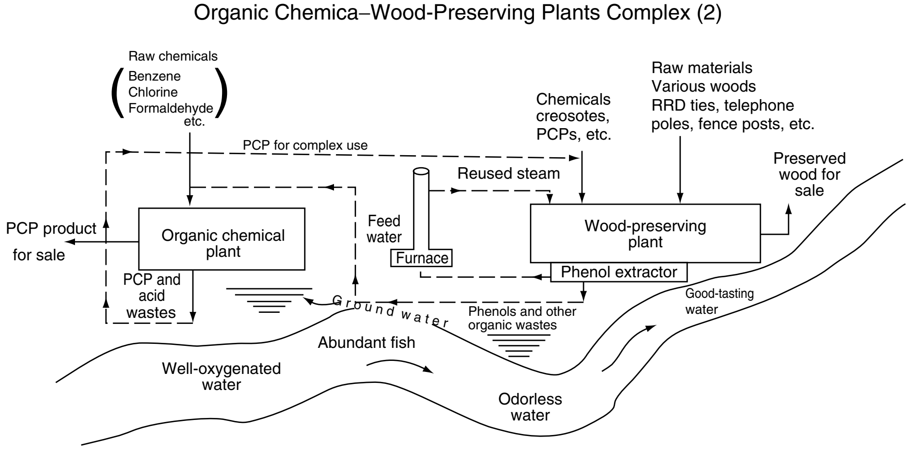


FIGURE 18.6. Organic chemical–Wood-preserving plants process.

a phenol extractor and the purified phenol back to the chemical plant for raw chemical supplement, while the other organic wastes from the extractor are burned in an incinerator. Steam from the incinerator is fed into the wood plant for heating the soak drums. No wastes are discharged into the groundwater or river and raw materials of both plants are supplemented by reused wastes.

E. Biomass Power Plant–Municipal–Forestry–Agriculture Complex

When power plants generate electricity by burning fossil fuels such as coal or oil, they also produce noxious, odorous, and greenhouse gases, as well as potential toxic residual unburned ash.

At the same time, when cities treat their wastes to produce sludges, foresters grow trees that result in waste trimmings, barks, and sawdust, farmers grow sugarcane and leave stalks, and other farmers graze animals that deposit various defecated sludge solids, pollution of the air, land, and water also results. Some of these solids are burned in the field creating air pollution, and some contaminate the land and groundwater and even surface water supplies during runoff periods.

When both the power plant facility and the biomass producers are located in one complex, many of these adverse environmental effects are eliminated. One potential configuration of this complex is presented in Figure 18.7.

Reicher (1999), an assistant secretary at the U.S. Department of Energy, believes that biomass can be used as an alternative to the traditional fossil fuels for producing electricity and other products.

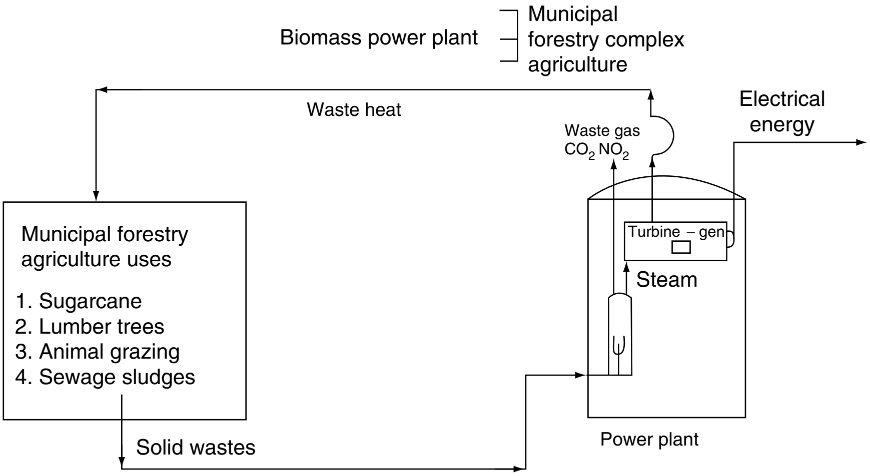


FIGURE 18.7. Biomass power plant–municipal–forestry–agriculture complex.

Reicher (1999) also believes that we will soon see federal legislation that encourages the use of biomass, perhaps as part of a larger electricity restructuring initiative. This indeed is good news for our EBIC concept, which includes the power plant in this case. Biomass, rather than fossil fuel, has the advantages of being diverse in origin and of releasing substantially less carbon dioxide into the air. Biomass also possesses much less, if any, mercury and sulfur, as do fossil fuel, and releases less (~20% less) nitrogen oxide when burned than fossil fuels.

Because biomass represents a renewable resource, environmental engineers should make every effort to use it to produce electrical energy even when not incorporating it into a complex. But using it in a complex, such as suggested in Figure 18.7, appears to be even more environmentally preserving and economically advantageous.

Waste heat contained in the turbine condensate of the power plant can also be reused to heat the facilities that produce the biomasses in the first place.

The city of Fallbrook, California, is considering building a large power plant fueled by burning green waste produced by agricultural and home wastes, turn it into electricity, and sell the power to San Diego Gas and Electric Company (SDGE) for distribution to its customers (McCormac 2003). A contract between SDGE and the developer of the complex calls for the plant to produce 40 MW of electricity per day to supply about 40,000 homes (1,000 MW/household) in 2006.

F. Steel Mill–Fertilizer–Cement Complex

Steel mills are actually five separate industrial plants in one, consisting of the following: (1) coke plant, (2) iron ore reduction plant, (3) steel production, (4) hot rolling mill, and (5) cold rolling mill. Predominant wastes originate from the coke and steel plants, although certain dusts, slag, and iron also come from the other plants.

Troublesome waste products include ammonia, cyanide, phenol, heat, and acidic ferrous sulphate or chloride pickle liquor. Steel mills also use huge volumes of water, mostly for cooling and quenching the steel ingots, and produce large volumes of air, water, and solid contaminants. They have developed a worldwide reputation as one of the most polluting industries of modern times. At the time of this writing, about 20 U.S. steelmakers had filed for Chapter 11 bankruptcy law protection since 1998, in part due to a glut of steel that sent prices to 20-year lows (Mathews 2001). Domestic steelmakers have tried to reduce their debts by increasing prices for specialty steel. However, domestic steel makers are also hurting because of poor investments, inefficient capacity, and failure to be competitive (Mathews 2003). By using this industrial complex, the steel will be more competitive because production costs will be lowered.

As already mentioned, I described this industry and recommended solutions to its waste-treatment dilemma in 1976. These plants require so much land area and employ so many people that their location in a separate industrial complex would be a natural development. Fertilizer and building material plants are likely candidates to join the complex as auxiliary industries. I have proposed and presented such a complex in Figure 18.8.

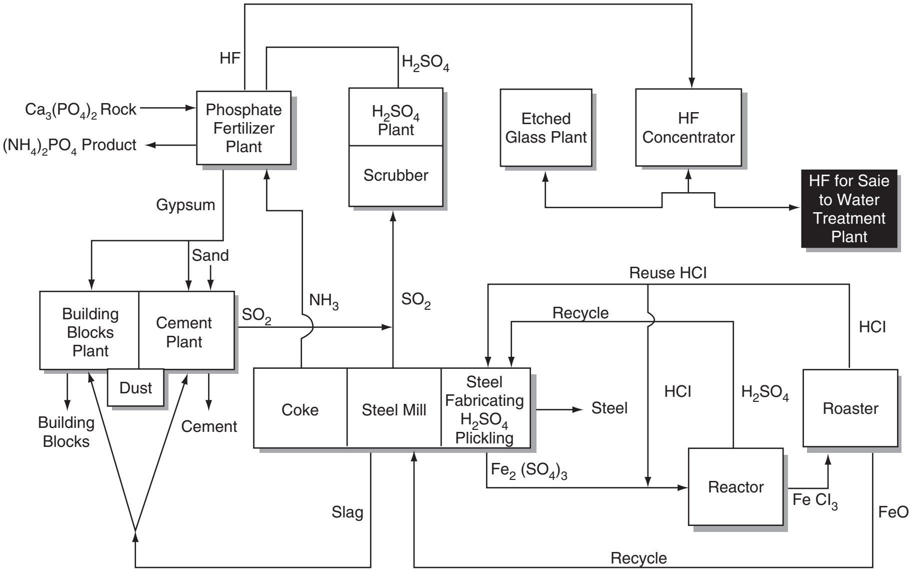


FIGURE 18.8. Steel mill–fertilizer–cement complex.

G. Fossil-Fueled Power Plant Complexes

Electric power plants face the task of producing more electricity at lower cost while minimizing external damage to the surrounding environment. This is increasingly more difficult to accomplish because of the problem of obtaining permits for producing nuclear power, the polluting characteristics of both oil and coal fossil fuels, and the untried utilization of more sophisticated wind-, solar-, and hydrogen-generated power. Because fossil-fueled power plants are currently cost effective and generally acceptable to the public, it is reasonable to use this type of fuel and attempt to ameliorate or abate adverse environmental consequences. The challenge is to accomplish this effectively, that is, at a minimum production cost and with little or no adverse external environmental consequences. To do this, one needs a more complete knowledge of the background of coal-fired power plants.

Coal-fired power plants generate the majority of electricity in the United States. For example, in 1986 these electric utilities produced 2,487.3 billion kilowatt-hours (kWh) of electricity, about 56% of the nation's total production for that year ("Monthly power plant report" 1986).

The U.S. Department of Energy encouraged the use of coal as a principal fuel (in lieu of gas or oil) by the electric utility and industrial sectors. Combustion residues from coal-fired power plants—fly-ash, bottom ash, boiler slag, and fuel gas desulfurization (FGD) sludge—are currently exempted from the Resource Conservation and Recovery

Act (RCRA), which requires the Environmental Protection Agency (EPA) to promulgate regulations for the disposal of hazardous and nonhazardous wastes ("Impacts of proposed RCRA" 1987).

On the basis of chemical origin, the EPA categorizes wet waste streams for the steam electric power-generating point source category as follows:

1. Once-through cooling water
2. Recirculating cooling system blowdown
3. Fly-ash transport discharge
4. Bottom-ash transport discharge
5. Metal-cleaning wastes (air preheater, fireside wash, etc.)
6. Low-volume wastes (boiler, evaporator, softener blowdowns, sanitary wastes, drains, etc.)
7. Ash pile runoff
8. Coal pile runoff
9. Wet flue gas cleaning blowdown

It should be noted that cooling water and wet ash handling systems and flue gas scrubber processes constitute the major discharge volume. Mean discharge flow rate per installed capacity from once-through cooling water systems is approximately 900 times as much as that from recirculating cooling water systems.

However, discharge from one-through systems is relatively clean and does not need treatment before discharge. General description of systems handling major wastewater streams are as follows:

Cooling water systems: In a steam electric power plant, cooling water absorbs the heat that is liberated from the steam when it is condensed to water in the condensers. Depending on the size, location of the power plant, and availability of a water body into which it is being discharged into, there may be either of the cooling water systems, once-through and recirculating, described as follows:

Once-through cooling water systems: In a once-through system, the cooling water is withdrawn from the water source, passed through the system, and returned directly to the water source. Discharge flow rates from such a system in coal-fired power plants may reach up to 55.4 million gallons per day (mgd)/MW. In the United States, about 65% of all power plants have once-through cooling water systems.

Recirculating cooling water system: In a recirculating cooling water system, the water is withdrawn from the water source and passed through the condensers several times before being discharged to the receiving water. After each pass, the heat is removed from the water by three major methods: cooling ponds or cooling canals, mechanical draft evaporative cooling towers, and natural draft evaporative cooling towers. Discharge from such a system in coal-fired power plants may reach up to 63,057 gal/day/MW.

Ash-handling systems: The chemical compositions of both types of bottom ash (i.e., dry or slag) are quite similar. The major species present in bottom ash are silica (20–60% as SiO_2), alumina (10–35% as Al_2O_3), ferric oxide (5–35% as Fe_2O_3), calcium oxide (1–20% as CaO), and small amounts of metal oxides. Fly-ash generally consists of very fine particles. The major species present in fly-ash are silica (30–50% as SiO_2), alumina (20–30% as Al_2O_3), and others including sulfur trioxide, carbon, boron, and so on. Distribution between bottom ash and fly-ash varies depending on the type of boiler bottom. Typically, bottom ash to fly-ash ratio is 35:65 for wet bottom boilers, and it is 15:85 for dry bottom boilers (Costle 1980). Wet ash handling (sluicing) systems produce wastewaters that are currently either discharged as blowdown from recycle systems or discharged directly to receiving streams in a once-through manner. In a coal-fired power plant, wet ash handling system discharges may change reaching up to 16,387 gal/day/MW for fly-ash ponds and 38,333 gal/day/MW for bottom ash ponds.

Flue-gas desulfurization processes: In the lime or limestone flue-gas desulfurization processes, SO_2 is removed from the flue gas by wet scrubbing with slurry of calcium oxide (lime) or calcium carbonate (limestone). The principal reactions for absorption of SO_2 by slurry are

$$\text{lime: } SO_2 + CaO + \tfrac{1}{2}H_2O = CaSO_4 \cdot \tfrac{1}{2}H_2O$$

$$\text{limestone: } SO_2 + CaCO_3 + \tfrac{1}{2}H_2O = CaSO_3 + \tfrac{1}{2}H_20 + CO_2.$$

Oxygen absorbed from the flue gas or surrounding atmosphere causes the oxidation of absorbed SO_2. The calcium sulfite formed in the principal reaction and calcium sulfate formed through oxidation are precipitated as crystals in a holding tank. The potential exists to use calcium sulfite in manufacturing cement within the proposed complex.

Background on Cement Manufacturing Plants

Portland cement is made by mixing and calcining calcerous and argillaceous materials in the proper ratio. Table 18.3 summarizes the relative amount of raw materials consumed for the production of Portland cement (Shreve and Brink 1977).

It can be observed that limestone represents the major amount of the raw material consumed.

Unit processes involved in cement manufacturing include storage and mixing of raw materials, drying, grinding and crushing, calcining, clinker storage, finishing additives and ball milling, and packaging for delivery. A schematic diagram of a typical rotary steam kiln boiler and isometric flowchart for the manufacturing of Portland cement is shown in Figure 18.9.

For each 100 barrels of finished cement by the dry process, 297,872 Btu of fuel as well as 6.4 kWh of electricity and 8 gall of water are required. Also required are 132 lb of limestone, 33 lb of shale, and 4.3 lb of gypsum (Shreve and Brink 1977).

TABLE 18.3
Amount of Raw Materials Consumed for Production of Portland Cement

Raw Materials	*Amount Consumed in 1981 (thousands of metric tons)*
Cement rock	24,204
Limestone	66,380
Clay and shale	8,536
Sand and sandstone	2,298
Blast furnace slag	86
Gypsum	3,272
Iron materials	1,040
Fly-ash	688
Miscellaneous	3,149

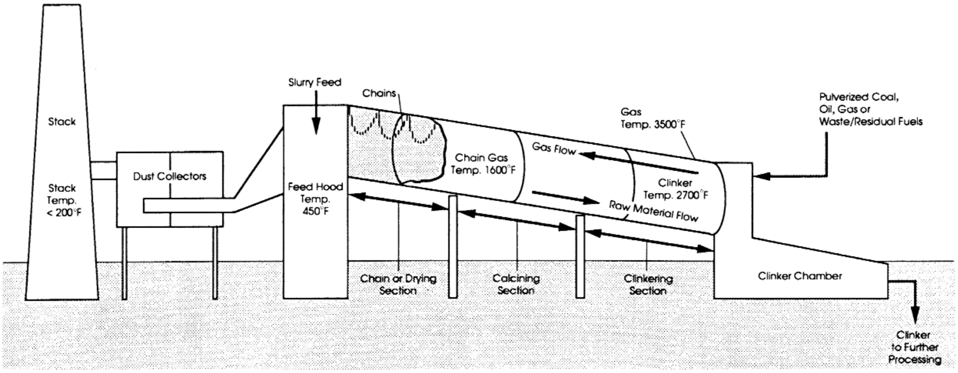


FIGURE 18.9. Schematic diagram of a typical rotary steam kiln boiler.

Background on Concrete Block Manufacturing Plants

The aggregates used for mortars and concretes can be conveniently divided into dense and lightweight types. The former class includes all the aggregates typically used in mass and reinforced concrete, such as sand, gravel, crushed rock, and slag. The lightweight class includes pumice, furnace clinker (or cinders in the United States), foamed slag, expanded clay, shale, and slate.

Environmentally Balanced Industrial Complex

An EBIC has been proposed for a coal-fired power plant in the schematic flow diagram shown in Figure 18.10A. The complex consists of three industrial plants, including a coal-fired power plant, and two ancillary plants: cement and concrete block manufacturing plants. The coal-fired power plant has the following waste streams:

1. Recirculating system cooling water blowdown
2. Boiler/evaporator blowdown
3. Fly-ash discharge
4. Bottom-ash discharge
5. Flue-gas discharge

Cooling water blowdown, boiler blowdown, and evaporator blowdown are determined to be the major wet waste streams from a coal-fired power plant. These streams will be directed to the kiln steam boiler in the cement manufacturing plant, as shown in Figure 18.10A.

Sulfur dioxide, which is released during the combustion of coal, will be scrubbed with lime/limestone slurry. The calcium sulfate formed after oxidation will then be utilized in cement manufacturing plant as a cement additive.

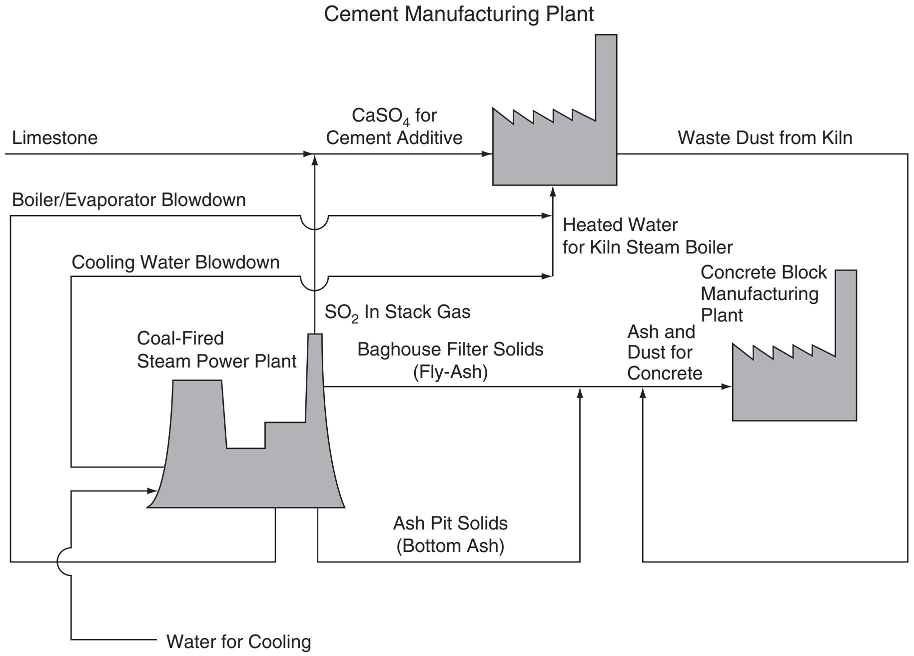


FIGURE 18.10A. Schematic flow diagram of the EBIC for power plant industry.

Waste dust from the kiln steam boiler in the cement manufacturing plant, as well as fly-ash and bottom ash formed during the combustion of coal in the power plant, will be transported to the concrete block manufacturing plant. These solid wastes will be used in the production of concrete blocks.

Reduction in Production and Environmental Costs

According to the proposed theory and obvious implementation of this zero pollution solution, production costs must decrease. Likewise, by eliminating industrial waste treatment, environmental costs must also decrease. The latter is especially valid when we include the benefits of eliminating adverse environmental impacts caused by the plant wastes. The sum of these two positive cost savings should be significant.

Nemerow (1987) reported as an example, that savings alone within a textile mill complex was $52.69/1,000 lb of cotton fabric from a typical small mill (12,000 lb of cotton fabric per day). From a preliminary study, the total environmental savings (from eliminating waste treatment) appeared to be greater than $104/1,000 lb of fabric. To both of these savings, we must add the savings from transportation of raw cotton and sized woven goods. In one instance and presuming a typical transportation cost in the southeastern United States, if $0.026/lb of cotton shipped, we can add $343/1,000 lb of fabric produced. The total savings of these three costs are almost $500/1,000 lb of cotton fabric produced. To allow the reader to grasp the significance of this, these savings represent 77% of the cost of cotton required ($590/1,000 lb of cotton) (*New York Times,* April 12, 1988, p. 48).

Simple Coal-Fired Power Plant Complexes

Almost half of all energy produced in the United States originates from burning coal. We still have an abundant supply of coal yet to be mined in the United States. It stands to reason that any future energy plan we use will highlight the use of coal. With that in mind, we should take a look at the environmental problems arising from the use of coal-derived power.

Some coals contain high sulfur contents that when burned give off excessive amounts of sulfur dioxide, an undesirable air contaminant. All coals, when burned, emit great quantities of carbon dioxide from the combustion of carbon. In addition, all coals, even when burned optimally, release both fly-ash into the smokestacks and surrounding air as well as boiler ash as solid waste usually to the land.

Huge capital and operating expenses are needed by these utilities to protect the environment from the detrimental effects of these gases and solid wastes. The utilities claim that they are not able to pass such costs on to the consumer without exceeding the limit of the consumers' ability to pay.

Without debating this last assertion by the utilities, it falls on the environmental engineer to provide some assistance. I have already proposed a rather complicated three-industry environmental complex in Figure 18.10, which may not be suitable in all instances where an isolated coal power plant is located. What is needed here is a simpler, easily applied form of complex that can be used in most cases with an isolated coal-fired power plant.

The advent of the problem of global warming (caused by an excess of combustion gases such as carbon dioxide) and a country-wide energy shortage (demanding more coal-fired power facilities along with other forms of energy) cause our current dilemma: how to produce more energy in an environmentally friendly way!

In 1999, for example, 2.265 billion metric tons of CO_2 resulted from all electric power generation, about one-third of the CO_2 released from all sources that year (Bradsher and Revkin 2001). American Electric Power is mentioned as “accepting the idea that government limits on carbon dioxide and other greenhouse gases are inevitable.”

I propose here two rather uncomplicated and readily adaptable types of industrial complexes to contain both the coal-fired power plant and another compatible industrial plant. These are shown in Figure 18.10B. In case one, that plant would simply

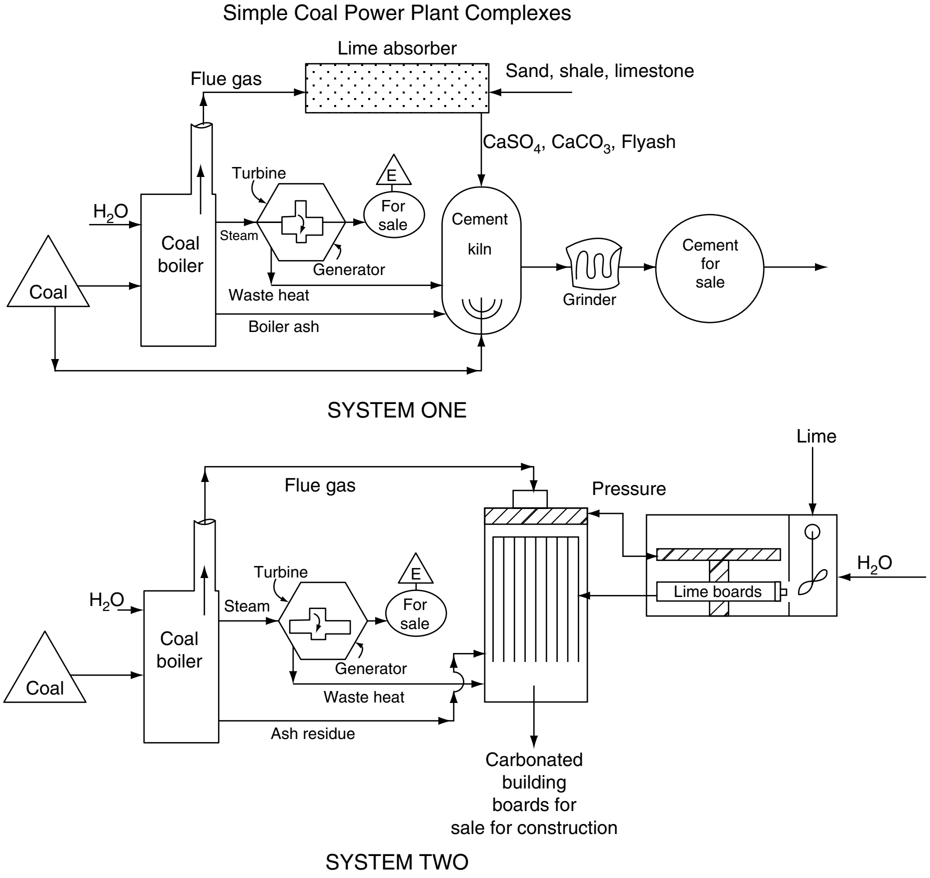


FIGURE 18.10B. Simple coal power plant complexes.

manufacture cement that would incorporate the three contaminants SO_2, CO_2, and fly and boiler ashes. The product cement may not be as high quality as Portland-type cement but would be usable, generate a profit, and eliminate the environmental contaminants of the coal plant.

The other complex, case two, would include a low-cost carbonated building board, which would be structurally sound for a limited number of construction purposes. It would contain the dusts and ashes from the combustion of coal and the chemically converted $CaCO_3$ and $CaSO_4$. The dusts and ashes may even lend a decorative appearance to the board, which will be strengthened by these solids and the carbonates and sulfates.

The key fact here is that no costly waste treatment would be required by the electric utility. The steel industry has been in desperate need of such cost-saving systems to survive in the global market. As proof of this cost-saving need by the steel industry, President Bush put tariff restrictions on foreign steel imports. "The administration expects the industry to use the tariff cushion to consolidate and rationalize operations, reduce costs, enhance efficiency, increase productivity, improve quality and service, and develop new products and markets" ("Steelmakers get Bush" 2002). In addition, the profitability of the ancillary cement and/or board plants would be ensured by the free supply of a portion of their raw materials and perhaps a partial subsidization of their operation by the owners of the industrial complex or by a government entity.

H. Plastic Industry Complexes

Plastics and resins are chainlike structures known chemically as *polymers*. Polymers are synthesized mainly by adding a free radical initiator and a modifier to the monomer (the building block of the polymer). Although not a great deal of wastewater arises from the polymerization process, more results from synthesizing the original monomer.

As long ago as 1967, the U.S. Department of Interior classified plastics in nine categories, but we are primarily interested in only two predominant types: polystyrene and polyolefins. In 1967, these types made up 46% of the total plastics and resins produced (Nemerow and Dasgupta 1991).

Polystyrene's combination of physical properties and ease of injection molding and extruding makes its use desirable. The crystal-clear product has excellent thermal and dimensional stability, high flexural and tensile strength, and good electrical properties. Styrene monomers (or mixtures) are purified by distillation or caustic washing to remove inhibitors. The purified raw materials, together with an initiator, are fed to a stainless-steel or aluminum polymerization vessel, jacketed for heating and cooling and contain an agitator. Polymerization of the monomer is carried out at about 90°C to approximately 30% conversion to create a syrupy mass. Water is used during this stage as a heat-exchange medium and is recirculated without contamination. Then the syrupy mass is transferred to suspension-polymerization reactors containing water and proprietary suspending and dispersing agents. These reactors are usually jacketed, and the contents stirred in stainless-steel vessels.

The syrupy mass is broken into droplets by means of the stirrer and held in suspension in the aqueous phase. Temperature is a critical variable in further polymerization of the product. The polymer is then sent to a blowdown tank where any unreacted monomer is stripped. The stripped batch is then centrifuged, and the polymer product is filtered, washed, and de-watered. A flowchart of this manufacturing process is presented in Figure 18.11 to aid you in following the manufacturing process.

Reaction water (suspension medium) and wash water are the two significant sources of wastewater from the manufacturing of polystyrene. They are shown in figure 18.11 as wastes A and B. About 1.5 gallons of water, excluding cooling water, is used and wasted for each pound of polystyrene produced. These wastes are not very polluting; they contain small amounts of catalyst and suspending agents used in suspension polymerization and heated water (120–180°F).

The catalysts are generally of the peroxide type, and the suspending agents may be methyl or ethyl cellulose, polyacrylic acids, polyvinyl alcohol, or miscellaneous compounds such as gelatin, starch, gum, casein, zein, and alginate. Inorganic materials such as calcium carbonate, calcium phosphate, talc, clay, and silicate may also be present in effluent reaction water. No plants employing typical technology have waste-treatment units; instead, 90% discharge these wastes into municipal sewers.

Polyolefins (polyethylenes) are composed of many different molecular weights from waxes of a few thousand to molecular weights of several million. Polyethylene is used for film and sheet, injection molding, blow-molded bottles, cable insulation, coatings, and other products.

There are two processes for manufacturing polyethylene: one for a low-density and the other for a high-density product. Both start with ethylene as the raw stock material. Heat, pressure, catalysts, and solvents are reacted with the ethylene, and then the product is purified by various unit operations, as shown schematically in Figures 18.12 and 18.13.

Both processes produce little wastewater. However, potential hazards that may generate water-borne waste are improper operation, spills, and wash-down of equipment and facilities. Typical process wastewaters contain a BOD of less than 10 ppm (U.S. Department of Interior 1967).

The Ultimate Plastic Problem

According to Sherman (1989), the United States produces 60 billion pounds of plastics annually, and sales of plastic products exceed $150 billion a year. By this year, 2000, the U.S. output may reach 76 billion pounds. Thayer (1989) expects plastic waste to reach 38 billion lb/yr by 2000 and to account for 10% of total municipal solid waste.

Because plastic production wastes are minimal as far as contaminants are concerned, little or no waste treatment is done at plastics manufacturing plants. This industry is rather unique in that the major wastes and environmental costs occur during and following the use of plastic products, which makes plastic waste treatment very difficult.

Until the late 1980s, most plastic products were disposed of in municipal solid wastes and were given the same treatment as these wastes. Landfilling and incineration were the predominant systems for plastic waste treatment for solid wastes.

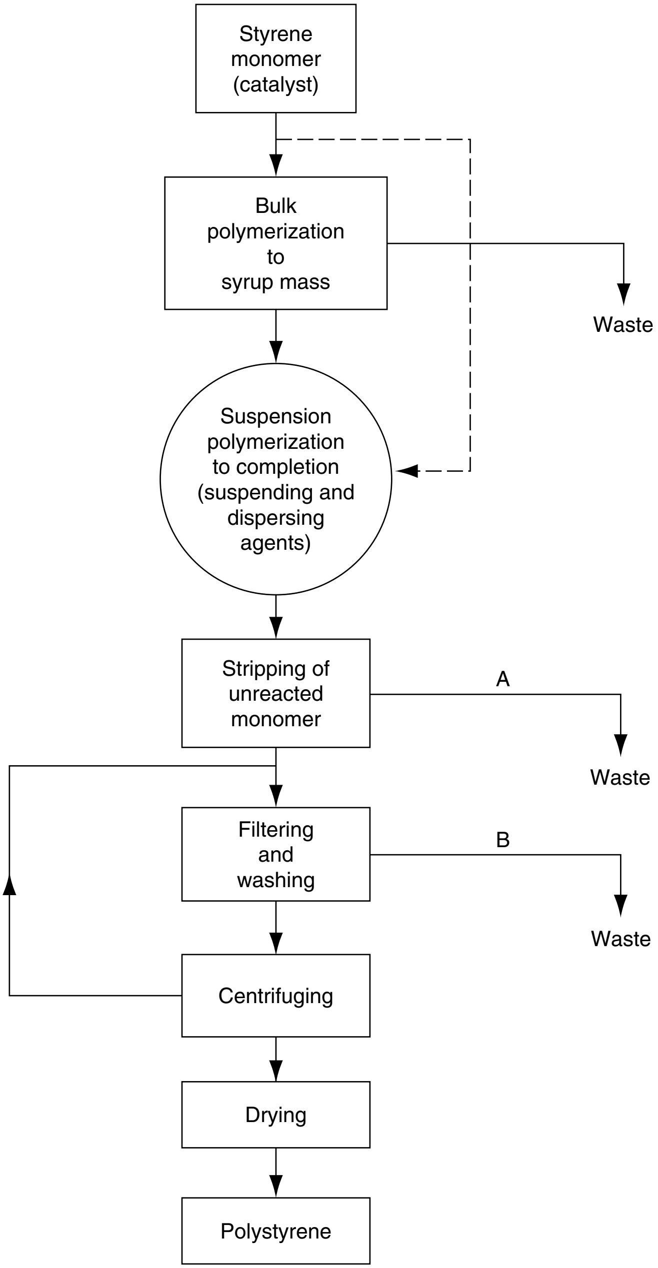


FIGURE 18.11. Flowchart for polystyrene production.

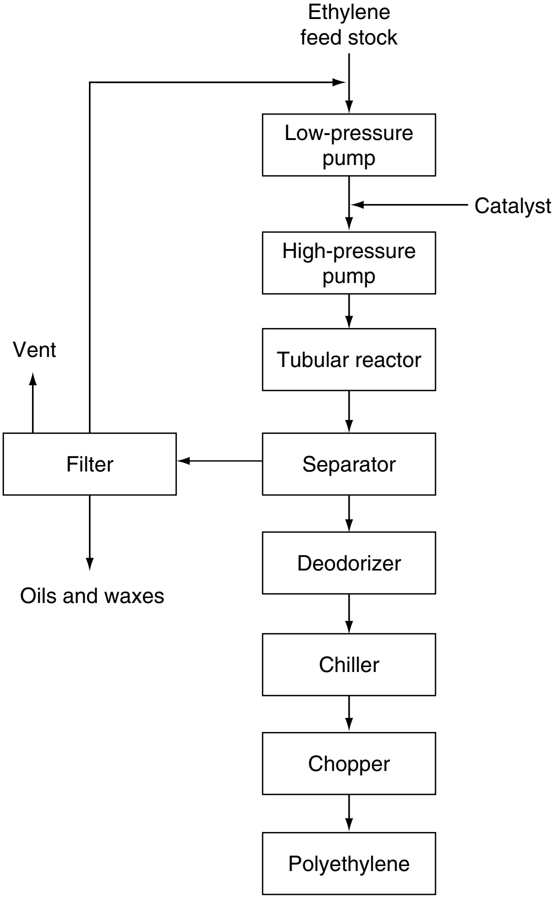


FIGURE 18.12. Tubular reactor process for low-density polyethylene production.

Cheremismoff and Cheremismoff (1989) report that “the option of landfill as a disposal method is rapidly diminishing.” For example, the number of legal landfills declined from a 1976 figure of 18,000 to 9,000 in 1989. Not only are landfill sites diminishing, but costs and limits for disposal of plastic materials are increasing. Plastics degrade slowly in soils relative to other ingredients in municipal solid wastes. Because we are rapidly approaching a crisis in the treatment/disposal of plastics, we must seek alternative and new methods.

The best choice, according to Sherman (1989), is waste-to-energy incineration. Most plastics ignite as easily as natural gas and emit CO_2, NOxs, and H_2O vapor. However, some plastics, mainly PVCs, can adversely affect the air environment. These PVCs, unless burned at more than 1,200–1,600˚F, will evolve hydrochloric acid, which

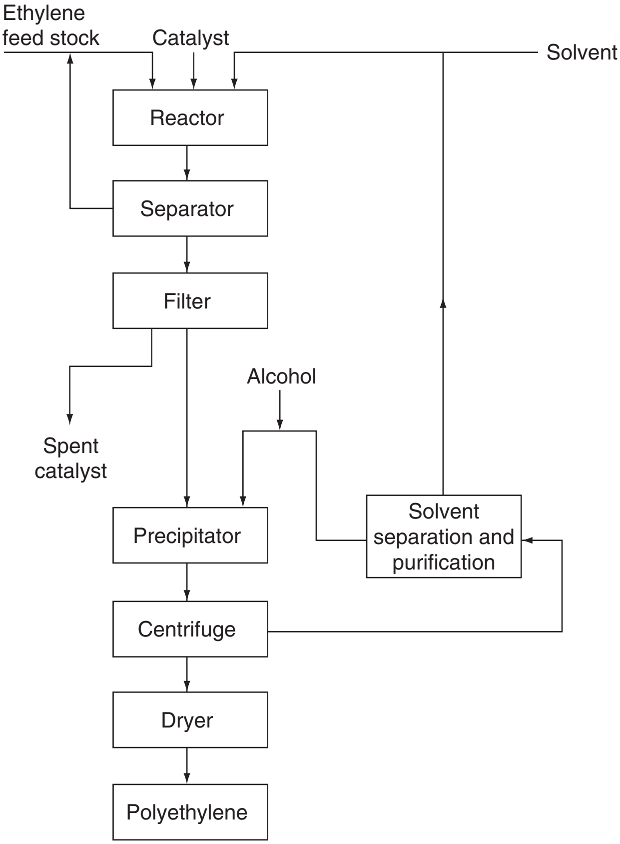


FIGURE 18.13. Philips process for high-density polyethylene production.

is corrosive to metals and antagonistic to humans who come in contact with the acid. Some other plastics contain cadmium or other heavy metals that remain unburned in the incinerator ash. Such metals are toxic when they enter the water environment through landfill leachates. One advantage of incinerating plastics is the high heat energy released from the burning: about 16,000 Btu/lb. Some waste-to-energy type of plants, which are rather expensive to build (~$100,000/ton/day) are described in *Industrial Solid Wastes* (Nemerow 1984).

Other potential problems with incineration as a method of treatment/disposal for plastics include enhancement of the "greenhouse effect" and ash disposal. The burning emits CO_2, which keeps the heat energy rays (infrared) from escaping the earth. The subsequent heating may alter the earth's climate, affecting agricultural output and ocean levels. However, there is still much controversy about any true CO_2 increase in the atmosphere. Even so, the small increase in CO_2 may also stimulate increased tree and plant growth. These green growths will evolve oxygen into the atmosphere and oceans to aid in their purification.

The ash resulting from incineration may constitute about 10% of the waste burned, contain heavy metals, and be expensive to dispose of by normal processes. Some progress has been made in using ash as an additive in concrete products meeting utilization specifications.

Another possibility for eliminating the plastic disposal problem is using waste plastics to make other useful products. Rubbermaid Company, for example, makes trash containers in Winchester, Virginia, out of reused plastic chips (Sherman 1984). Lehrman owns BTW, a company that reprocesses used plastics to make woodlike fence posts, car stops, and picnic tables (Kollin 1991). Main reprocessing units include pulverizers, extruders, and other pressure from machinery. The cost of reused plastic varies from $0.23 to $0.40/lb, almost as much as virgin resins ("Profitability problems plague" 1990). Prices, however, do not present the problem that collection and separation of the different plastics cause. Recycled polyethylene can also be used for carpet fibers, and polystyrene is used for a variety of durable goods such as office supplies, hair accessories, cafeteria trays, license plate holders, and loose-fill packing material.

At this point in the solution to the problem, I suggest, once again, the use of a plastic industry environmentally balanced complex. However, in this case, I propose merging only two facets of the plastic industry: virgin plastic manufacturing and recycling plastic collectors. Such mergers would result in recycled plastic products similar to the originals. An example of such a complex is shown in Figure 18.14.

Some limits on quantity and quality of recycled plastics and additions of processing equipment undoubtedly will be necessary to optimize the complex. However, the merger appears worthwhile to both industries. The plastic manufacturer will have lower raw material costs and recyclers will not have typical marketing problems with the final product. In addition, as usual no wastes result from the complex and a considerable plastic solid waste problem will have been removed from the environment.

I. Cement–Lime–Power Plant Complexes

In many cases, it is possible to combine more than two industries in a complex to more fully utilize all waste products and optimize production costs. Such a situation exists in the manufacturing of cement, lime, and power.

The separate production of cement and coal-fired power production has already been presented and shown in Figure 18.10. I refer you to this earlier material for review of their manufacturing materials processes and wastes. Here, I present the background of lime manufacturing and illustrate how it would work into the complex concept.

Lime production is an ancient industry. Today, lime and limestone are employed in more industries than any other natural substances (Shreve and Brink 1977).

Lime itself is used for medicinal purposes, plant and animal feed, insecticides, gas absorption, precipitation, dehydration, and caustisizing. It is used as a reactant in paper making, de-hairing hides, manufacturing high-grade steel and cement, water softening, recovery of byproduct ammonia, and the manufacture of soap, rubber, varnish,

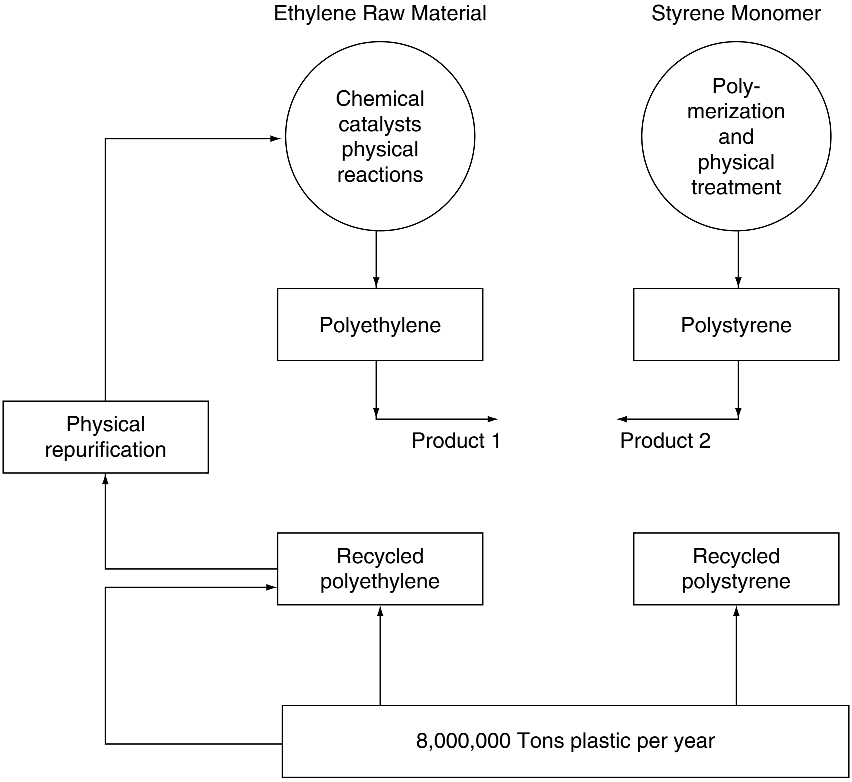


FIGURE 18.14. Plastic manufacturing industrial complex.

refractories, and sand-lime brick. Lime is also an essential ingredient in mortar, plaster, and soil additives.

There are several types of lime, varying with the lime content, water content, and specific use requirements. All types originate with limestone, so lime manufacturing is usually done near limestone mining deposits.

The carbonates of calcium and magnesium are obtained from deposits of limestone, marble, chalk, dolomite, and oyster shells. Quarries are selected that yield a rock consisting of low amounts of silica, clay, or iron and a naturally high concentration of calcium, magnesium, or both.

Impurities can adversely affect the desired hydraulic qualities of the resulting lime. Both overburned and underburned limestone leave undesirable lumps in the product lime.

Considerable energy (power) is required in this industry for blasting limestone out of the mines, for transporting and sizing of rock, and for burning (calcining) it. Calcining requires 4.25 million Btus per ton of lime produced, and subsequent hydration liberates 15.9 kcal. The volume of rock declines during calcining and swells during hydration. The amount of coal required for calcining varies from 1 to 3⅓ pounds (depending on the kiln type) per 3¼ pounds of lime produced. Calcining takes place at 1,200–1,300°C.

The sequence of actual operations in manufacturing lime is: (1) blasting the limestone in the quarry, (2) transporting the stone to the plant, (3) crushing and sizing of stones, (4) screening to remove small (<4 in.) and large (>8 in.) stones, (5) moving the uniform-size stones to a vertical kiln (large size), (6) taking fines to a pulverizer to produce powdered limestone for agriculture uses, (7) burning the limestones in vertical kilns to give lump lime or in a horizontal rotary kiln to make fine lime, (8) packaging of finished lime in barrels or drums or sending it to a hydrator to make hydrated lime, and (9) packaging of slaked lime in bags.

A typical schematic flow sheet is presented in Figure 18.15. An existing complex of this type is already in operation in Brooksville, Florida, as shown schematically in Figure 18.16. The complex is claimed to be "the world's first combination of pulverized coal/fluidized bed combustion boiler producing lime and electric power, integrated with a cement plant. Nowhere else in the state (Florida) is there a facility that's using the waste material from the mining, in the case of limestone fines which could not be sold otherwise, and making major products like Portland cement and lime" (Lawhome 1989).

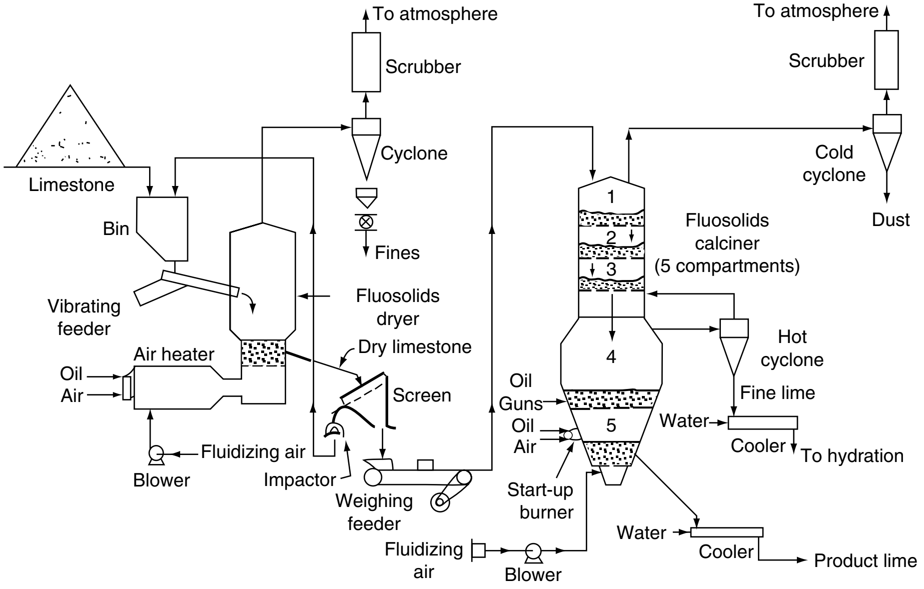


FIGURE 18.15. Fluosolids system (Dorr-Oliver, Inc.).

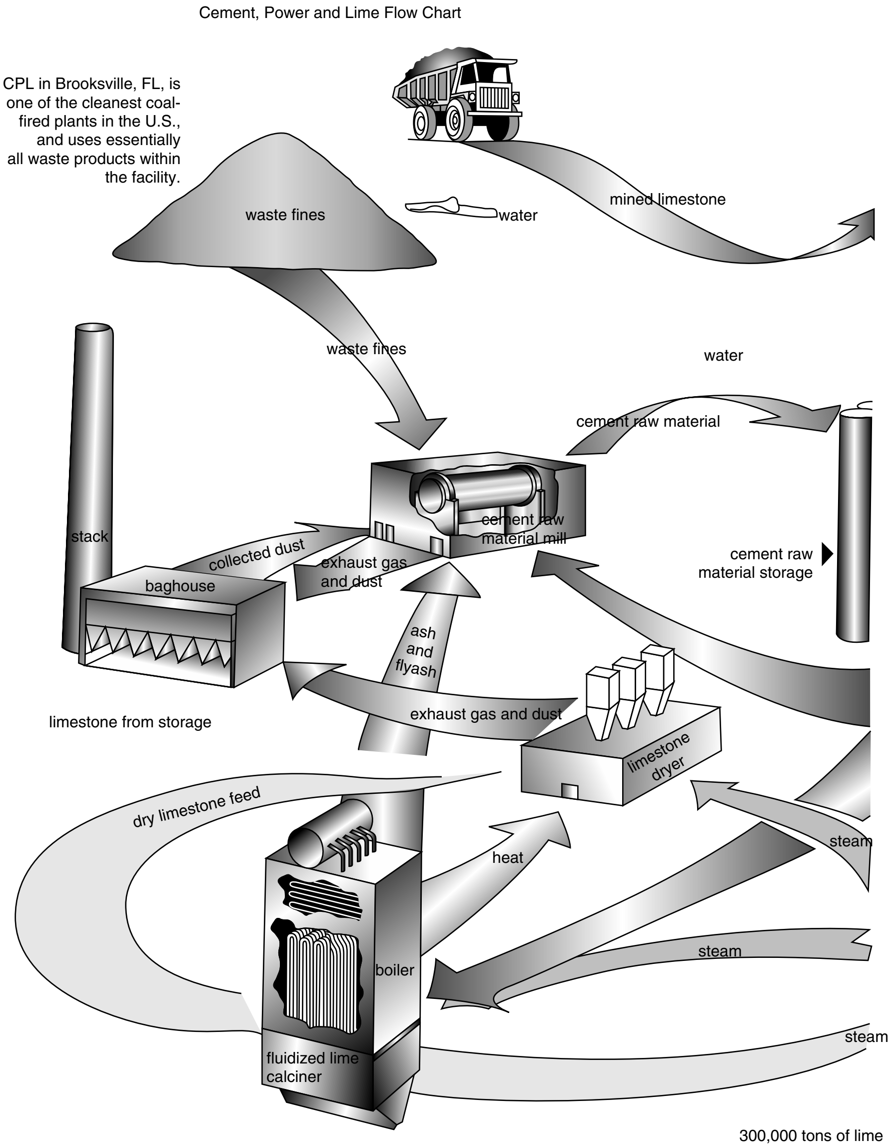


FiGURE 18.16. Cement, power, and lime flowchart. Used with permission from John Wiley and Sons.

The Brooksville plant will produce about 600,000 tons of cement a year and 330,000 tons/yr of chemical lime. The lime or CaO will be used for gas desulfurization, acid pond neutralization, agriculture, or in building products. According to Lawhome (1989), the limestone quarry plant generates about a ton of waste product for each ton of usable stone. The limestone fines are not suitable as an aggregate or as a stable fill material, but do contain large quantities of calcium and silica.

This composition is required in raw material in the manufacture of cement. The plant's energy efficient co-generative design allows the simultaneous manufacture of lime and cement, which, in turn, reduces operational costs of the electrical power plant. Hot air, which comes from the cooling plant cement clinker, is used as combustion air for the power plant boiler. Waste heat in the form of cement produced by the generator is used to dry the limestone at the cement and lime operations. In addition to lower power costs, ash from the combustion of coal in the power plant provides additional iron and aluminum—two cement raw materials that are not present in adequate quantities in the limestone fines.

A state-of-the-art computerized control room, manned 24 hours a day, supervises every aspect of the plant's production facilities. Highly trained personnel monitor production quality to ensure that finished products meet or exceed strict specifications. A chemical analysis department repeatedly tests lime and cement samples for mineral content and consistency.

Initial engineering and design for the cement power and lime cogeneration project got under way in 1982, and production began in 1984. Various components of the facility, including the cement plant, have been in operation since 1988.

Design for the 125-megawatt coal-fired plant was provided by Larramore, Douglass, and Popham, Inc. of Chicago, Illinois. The power produced at this facility will be sold under a long-term contract to Florida Power and Light Company.

J. Wood (Lumber) Mill Complexes

Sawmill and planing mills (Standard Industrial Classification Code 2421) produced more than 162 tons of solid waste per employee as far back as the 1980s (Nemerow 1984). Small producers of lumber and wood products also generated 16,083 yd^3 of solid waste per firm per week, or 836.33 yd^3/firm/yr. This was contributed by 17,247 employees per firm, for an annual discharge of 48,492 yd^3/employee.

Rough lumber from trees is brought to the lumber mill and sawed and planed to appropriate lengths and widths, largely for sale in the housing market. Planing removes the tree bark, and saws produce sawdust in addition to finished lumber product. Most sawmill waste (sawdust and bark) has typically been burned or reclaimed as soil conditioner (Nemerow 1984).

The burning of these solid wastes, though not requiring an outside source of energy, contributes potential air pollutants of unburned carbon and ash. Soil conditioning with these same wastes requires preparation, transporting, and locating a suitable market, all of which cost lumber mill owners time and money.

A potential solution to the problem of sawdust and bark wastes originating from lumber mills is an EBIC in which these wastes are used directly to produce other products. Such a complex is shown schematically in Figure 18.17.

In this complex, the plant will pyrolyze the wastes (sawdust and wood chips) into oil vapors. The vapors are condensed to make fuel oil or other chemicals (product 3). The remaining gases are burned to generate electricity (product 2). Finished lumber, naturally, is the prime product of the complex (product 1). Nonburnable gases such as CO_2, CO, and NOs are also obtained from the condenser/pyrolyzer and used to stimulate the growth of algae in a separate unit operation. This takes place in a greenhouse to use natural sunlight. The algae serves as food for small seafood such as shrimp, which, along with some algae/herbs, are sold as food products (product 4).

Such a complex has been suggested ("Process converts wood waste" 1991) to convert 70–90% of the wood waste into salable products; at the same time, virtually no

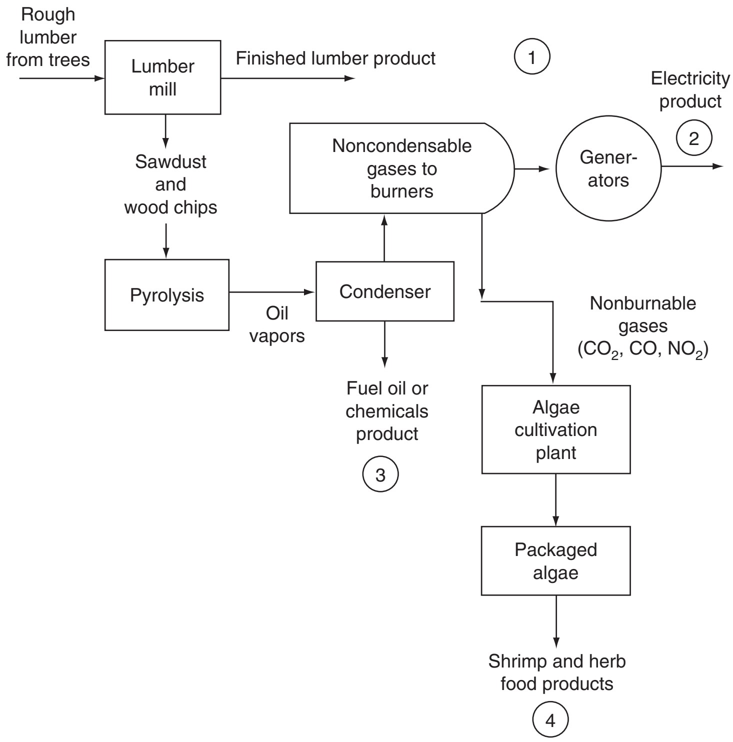


FIGURE 18.17. Lumber mill complex—four products.

pollutants are emitted. There are also possibilities for converting bark and sawdust into other useful products, such as resins and tanning agents from bark and product fillers from sawdust. These would need exploration in individual cases.

K. Power Plant–Agriculture Complexes

Electric power and food are two of the vital necessities for human life. It is imperative that we preserve both industries and produce their products as efficiently as possible. By combining operations in a single complex, we can accomplish two objectives: efficient production and a pollution-free environment.

One possible configuration of combining electric power production and food production is presented in Figure 18.18. In this complex, a low-sulfur fossil-fuel power plant produces three main wastes: (1) heated water, (2) flue-gas fly-ash, and (3) boiler residue ash. These wastes are described in detail in Section G, earlier in this chapter. The heated cooling water is reused within the complex to enhance the growing of fish. Fish will metabolize food faster and thereby grow at a higher rate if the temperature is raised, which is especially significant for colder climates. Aquaculture has more than tripled in size in the last 10 years, with annual U.S. sales of farm-raised bass, salmon, and catfish at $1 billion, and worldwide sales at $40 billion (“A farm for fish” 2000).

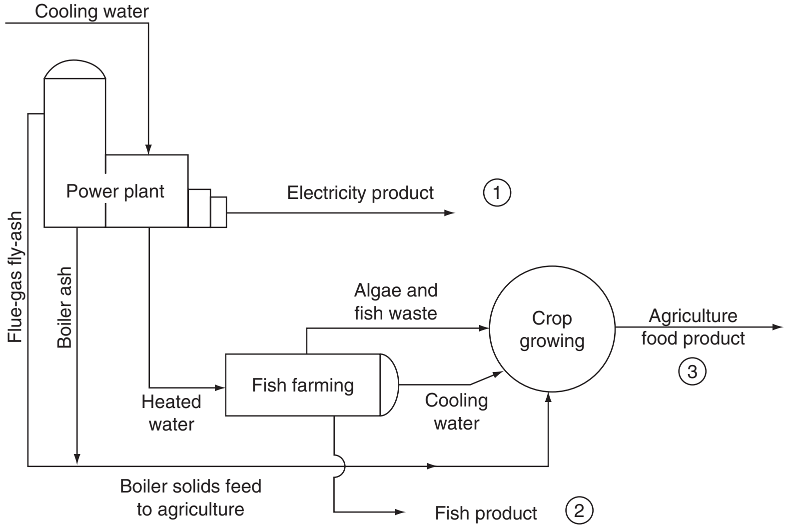


FIGURE18.18. Power plant-agriculture complex.

Both ashes from the flue-gas and boiler residue are fed to the agriculture growing area to enhance the soil. The minerals in these ashes will increase crop growth and yield more food per acre. At the same time, no ash wastes will reach the outside environment.

As shown in Figure 18.18, three products will be sold outside the complex: (1) electric power, (2) fish, and (3) food crops. Algae and fish wastes, produced in the fish-farming waters, will also be reused as fertilizer for the crops. No pollution will reach the air, water, or land environments outside this complex, especially if the power plant uses low- or no-sulfur fuel. This would be possible by using only low-sulfur coal or oil or natural gas as fuel.

The Electric Power Research Institute (EPRI) (2000) announced a new filtration technology that could make aquaculture more efficient. Its improved-recirculation aquaculture systems cost less and provide better filtration than traditional systems, ensuring healthier fish stocks and improved productivity. The EPRI says its filters use waste heat from power plants to harness energy that otherwise would be lost. In addition, the aquaculture systems are relatively small and can be located near urban areas. These systems are claimed to offer a higher degree of environmental control than traditional fishing methods.

L. Cannery–Agriculture Complexes

Canneries are in the business of producing food products for direct consumption by the purchaser. Under most existing conditions, they import fresh fruits and vegetables from considerable distances. This not only results in added costs of transportation but also increases spoilage and waste of raw materials during the travel and extra handling.

It would make good economic sense for canneries to grow their own raw materials within a complex. But because farming is an entirely different enterprise, coordination of farming with the cannery operation would be required. The land areas and their usage required in agriculture must be integrated with the relatively smaller areas of canning. Moreover, the two enterprises require workers with different backgrounds and abilities.

However, if the two plants' processing operations could be combined in one complex, the entire system would be more cost effective. In addition, the normal wastes produced by each plant would be used within the complex to eliminate any adverse environmental impact to the surrounding area. A typical configuration of such a complex is shown in Figure 18.19.

In this complex, the farming industry would grow fruits such as tomatoes and peaches and vegetables such as beans and carrots. These crops would be cut and/or picked in the field and mechanically conveyed directly to the adjacent canning plant for processing. Waste cuttings, rot, and extraneous organic residues remaining after harvesting would be collected and trucked directly to the fermenter for digestion to methane gas.

Runoff from the farming area carrying excess or unused fertilizers and pesticides would be collected in drainage ditches surrounding the growing area. Instead of polluting

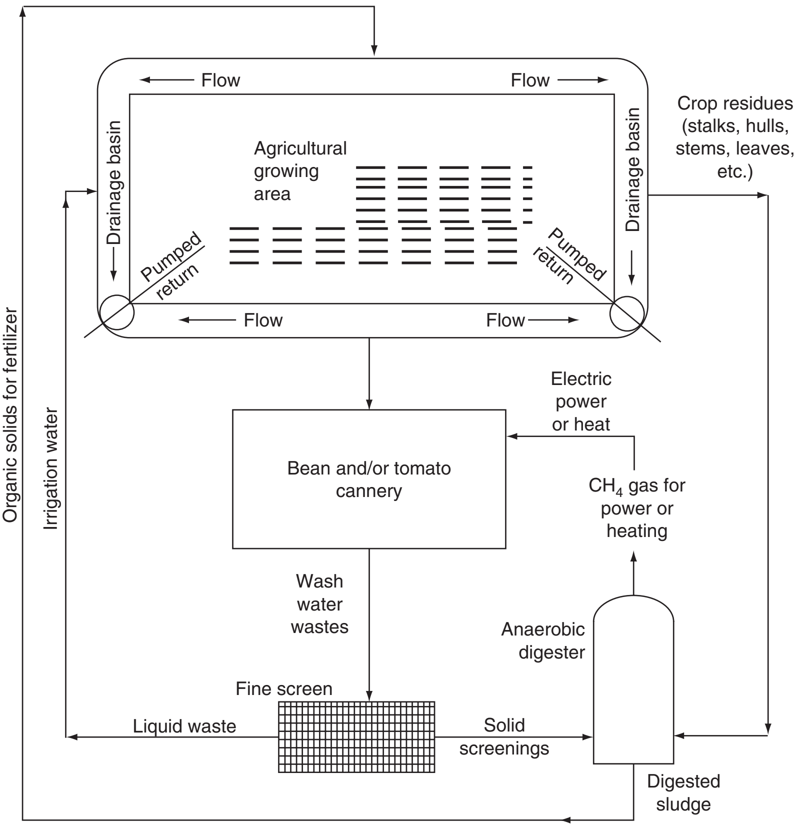


FIGURE 18.19. Cannery-agriculture complex.

the area water environment, this runoff is collected and pumped back to the growing area through perforated aluminum pipelines. In this way, water is conserved, as well as potentially contaminating chemical phosphates and insecticides.

The wastewater from the cannery is screened and returned to the farm growing area as a source of valuable water. The screenings are delivered to the farm to enhance the production of methane gas.

The digester sludge waste, which is distributed on the farmland crop-growing area, increases the fruit and/or vegetable yield because of its value as an organic fertilizer. The methane gas (CH_4) produced by the digester is used internally to heat the cannery buildings, sold externally to heat the cannery buildings, or sold externally to local power plants to produce power for the cannery or local homes of industrial workers.

No wastes leave the complex to cause adverse effects on the environment. Furthermore, canned fruits and vegetables are produced at a minimum cost.

M. Nuclear Power Plant–Glass Block Complexes

One of the biggest environmental concerns facing the world today is the problem of waste disposal from nuclear power plants. Safety hazards appear to be waning as a result of better plant design, operation, and supervision. Low-level wastes have never caused serious environmental problems. Only high-level radioactivity resulting from replacing spent fuel rods has been of serious and ongoing concern to the Atomic Energy Commission (AEC) and to environmentalists. Nuclear energy as a viable alternative to the use of coal or oil fossil fuel is an attractive possibility for the future.

If the environmental consequences of nuclear energy production can be overcome, its acceptance and use will solve an enormous energy dilemma. This involves devising solutions for both the excessive heat releases in the cooling water and the dangerous radioactivity continued in the high-level fuel reprocessing wastes.

A possibility for abating both waste problems is the use of a balanced environmental complex, such as that shown in Figure 18.20. This example complex contains

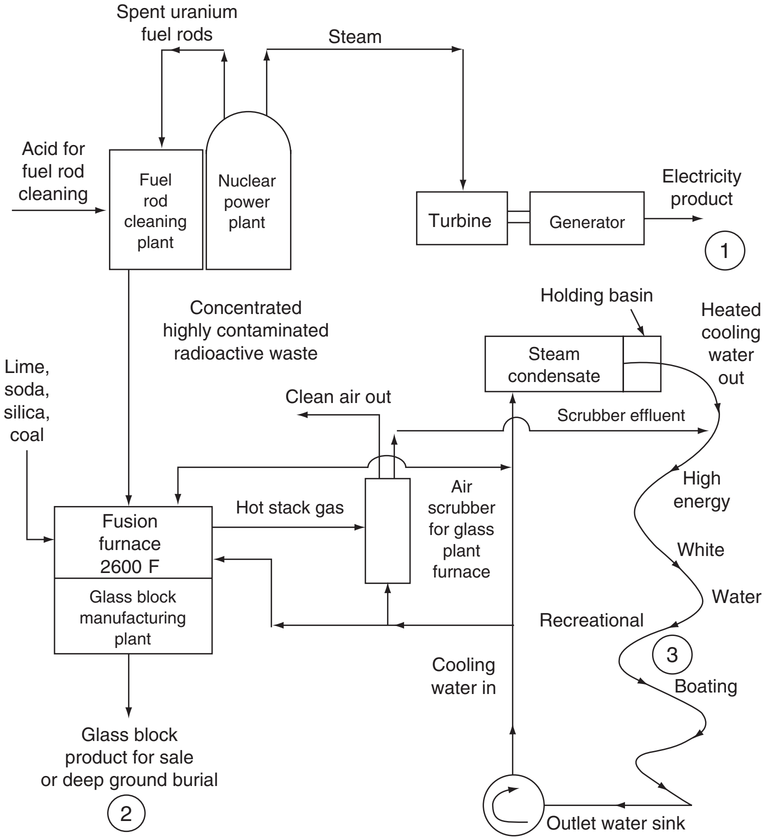


FIGURE 18.20. Nuclear power–glass block complex.

plants producing three major products: (1) electricity, (2) decorative glass blocks, and (3) a recreational boating facility.

Electricity is produced by the nuclear power plant. The cooling water used to condense steam exhausting from the turbine contains excessive heat and high energy. It is used as a source of water for a white-water recreational boating river. This river meanders toward an outlet water sink (lake, river, or ocean), losing its heat and potential energy as it flows downhill and around bends to the outlet. Boating obstacles are placed along the recreational path to enhance the challenge to its users. The outlet sink also serves as the source of cooling water intake for the condenser. Any potential low-level radioactivity leakage from the uranium fuel rods into the stream, and subsequently into the condenser, would be retained in the holding basin, whose effluent is continuously monitored before discharge to the recreational river. Recreation, naturally, would be discontinued during periods in which any release of radiation was detected.

The uranium fuel rods, when reprocessed, are removed to the adjacent cleaning plant where nitric acid and other cleaning agents are added to refurbish the rods. The high-level wastes are concentrated by evaporation before being sent to the block manufacturing plant. Here, lime, silica, soda, and some coal are added, and the mixture is sintered at 2,600°F to form a molten glass product. The liquid glass is poured into blocks, cooled, and removed to be sold after complete monitoring for radiation and testing for physical durability as a decorative building material or buried in deep, dry underground locations for environmental security. The hot furnace gases are precooled by using some of the outlet sink water and then sent to a scrubber to remove any excess sulfur and carbon dioxide.

The scrubber effluent is also returned to the white-water recreational boating river. Thus, no radioactivity or heated water escapes from the complex. Furthermore, a recreational industry is supported, and electricity and glass block products are manufactured at lower total costs than if located in separate places.

In 2000, the federal government reported that it will spend $265 million over at least 9 years to remove safely and store a leaking radioactive waste dump (“Radioactive waste cleanup” 2000). What a waste of both time and money! It could have considered constructing an environmental complex on the dumpsite. This solution could have been done for less than $265 million, taken a shorter time than 9 years, and have been more environmentally safe. The radioactive waste could have been fused and fabricated into decorative glass blocks in an adjacent block manufacturing plant. The block plant could produce a product for sale outside the complex, the costs of which would diminish (or eliminate) the disposal costs that would have been incurred by the federal government. Further, it is much safer to reuse the environmentally secure glass blocks in building construction than placing the waste pile in a new lined dump area.

In fact, designing and operating an EBIC on an existing hazardous waste site might be considered an economically superior alternative solution to waste treatment at the same site. Such sites would have to be made secure by excavating and diking before reusing the waste contents in manufacturing a compatible product.

By the year 2001, the nuclear industry and the federal government’s Department of Energy had been working on a “dump” for its wastes for almost 20 years instead of reusing them in a safe product. Millions of dollars have already been spent on the Yucca

Mountain U-shaped tunnel "dump" and no radioactive debris has yet been stored there. The major deterrents to this solution have been political, court decisions, and public outrage (the NIMBY reaction). Conceivably, if we had put that much time and money into the EBIC system, we would have operating complexes by now. In addition, it would have been easier to increase production of nuclear energy to alleviate the existing electric energy crisis in the United States.

It is true that the reuse of nuclear wastes represents a formidable problem. Most of these wastes are bulky and dangerous to handle. Low-level radioactive wastes—most of which are sent to a depository in South Carolina until 2008—consist of clothing, tools, soils, and construction materials used in and about the reactor. High-level wastes, which consist of filters, resins, and equipment parts, come from the reactor core. These are mainly stored nearby the 103 reactors of origin in each state in either very deep (>40 ft) or oblong-shaped steel-lined concrete vessels. It is claimed that "on average, each reactor produces enough low-level nuclear waste each year to fill one sports utility vehicle" (Wilkie 2001). The Department of Defense admits that these storage vessels are secure for only about 100 years and represent a danger of explosion if water seeps in.

However, the Bush administration appears content to allow the 10 millions of tons of uranium waste piled up near Moab, Utah, to sit exposed to rain and seepage into the Colorado River. Instead, the administration proposes to cap the pile in place despite the chance of groundwater leaching ("Toxins and Water" 2001). Another objection to underground storage such as the Yucca site was brought out by W. Kenneth Davis, a former Department of Energy official, in a protest against shipping long distances the dangerous radioactive material ("Ex-official ends support" 2001).

However, the Yucca Mountain project was finally approved by the Senate in 2002. "Every year the nation's commercial nuclear power plants generate 2,000 tons of spent reactor fuel, and the accumulation of highly radioactive waste has grown to 45,000 tons" ("Yucca Mountain" 2002). We have been paying a tax for this disposal for years (added onto our electric bills). Americans have been taxed $14.1 billion for this nuclear dump—and the government has earned an additional $6 billion in interest ("$20 billion sits in nuclear dump" 2002). "Utilities have been collecting the fee—about $0.1 cent for every 10 kWh of nuclear-based electricity used—since 1982." The dump could begin taking waste as soon as 2010 ("$20 billion sits in nuclear dump" 2002).

Most of these bulky low- and high-level radioactive wastes would have to be reduced in volume by careful incineration before they could be used in an EBIC such as suggested here in Figure 18.20.

N. Animal Feedlot–Plant Food Complexes

Large-scale livestock operations have removed animals from pasturage and now handle large numbers in small confinement areas (feedlots) where feed and water are brought to the livestock (Nemerow and Dasgupta 1991a). Loehr (1967) reported that treatment and disposal of animal wastes collected in the feedlots are complicated by the nature of the wastes, the volume of wastes to be handled, the lack of interest by the livestock producer in waste treatment, and the proximity of a suburban population. These wastes are high in organic solids—both suspended and dissolved BOD, and nutrients such as ammonia. Land disposal and anaerobic lagoons have been used to treat the wastes. As a result, production costs have been increased to include waste treatment. It makes sense to eliminate these treatment costs by substituting ancillary industries to use the wastes.

Figure 18.21 shows a potential combination of plants to handle all feedlot wastes and, at the same time, produce other useful products. In this complex, the animal feedlot is the major plant and the hyacinth food plant and digester are ancillary plants. The feedlot produces mature animals ready for sale in the open market, and hyacinth production makes plant food, partially for reuse as animal food and partially for feed for the fermenter. The fermenter makes methane (CH_4) for outside sale or for heating any of the complex buildings. A secondary hyacinth basin recovers settled sludge from the first basin and makes more hyacinth plants for similar usage.

All feedlot wastes are used in the complex to grow hyacinth plants in shallow-growing basins in natural or artificial sunlight. Hyacinths are crushed and returned to

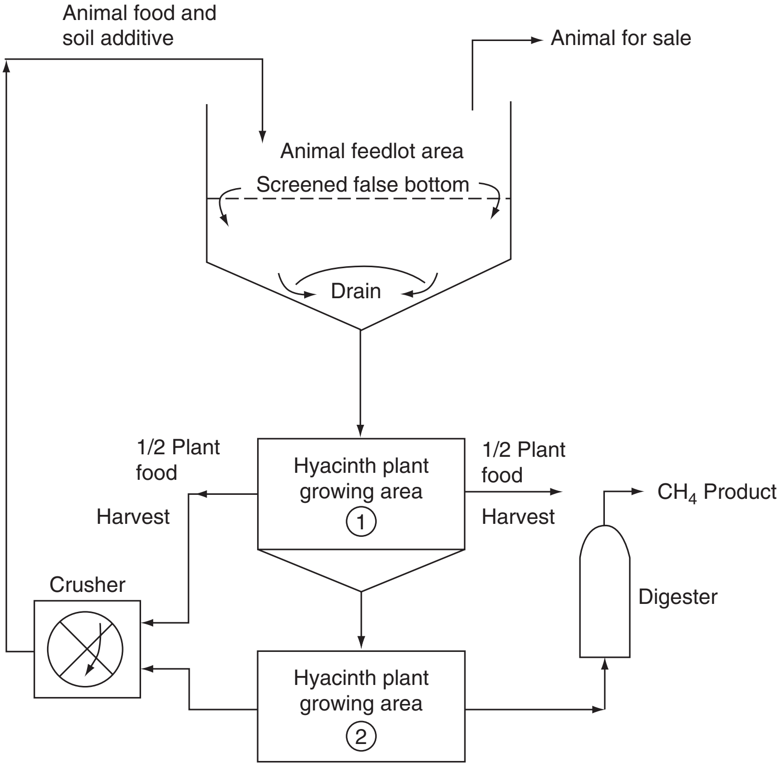


FIGURE 18.21. Feedlot–food production complex.

the feedlot area as food for animals. The fermenter produces methane gas for digesting one-half of the hyacinth plants from the first growing area. The methane becomes the third product made in the complex.

A typical application of this complex could be used for the recovery of hog wastes from hog farms, which generate great quantities of manure. Inefficient disposal by lagooning of these wastes leads to all kinds of adverse environmental effects including seepage into the groundwater. Such a situation was reported in *The Wall Street Journal* (Kilman 2001b). By using a three-product industrial complex, we have provided animals with a feedlot area for a given period without creating any adverse outside environmental effects.

O. Coke (Steel Mill)–Tar–Benzol Plants Complex

At the turn of the twentieth century–and before–coal was burned in what was known as byproduct coke ovens to produce gas fuel and sometimes high-grade tar. The gas was sold and used to provide lamp illumination and to heat local residences and factories. Today this gas has been replaced largely by natural gas piping and transportation systems. However, in some places on the world, byproduct coke ovens are still used for a variety of products.

Where these ovens are still used for gas production in individual locations, many detrimental wastes also are evolved. These wastes include coke and coke breeze, tar, gas liquors and sludges, benzol, ammonia, and various quench liquors, cooling water, and scrubber chemical contaminants.

Present-day coking is carried out by a series of manufacturing processes: (1) coal is brought into the plant, crushed, and screened; (2) this screened coal is then charged into a hot, empty oven; (3) the process of pyrolysis converts the coal into coke and gases; (4) the residual hot coke is discharged from the oven and quenched; (5) condensible gases are cooled and liquified and collected separately; (6) (foul) residual gases are cooled and tar extracted from them; (7) ammonia is separated from the gas with sulfuric acid; (8) further gas cooling can yield other organics such as benzene and toluene; and (9) contaminating hydrogen sulfide can then be removed from the gas leaving it purified sufficiently for sale for lighting and/or heating.

The whole process starting with coking of coal and ending with purified fuel gas involves and includes several small industrial operations. These can be combined in one efficient and effective industrial complex in which all byproducts are turned into valuable products for sale outside the complex or reused within the complex to aid in manufacturing.

The products for sale would include tar, sold for roofing fuel, or road surfacing; gas for illumination and/or heating, coke for steel making, benzol sold to chemical companies, and ammonium sulfate for sale to fertilizer manufacturers. Other wastes and byproducts such as coke breeze, filtered quench water, ammonia cooler water, and gas liquor sludge can be reused within the complex.

One potential complex for this industry is schematically presented in Figure 18.22.

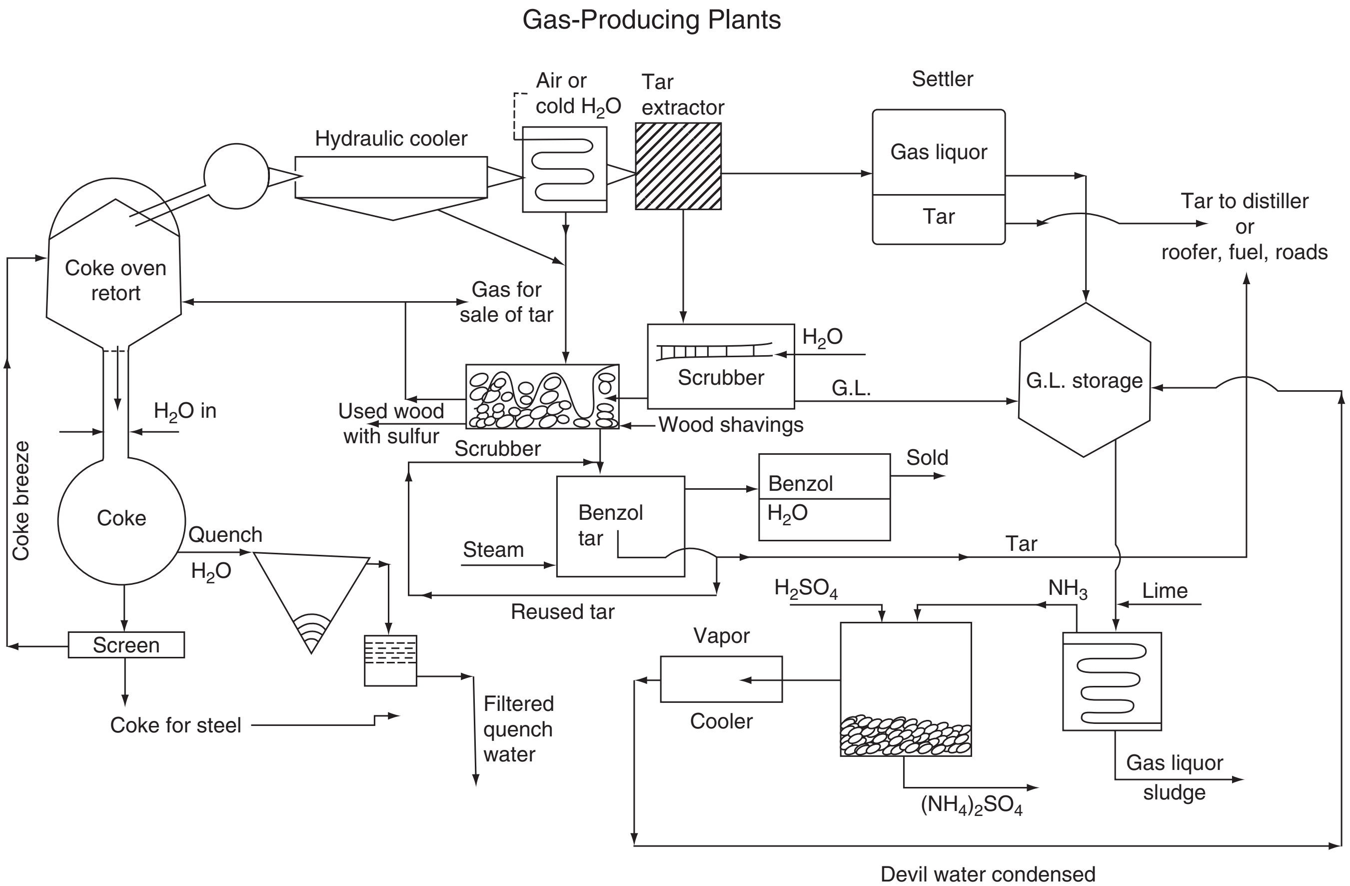


FIGURE 18.22. Gas-producing plants.

P. Wood–Ethanol Complex

It is becoming increasingly evident that we must devise an economical, suitable, and less polluting fuel for automobiles. One potential fuel is ethanol–already used to some degree as an additive to gasoline fuel. Ethanol can be produced by fermentation of many cellulosic organics. Wood waste is an ideal source of the cellulose. Wood cellulose has been shown to yield ethanol effectively by a number of researchers since at least the last quarter of the twentieth century (Shreve 1984).

Wood waste contains cellulose, which can be converted to sugar, which can then be fermented to yield ethanol, a source of fuel for motor vehicles. In Figure 18.23 (adapted from Shreve 1984), I show a flowchart for a process that has been used to make a dilute alcohol.

The cellulose wood waste must first be hydrolyzed. The hydrolyzed vapor is then neutralized with limestone and the resulting gypsum separated before feeding the partially decomposed cellulosic material (mainly hemicelluloses and sugars) to the fermenter.

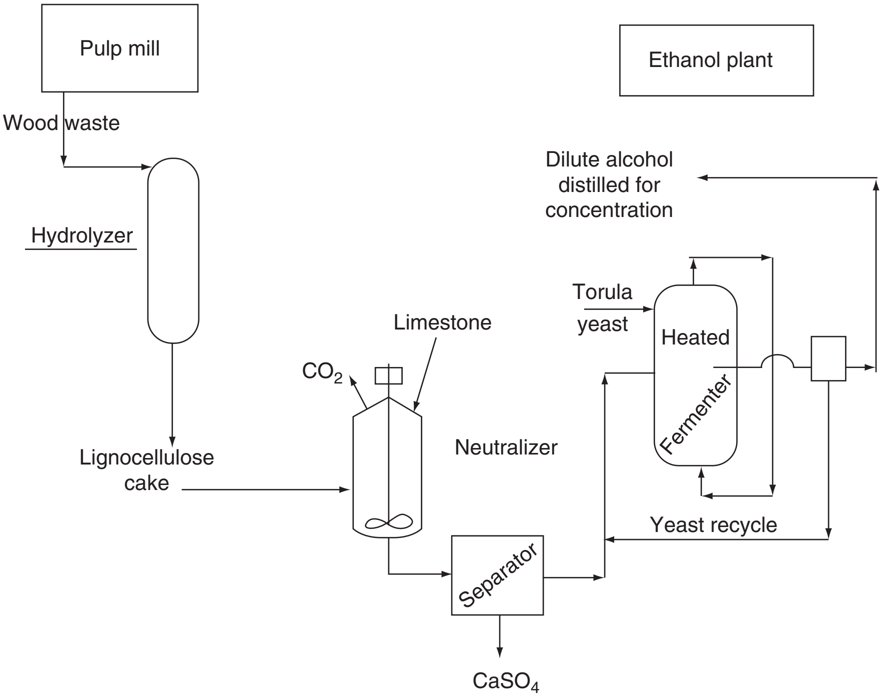


FIGURE 18.23. Flow chart of dilute alcohol production.

In the fermenter, the sugar-like residual of the cellulosic waste is converted—with the aid of a starter yeast culture—to a dilute alcohol product. The latter is distilled to concentrate it for sale as a fuel.

Pulp mills using hardwoods to make paper by the sulfite process evolve waste liquors containing up to 3% sugar. These waste liquors are often steam-stripped to remove their sulfites after which diammonium acid phosphate is added to enhance the growth of yeast, pH adjusted, and the mixture added to continuous fermenters inoculated with yeast cultures. Aerobic fermentation follow at about 35°C, after which the torula yeast obtained contains about 47% protein along with high vitamin content. The yeast product is used as animal feed supplement quite comparable to meat and milk. This offers an alternative to ethanol production.

Q. Water, Electricity, Chlorine, and Lye Plant Complex

Besides food and habitat, water and electricity are vital commodities. This complex produces both commodities as well as chlorine and sodium hydroxide for chemical suppliers (Figure 18.24). Because more than one-third of the U.S. population lives within a few miles of the oceans, industrial plants, which use ocean raw materials and serve the near-ocean inhabitants, ideally should be located there as well.

Ocean waters contain about 3% salt (30,000 ppm) and are full of seaweed or kelp, especially near the shoreline and even on the beach. Today freshwater can be produced from seawater more effectively and economically than ever before. The increased population of the coastal areas is hungry for this water to support life. The seaweed and kelp can be dried and burned and the heat used to boil water to produce steam to drive a turbine tied to a generator, which will result in electric energy for this same coastal population. Some will also be reused within the complex to electrolyze the brine and to provide pressure to the reverse-osmosis system. More burnable organic matter in the form of algae can be grown in ponds through which the boiler flue gas is sent. The carbon dioxide in the flue gas would stimulate the algae growth, aided by natural sunlight usually abundant in seacoast areas.

Newer and better designed reverse-osmosis seawater treatment systems are now available for use. More durable and effective membranes, which can withstand up to 1,000 psi pressures, will remove larger molecules from the seawater and permeate pure water for coastal societal use. The impurities, largely NaCl molecules, build up in the rejected membrane material and become a brine solution, which is very high in NaCl concentration. Usually this brine is discharged back to the sea (LaRue 2001). However, in our complex this brine would serve as a raw material to manufacture both chlorine and sodium hydroxide. This would be accomplished by electrolysis of the brine to liberate chlorine at one pole and sodium ions at the other. Chlorine would be reused at the water plant in the complex to disinfect the water while sodium dissolved in water would be sold to chemical companies to manufacture products such as soaps.

Here we have a four-product industrial complex with little or no wastes entering the environment outside its confines. Two of these products are vital for human survival, whereas the other two provide necessary and useful chemicals with a real monetary value.

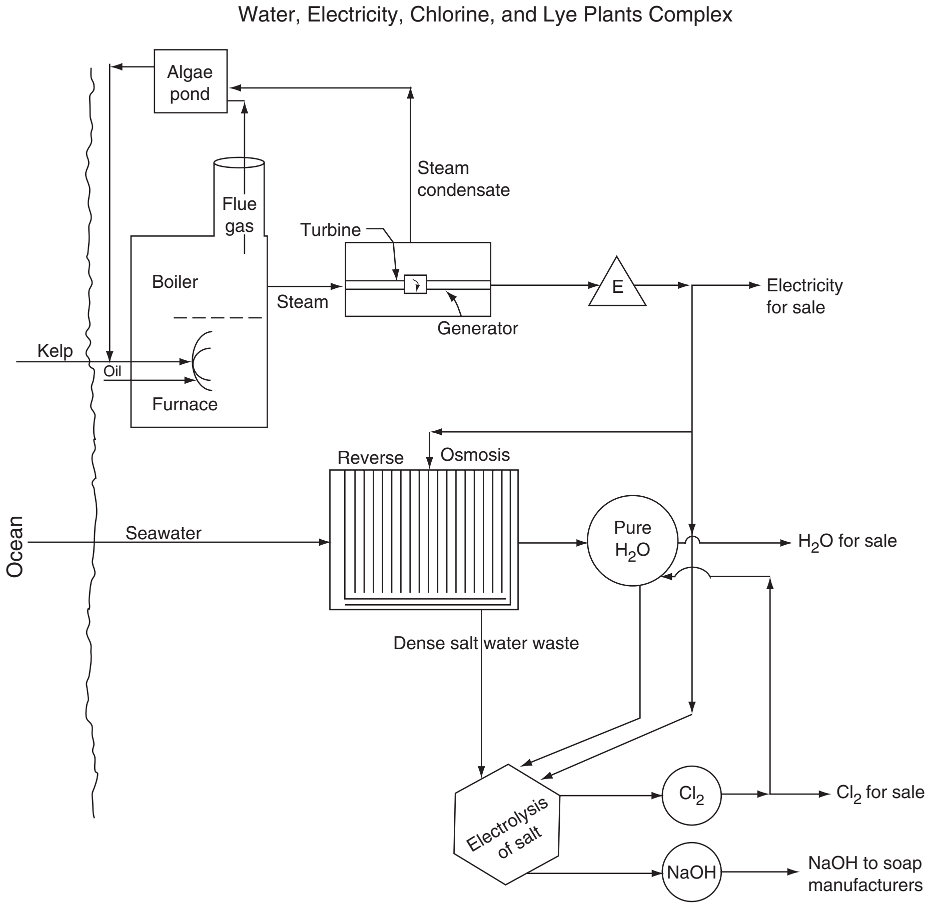


FIGURE 18.24. Wood, electricity, chlorine, and lye plants complex.

R. Aluminum, Electricity, Red Brick Plant Complex

The production of aluminum requires a great quantity of power, 51.4 kWh/ton of aluminum (Nemerow 1984). This electrical demand represents about 70% of the total aluminum production cost. These plants are usually located, therefore, in places with inexpensive power costs. In the past, this meant near or as a part of a hydroelectric power facility, the lowest-cost source of electrical power. Because most of these sites are already taken, or the competitive demand for elevated water stored in the reservoir for power is so great, other sources and types of low-cost power must be found for new aluminum plants. Such is the case proposed in Figure 18.25, in which Canadian power is imported from long distances through undersea electric cables to the refinery complex. Electricity is generated in Canada by burning local natural gas and the

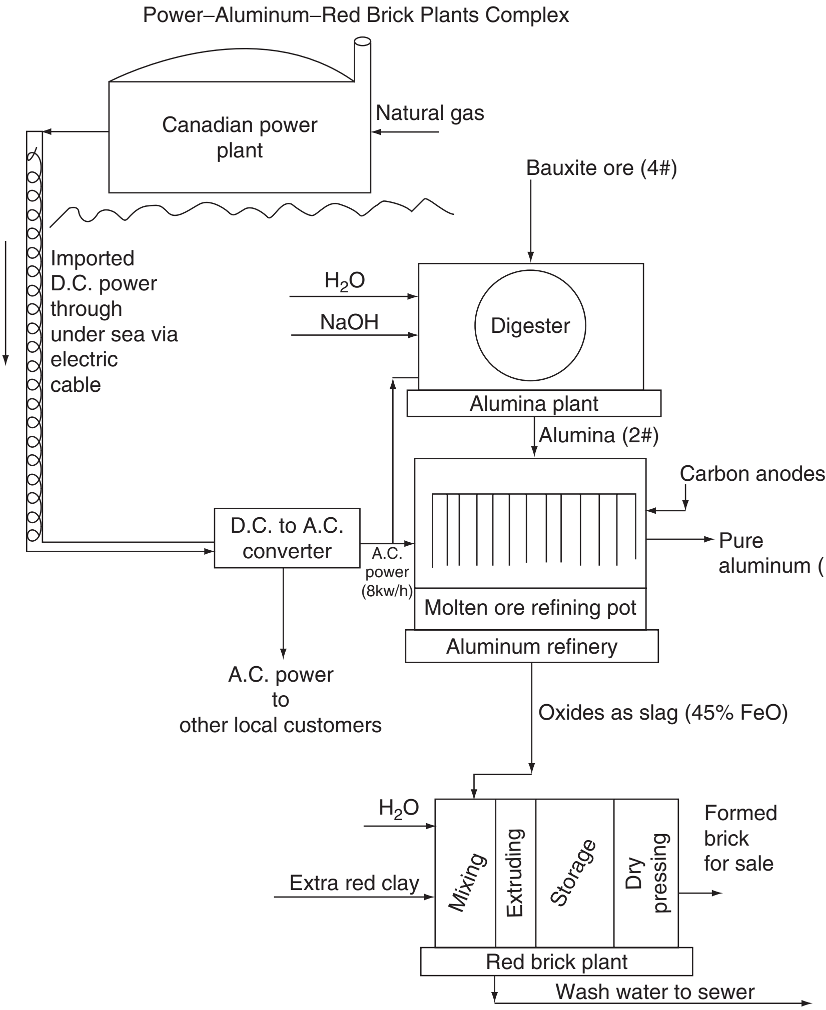


FIGURE 18.25. Power–aluminium–red brick plants complex.

manufactured DC electricity transmitted through deep-water cables to the refinery (Caffrey 2001). Naturally, a local hydroelectric plant's electricity could also be used (rather than importation of Canadian power) if such were available. If electricity is imported, the Canadian facility would shoulder the environmental burden of treating flue gas and heated water emissions, as well as boiler ashes. Because the capital cost of the cable transmission system is considerable, excess AC power can be sold at the converter site to other local customers.

The importance of electricity in the production of aluminum is evidenced in the closing of Alcoa's Maryland smelter ("High costs weigh" 2006), which reported an average aluminum price in the fourth quarter of 2005 rose 12% to $2,177 per metric ton, largely because of high prices in electricity, which can account for one-third of total production cost.

Figure 18.25 depicts a complex in which power is imported to operate the aluminum plant's refinery. The predominantly iron oxide, red mud sludge is reused as the main raw material for the red brick plant. Some imported red clay is used to supplement the refinery sludge. Pure aluminum is sold in various forms (usually in 5-lb ingots) to outside customers.

The red mud sludge is mixed with a very small amount of water and red clay and extruded into storage bins. From there, the red clay mixture is pressed and formed into bricks for sale to local building contractors.

In the refining of bauxite ore, two sequential steps are necessary: (1) reduction of the bauxite ore to alumina (an oxygen alumina compound) and (2) aluminum production by smelting at the refinery. Capital costs are high (in one case, $200 for mining the bauxite, $750 for alumina production, and $1,630 for alumina smelting, for each ton of aluminum metal produced) (Nemerow and Agardy 1998). These costs are 1979 ones and must be updated for current values; however, the relative proportional power capital costs remain about the same.

In this complex, aluminum is produced at a reasonable manufacturing cost. Wash waters are reused within the plant and waste sludges are sent to the brick plant as raw material. No wastes of any consequence leave the complex to contaminate the environment.

S. Corn Growing and Processing–Alcohol Producing Complex

The manufacture of industrial alcohol by fermentation has always been an important production in the United States. At the beginning of the twenty-first century, it is becoming an even more vital product. This is because federal regulations require cities subjected to air pollution to put oxygen additives in gasoline (Kilman 2001a). Oxygen additives aid in burning gasoline more completely to leave less reduced carbon (such as CO) in the air. California had been using a petroleum byproduct, MTBE, to provide the oxygen. However, after finding excessive MTBE exhausted by autos in groundwater supplies, the State of California will force drivers to put corn-derived ethanol (mixed with gasoline) in their gas tanks. The industry predicted that it would need to expand by about 30% just to produce the ethanol that California required by 2003. Further, the U.S. annual market for ethanol has doubled to 3.5 billion gallons over the last few years. All this means that probably new corn fermentation plants will be built in the near future. An opportunity exists to include such new industrial alcohol plants as part of a more efficient industrial complex. A logical system would include corn growing and processing as a component of the complex. In this way, the agricultural wastes resulting from the corn growing and the contaminated liquid wastes from the alcohol plant can all be reused within the complex. I have depicted such a potential complex in Figure 18.26.

In this system, corn is grown in an agricultural area within the complex. The cornfield is fortified with fermenter slops and waste condensates from the alcohol plant.

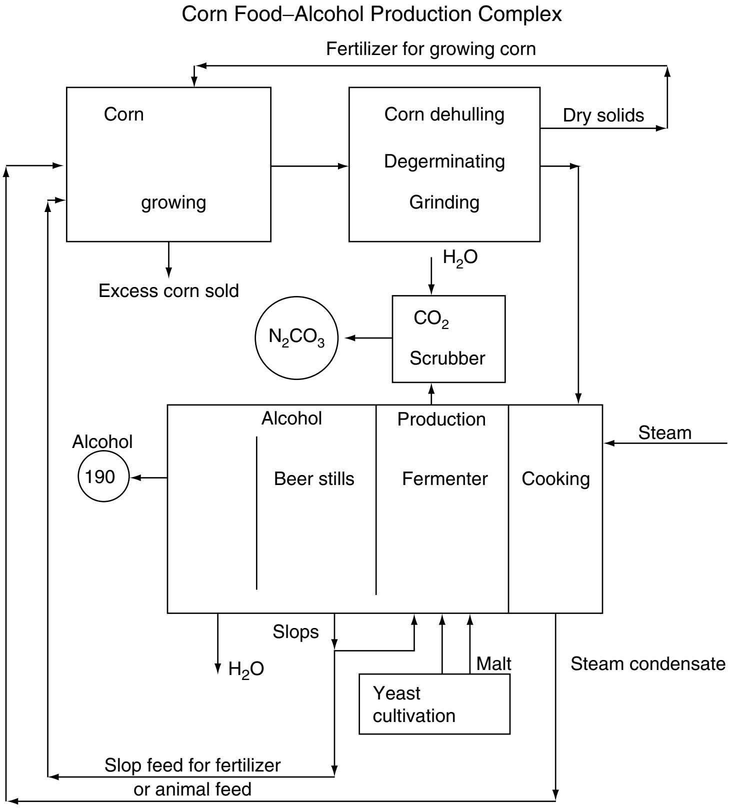


FIGURE 18.26. Corn food–alcohol production complex.

The corn dehulling, degerminating, and grinding of solid wastes are also distributed evenly over the corn field between plantings for soil improvement. The processed corn will be fed to the alcohol plant as its major raw material. Excess corn not required in the production of alcohol will be sold in the open market for human and/or animal consumption.

The ground corn will be hydrolyzed with malt or acid, mixed with yeast cultures, and fermented to a "beer." Further distillation of the "beer" by steam will produce industrial alcohol for sale to the refineries to make "modified gasoline." Slops, contaminated condensates, and wash waters will be fed to the cornfield to increase agricultural product yield.

The two-industry complex will not discharge any contaminants outside the complex.

T. Restaurant–Paint Manufacturing Complex

The fast-food restaurant business is plagued with the dilemma of how to dispose of its used vegetable oils from deep-frying potatoes and meats. The usual practice is to dump waste oils into a grease trap type of treatment. Most of the oil floats to the surface of the grease trap and is usually skimmed off into vats to be picked up by grease scavengers for transportation and sale to processors such as renderers. This practice is not only inefficient, but also costly and prone to operational problems. For example, George Markowvics, an employee of the Department of Environmental Protection (New York City), experiences many of these problems (Newman 2001). "America's sewers are in a bad way. Three quarters are so bunged up that they work at half capacity, causing 40,000 illegal spews a year into open water. Local governments already spend $25 billion a year to keep sewers running." Although many things such as roots, corrosion, and bottles will clog sewers, now "blockages are almost all wrapped in fat" (Newman 2001).

Grease traps, if and when used in restaurants, are often accessible for cleaning and pumping with difficulty. The grease collectors often complain that the grease that they collect, as is, is too watery for reuse by renderers. If grease traps are too small (MGM Hotel in Las Vegas required five 15,000 gallon traps) or are designed or operated inefficiently, grease will overflow into the municipal sewer. In any event, grease recovery from individual grease traps is neither the easiest nor the most desirable task. And the reward for proper operation and collection is usually insufficient to result in a problem-free system.

A solution to the restaurant grease problem is to make the recovery of reusable oils cost effective. One way to do this is to combine all the waste fats of two or three restaurants in one "strip mall" area into one large well-designed and well-operated grease trap and in a complex in which the oil recovered can be reused on-site by an industry as part of its raw material.

One such industrial plant is a paint manufacturer. Usually paint producers require certain amounts of oils as thinners, extenders, and antifoam agents in their raw paint mixture. Even water-based or alkyd paints use some oils. As pure raw materials, these oils add to the cost of the finished paint product. Potentially, grease-trap oil could be used for this purpose after some refinement (probably acid treatment and filtration).

In Figure 18.27, one potential complex of restaurants and paint manufacturing is proposed. In this complex, three fast-food restaurants (perhaps one Chinese, one ribs, and one chicken special) collect their waste cooking oils in a single large easily accessible central grease trap. The trap is maintained by an EBIC employee to ensure that the floated oil is piped continually to the paint manufacturer. At the same time, the grease trap underflow is led directly to the municipal sewer for normal treatment by the city. The recovered oil is acidified, filtered, and added to the paint mix of pigments, resins, and so on.

Various paint plant cleanup wastes are collected, stored, and reused in the proper amounts and types of ensuing mixes.

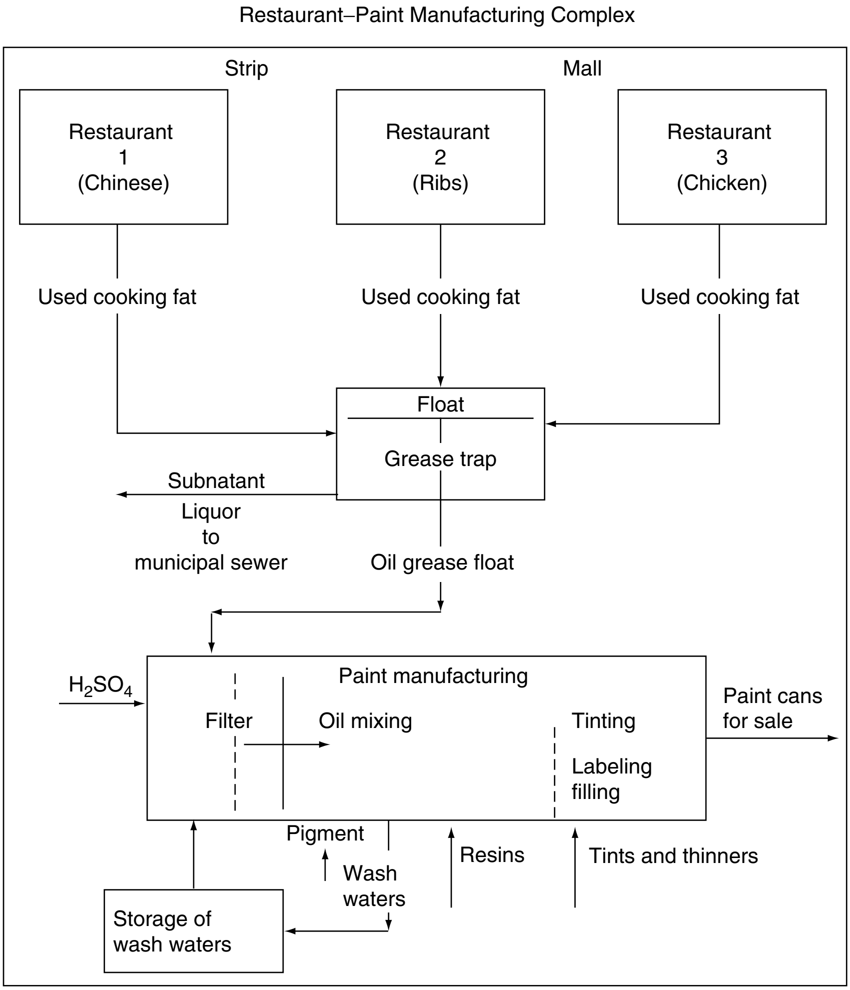


FIGURE 18.27. Restaurant–paint manufacturing complex.

In this way, neither restaurant nor paint liquid wastes reach the environment outside the complex. Instead they are all reused within the complex to avoid contamination and reduce costs of products for sale.

U. Offshore Oil Drilling –Seashore Recreation Industrial Complex

This complex offers a unique opportunity to unite the wastes of one offshore oil-drilling industry with the needs and uses of another nearby ocean-using industry, ocean beach recreation. It is unusual because the two industries do not have to be relocated; they already exist together. They operate by using the same offshore ocean water and will both be enhanced by an even closer symbiotic relationship proposed in this complex.

The offshore oil-drilling industry produces not only the dangers of oil spills, toxicity, and explosions, but also the final disposal of its oil-drilling platform and drill-cutting piles following its useful life. Oil drillers use a sometimes modified drilling fluid—usually water—to penetrate the depths of the well to drive the oil out to the surface for recovery and sale. The drilling water is often contaminated to some degree and represents a problem of proper disposal. In addition, oil spills, though infrequent and unpredictable at the onset of operation, also represent environmental concern.

Beach recreation often supports an offshore fishing operation that can be improved by any techniques that result in increased fish life. The beach sand itself is usually eroded annually by excessive storms causing higher peak tides and winds. Any practice that diminishes these wind and tidal effects will protect the beach sand, reducing the inconvenience and the cost of replacement. Ocean beach users require water for various purposes such as washing sand from their bodies and flushing toilets and watering adjacent plants and trees. These uses do not normally require water of pristine purity. In fact, the use of potable water for these purposes has long been claimed as both a waste of a valuable and diminishing resource, and an unnecessary expense for the user.

The suggestion of leaving the oil drill-cutting piles in place was offered by the Phillips Petroleum Company of Norway in 1999 (Alastair 2000). There "is no proven technology that could remove large amounts of heterogeneous sediments from the deep water of the northern North Sea." The inference, then, is that despite its potential toxicity to marine life for up to 20 years, it is best left *in situ* after finishing the drilling.

Another offshore drilling problem occurs in the canals used by the oil industry to transport oil (and wastes), which may contaminate wetlands with saltwater. Pipelines could add to the problem (Pflum 2000). As a result, any practice such as proposed here should eliminate this problem.

Herrick (2001) reports on platforms and rigs by admitting that when the work (of the oil drillers) is done, "an enormous mass of metal remains to be cleaned up." He confirms that federal lease agreements require that the oil drillers leave the ocean floor as they found it. But he also confirms that "tearing down the multi-million dollar platforms and hauling them to shore to sell for scrap can cost as much as tens of millions of dollars." He reports as well that "the leading alternative is converting rigs into artificial reefs." He found that first coral and colorful sponges cling to the underwater jacket, then shrimp and crab follow, and soon fish appear.

Vickie Chachere (2001) points out the current practices and objections to offshore drilling. She also reports on modern more environmentally safe types of equipment such as "the sleek and modern, $1.2 billion structure 130 miles southeast of New Orleans—twice as tall as the Sears Tower and known in the drilling business as a

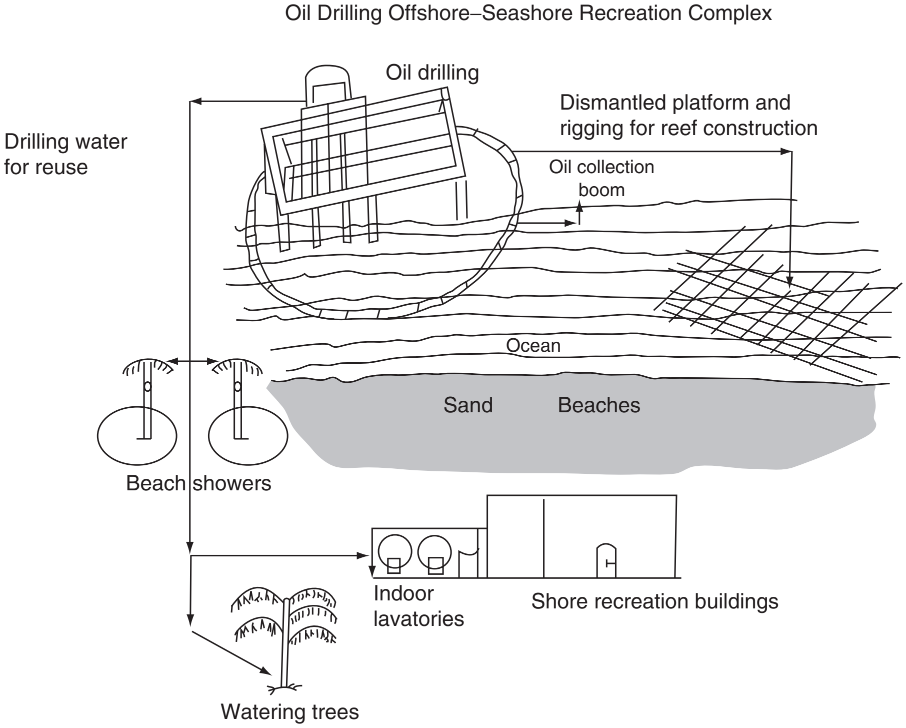


FIGURE 18.28. Oil drilling offshore–seashore recreation complex.

tension-leg platform. It can produce up to 200,000 barrels of oil a day or 2 percent of current domestic consumption."

In our proposed complex, waste oil-drilling waters will be pumped to shore to be used by the shore-side recreation facility for sand washing, toilet flushing, and plant watering. The used platform and rig will be dismantled and used near shore to form reefs for fish propagation and sand erosion protection. Oil leaks will be minimized by modern oil-drilling operations and, if and when they occur, will be collected by booms and recovered and reused for heating purposes onshore. All these are depicted in Figure 18.28.

V. Metals Plants–Dry-Cleaning Coffee-Decaffeination–Plants Complex

Trichloroethylene (TCE, $\underset{\text{cl}}{\underset{|}{\text{CL}}}—\underset{\text{cl}}{\underset{|}{\text{C}}}=\text{CH}$) is another very toxic and hazardous industrial waste that "begs" for safe and economical recovery and reuse. Fortunately, the major industries requiring and using this organic chemical solvent are now well known to the environmental engineer. The metal parts plants use TCE to clean the grease preservative off its incoming metal parts. The dry cleaners use TCE to dissolve and remove the organic clothing contaminants from the garments. Discharge of either of these plants' TCE wastes into the environment has been known to me to cause pollution. It makes good common sense to recover the wastes of dry-cleaning plants for potential reuse in coffee manufacturing. In the latter, TCE is used to remove the caffein from the coffee bean. The slightly contaminated TCE waste from the coffee plant can be reused by the metal parts plant to remove its grease and then by the dry cleaner to remove more grease from clothing.

Eventually excessively contaminated TCE waste must be distilled before reuse. The still bottoms can be landfilled periodically or reused as grease lubricants within the metal parts plant.

Such a three-plant complex is shown in Figure 18.29, in which no hazardous TCE wastes reach the outside environment and a valuable (useful) raw material (TCE) is provided internally.

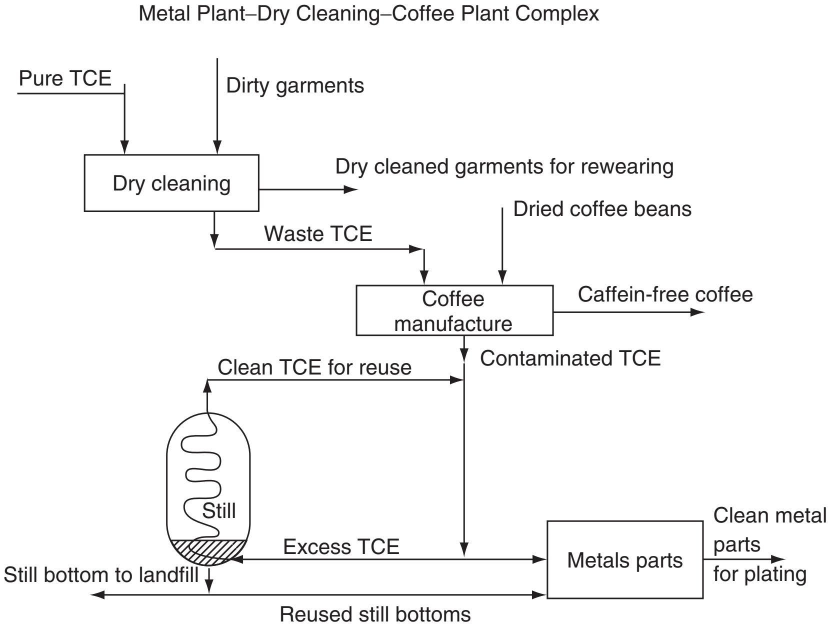
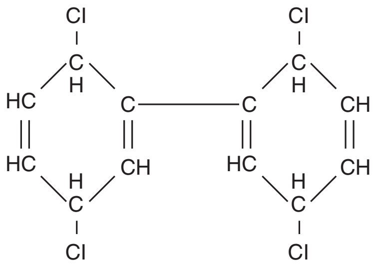


FIGURE 18.29. Metal plant–dry cleaning-coffee plant complex.

W. Electrical Storing and/or Converting Voltage–Wax Manufacturing Complex

Polychlorinated biphenols (PCBs) comprise a unique group of toxic chemicals that can be represented by the following chemical structure:



They are used in small quantities in the manufacturing of lubricants, duplicating paper, printing inks, paints and coatings, adhesives, plastics, and so on. When paper wastes are reused and de-inked, some small amounts of PCBs are also found in the mills' wastes. Therefore, they may be found in small concentrations in wastes from these product manufacturing plants. However, their concentration is usually too small for economical recovery and reuse, but large enough to cause environmental problems because of their resistance to decomposition and perseverance in water and soil.

In one industry, they are used and discharged in large enough amounts to be hazardous to the environment and to warrant their collection, recovery, and reuse in an industrial complex. Such an industry stores power and converts the power to various voltages (using capacitors and transformers). PCBs are used there as both coolants and lubricants. When they become used to a point of excess contamination or degradation, they are wasted. If wasted to a flowing river such as General Electric did in the Hudson River, they can and did cause decades of problems mainly with bottom-feeding fish and the utilization of these fish for human food.

When attempts are made to dredge river bottoms, problems arise as to what to do with the contaminated sludge, environmental safety, and the huge cost of such procedures. One possibility that appears feasible is to mix the sludge with cement kiln dust, layer it in the atmosphere to neutralize the chlorine, and then safely place the treated sludge in a chemically safe landfill (Sell 1992). However, direct reuse of the PCB waste in an industrial complex would eliminate all these intermediate treatment costs, hazards, and problems with recovery after contaminating the river environment.

Direct PCB reuse in the wax manufacturing industry appears to present the best opportunity for successful environmental protection at the least cost. PCBs are used as "extenders" in the manufacturing of wax, especially carnauba and paraffin types of wax. Product compatibility and mass balances of PCB wastes and wax needs will play important roles in the acceptance of this system. Such a complex is shown schematically

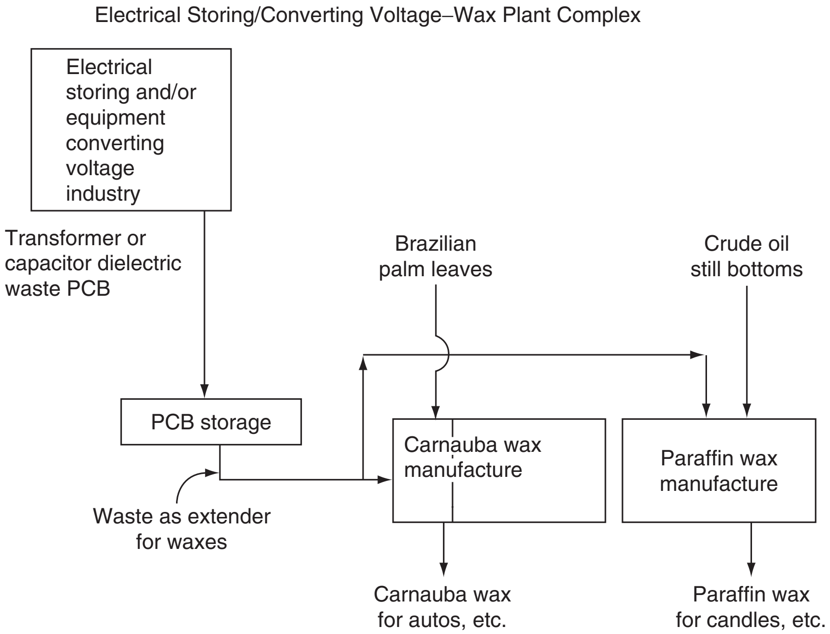


FIGURE 18.30. Electrical storing/converting voltage–wax plant complex.

in Figure 18.30. The figure is self-explanatory and only requires the import of Brazilian palm leaves and/or crude oil still bottoms. If the PCB wastes can be stored and fed to the wax plants properly, no hazardous PCB wastes should enter the outside environment.

X. Nuclear Power Plant Waste Processing–Cannery Complex

Another potential industrial complex arises out of the need to protect not only our normal environment, but also in emergency situations. Simply stated, nuclear power plants produce a hazardous waste from the reprocessing of spent uranium fuel rods. In usual practice, these wastes are stored (before or after dangerous transportation in "safe" facilities, hopefully until after many generations they someday can be released safely into the environment). These operations can and do result in wastes that pollute the environment.

In a similar mode, but in an entirely different industry, when we process fresh fruits and vegetables, the produce must be preserved and protected from bacterial contamination until it is ingested by the consumer. Once again, in usual practice, this is accomplished by washing, heating, and/or steam sterilization. These operations, likewise, result in wastes that pollute the environment.

Although we would not likely think of the “marriage” of these two dissimilar industries in one complex, I propose we consider co-locating them together. The primary purpose of this proposed merger is to protect the environment from radiation and microbiological-type wastes. In these days when the heretofore unthinkable “intentional” contamination is possible, both nuclear and bacterial contamination may be prevented by industrial complexing.

At this juncture, I suggest that you refer to the schematic layout shown in Figure 18.31. Here, we are merging, in reality, three separate industrial operations in one complex: nuclear power production, nuclear waste reprocessing, and cannery production.

The reader should be familiar with the basic dangers of ionizing radiation, which can be released from these wastes if they are left unshielded from the outside environment. Ionizing radiation is simply radiation with sufficient energy to remove electrons from atoms. It can cause changes in the chemical balance of cells that may result in cancer and/or harmful genetic mutations, which can be passed on to future generations. Current regulations permit a maximum of 5,000 millirems of this radiation annually.

Storage of nuclear wastes on-site in water presents certain environmental hazards. This is one reason for treating and reusing the rods and wastes as soon as possible. If a breach of a waste pool occurs from an earthquake or sabotage, the leak would release radiation, as well as exposing the stored rods or pellets to the air and overheating, leading to further release of radiation. Without water to cover the fuel elements, a possible fire or meltdown can occur.

Nuclear power, which represents about one-fifth of all power produced in the United States, is obtained from the heat energy released from uranium rods. As a result of this operation, these rods when eventually “spent” must be reprocessed, mainly by acid cleaning. The wastes contain small amounts of radioactive elements dissolved in strong acids. If these wastes can be concentrated and separated into their two major components, acids and radioactive elements, the radioactive component could be made into an “enclosed beam radiator,” while the acids can be reused in further reprocessing operations.

Such a radiation beam is already a reality and manufactured by Surebeam in San Diego, California (Calbreath 2001), and used in Hawaii to irradiate papayas before shipment around the world. Similar devices are proposed for and may already be in use in U.S. Post Office processing buildings to prevent anthrax contamination of the mail. The radiation source produces gamma rays, electrons, or x-rays, which kill disease-causing bacteria. This treatment, however, is not without some drawbacks cited by its critics (Hauter 2001). These critics claim that “we oppose the use of ionizing radiation to ‘treat’ food because this process destroys vitamins and other nutrients, and can form chemicals known or suspected to cause cancer and birth defects.” When radiation beam treatment was proposed for sterilizing mail in post offices, it was pointed out that it ruins unprocessed and unused film and damages some electronics as well. This should not be a problem in this example, however.

As shown in Figure 18.31, the spent fuel rod wastes are concentrated and acids separated from the uranium component, the latter being formulated and housed in a storage vessel to be used by the cannery to irradiate fresh produce. The waste acid portion is recirculated and reused in cleaning the next batch of spent fuel rods.

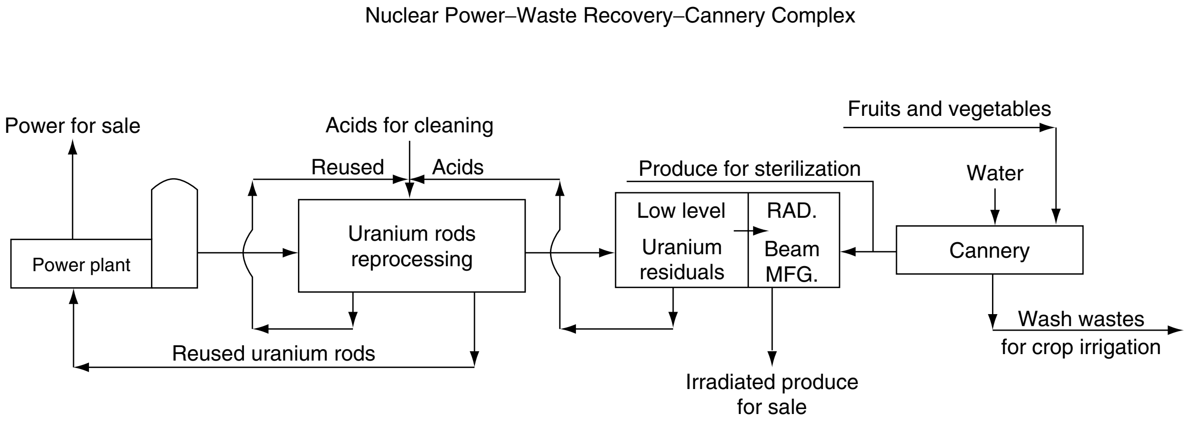


FIGURE 18.31. Nuclear power–waste recovery–cannery complex.

The only wastes emanating from the cannery are the wash waters from cleaning the produce. These wash waters containing mainly soil, leaves, and ground detritus are also recirculated and reused in irrigating the adjoining fruits and vegetables growing in the agricultural fields nearby. This is vital because water scarcity has a direct effect on food production. About two-thirds of all the freshwater consumed each year is used to irrigate crops.

As usual, with these examples of balanced industrial environmental complexes, no wastes leave the complex. Instead, radiation and suspended solid wastes are reused within the complex in making ancillary products for sale. The products for sale are nuclear power, radiation beams, and fruit and vegetable produce.

Y. Electric Power–Drinking Water Plant Complex

More and more situations are arising in which people in or near an expanding metropolitan area require both additional electrical energy and water. If we examine these two industries—electrical energy and drinking water—they appear to possess some interdependency.

The power plant needs cooling water for its steam condensers and clean water for steam generation. The water desalination plant produces both the excess clean water for the power plant and salty cooling water for condensing the steam. The water plant is able to send most of its pure water to people for drinking water and the rest to the power plant for steam production. Its saltwater residue (i.e., rejected impure water) because of its low (seawater) temperature is beneficial to the power plant for condensing the turbine steam, which can then be reused as a source of clean water.

The desalination plant will have no unusable wastes when made a part of the two-plant complex shown in Figure 18.32. The electrical energy plant will have no liquid wastes if its cooling waters are stored to lower its temperature and then reused. Also, if its fly-ash is collected by electrostatic precipitation and its flue gases passed through sodium hydroxide (to make a soda ash product) before discharging to the air, no air contaminants will arise. The soda ash is then used in the desalination plant to soften the drinking water before municipal use.

Two current examples of this potential complex have been made public. In 2002, Marathon Oil Company (Lindquist 2002). Announced that it would be the "lead partner in an energy complex near Tijuana (Mexico) that would include a liquefied natural gas regasification plant and an electrical power plant." Plans for Marathon's LNG facility are reported to include a marine terminal to accommodate tankers transporting the LNG from worldwide locations, an off-loading terminal, and an onshore plant that can re-gasify 750 mcf of LNG daily and a pipeline to deliver the gas to customers. The company proposes to cool the power plant with Tijuana wastewater and may also build and use a desalination plant to use Pacific Ocean water to provide 20 mgd of additional cooling water for the electric turbines.

The second (Roletti 2002) is planned by the City of Carlsbad, California, which is studying the feasibility of building a seawater desalination plant next to the Encino power plant. The city would like to "extract salt from ocean water and convert the water

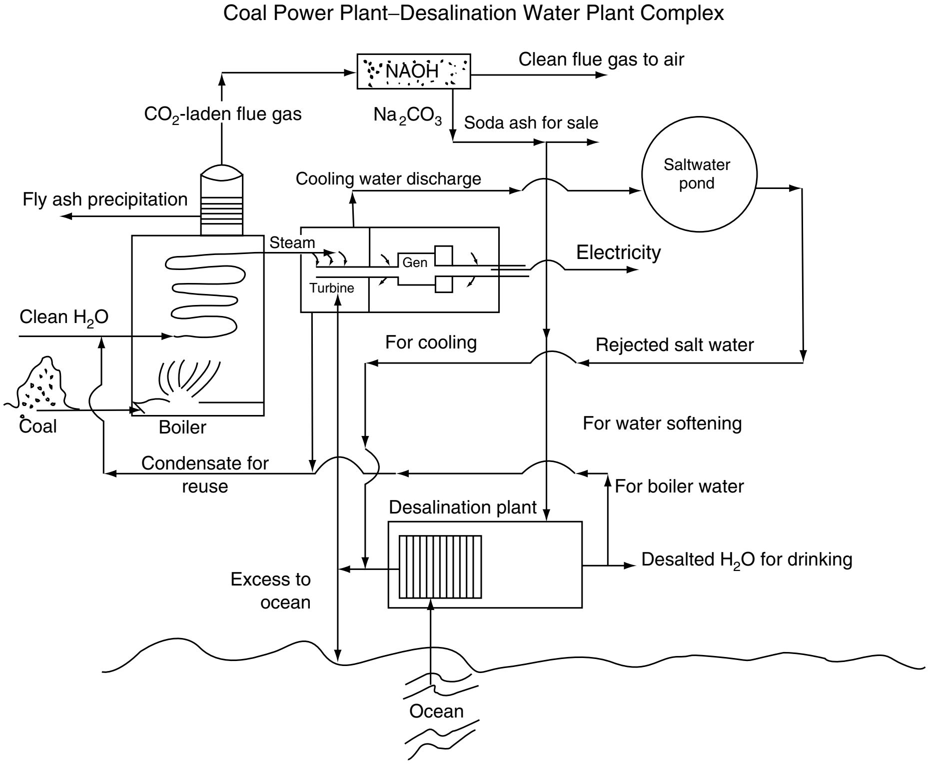


FIGURE 18.32. Coal power plant–desalination water plant complex.

into 50 mgd of drinking water. Building the plant next to the power plant is considered feasible because the two operations could share common infrastructure." Presumably they could share common ocean intakes of fresh seawater and outfalls of cooling water and salty reject waters.

Although each of these examples proposes somewhat different systems, both show interest in complexing plants to share raw materials and wastes.

Z. Vegetable Pickling Cannery–Inorganic Chemical and Chlorine Plant Complex

Sometimes an industry produces a waste that does not easily lend itself to treatment and "begs" for reuse by the proper industry partner. Such a situation exists in this example where brine waste is the nemesis and an inorganic chemical plant serves as the "willing and able" partner.

The vegetable pickling (brine) wastewater usually is only one of several wastes from this type of cannery (such as a pickle plant). Other wastes would include lime water, alum and tumeric wastes, and syrupy (vinegar and sugar) wastes. These latter three wastes could be impounded and reused to exhaustion before being monitored for proper pH and biologically treated or reused by ancillary industries. However, it is the brine waste that defies reuse more than once or twice before it must be discharged. This waste is mainly salt with some dirt and preliminary fermentation products.

Because of its sodium and chloride content, the brine waste could be used as a raw material for an inorganic chemical and chlorine manufacturer. By using a mercury cell, continuously fed brine can be partly ionized in one compartment (electrolyzed) between a graphite anode and a moving mercury cathode. Chlorine gas liberated at the anode can be sold directly as the gas or converted into bleaching powder by reacting it with the lime water from the cannery.

The sodium (amalgam) hydroxide can be passed through a bed of limestone to produce a Na_2CO_3 (soda ash) product. This product can be sold to the local water plant to soften its drinking water and/or sold to chemical companies for a variety of uses.

This type of complex rids the vegetable pickling plant of one of its most troublesome wastes while creating a new ancillary industry making chlorine or its compounds, as well as soda ash. In Figure 18.33, the cannery and chemical plants are depicted as "partners" in this industrial complex. Presumably other, primarily organic, wastes

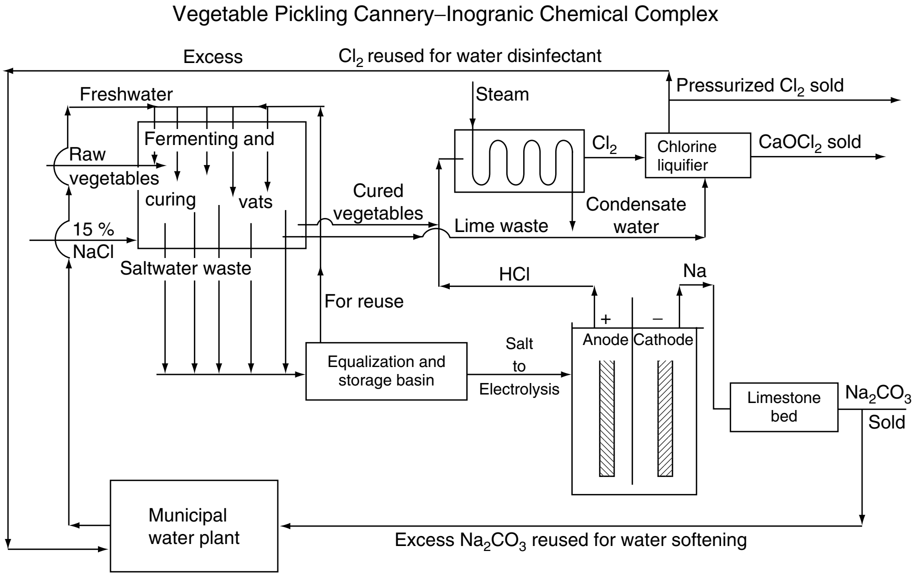


FIGURE 18.33. Vegetable pickling cannery–inorganic chemical complex.

produced by the cannery are treated biologically and/or reused in the cannery or in another ancillary industry. On the other hand, the "difficult" brine waste is equalized, stored, and then sent to the adjacent chemical plant as a raw material. Here, it is essentially electrolyzed to produce chlorine gas at the anode and sodium (amalgam) hydroxide at the cathode. The former is pressurized to a liquid and sold to the water purification plant or to other chemical companies. Or it is reacted with the lime vat water from the cannery to make bleach powder, also for sale to chemical companies. The sodium hydroxide is passed through a limestone bed to produce, on a batch basis, soda ash for sale to the local water plant or other chemical plants.

In this way, a "nasty" waste that may be detrimental to receiving waters if discharged has been reused by an industrial complex partner (the chemical plant). In addition, two or more new products result from the partnership, adding to the economic advantage of the overall combined operation.

AA. Sugar–Ethanol–Gasoline Plants Complex

While we still use gasoline to power most of today's automobiles, we need to reduce our dependency on foreign oil to produce it. One way of doing this is to dilute the gasoline with an additive such as ethanol, which is reputed to have no adverse effects on gas burning or power efficiencies.

The cost of this production can be reduced by manufacturing the ethanol at a site adjacent to the oil refinery. To accomplish this, we can grow an agricultural crop such as sugarcane in the environmental complex, convert it to sugar, ferment it to alcohol, and finally feed it to the oil refinery for dilution of the gasoline.

Traditionally, most of the ethanol produced in the United States is manufactured by fermenting corn in mid-America. The ethanol must then be shipped to the various oil refineries throughout the country for dilution with the gasoline. The EBIC avoids this transportation step, cost and potential danger. Our proposed complex also allows for the use of other crops indigenous to the local area as an ethanol source.

In a typical complex as shown in Figure 18.34, sugarcane is grown in a field within the complex and adjacent to the oil refinery. The cane is harvested and transferred to the sugar refinery within the complex. The sugar product is delivered for sale or sent to the fermenter for conversion by anaerobiosis to ethanol. The sugarcane bagasse is burned in the refinery's boilers for steam heat and/or power. The cachaza from the sugarcane plant is fed to the fermenter as an added source of ethanol. The ethanol is stored for periodic transfer to the adjacent oil refinery where it is diluted (usually 90-10) with refined gasoline for direct sale to the gas stations. The typical distillation gas wastes from the oil refinery are passed through lime filters before being released to the air environment. Periodically, lime (now primary calcium sulfate) filters are removed and distributed on the sugarcane-growing field for extra fertilizer.

In this way, no wastes leave the complex from the sugarcane field, the sugar refinery, fermenter, or oil refinery to contaminate the surrounding environment. California is already considering converting part of its agricultural land to sugarcane for the specific purpose of producing ethanol ("A cash crop?" 2002). "Dozens of

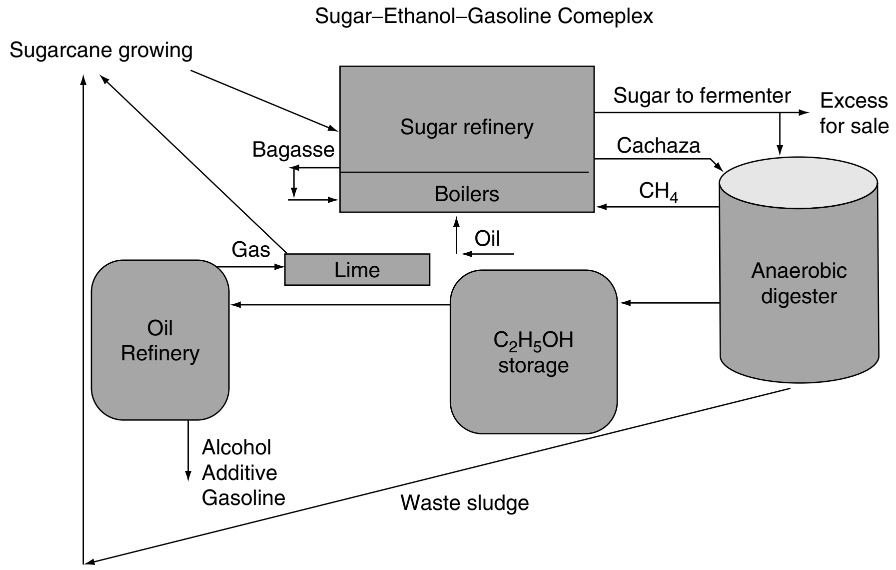


FIGURE 18.34. Sugar–ethanol–gasoline complex.

Imperial Valley alfalfa and cotton farmers are mulling over whether to grow the unlikely tropical grass for conversion into the gasoline additive ethanol." The rationale for this is the "considerable transportation costs" of importing ethanol from the midwest (corn) belt. Previously used methyl tertiary-butyl ether (MTBE) as an additive is being discontinued because "it has been found to contaminate waterways" and is "a suspected carcinogen that is believed to have contaminated more than 10,000 sites in the state."

In a further follow-up ("Ethanol use is headed" 2002), BP, the largest gasoline supplier in California acknowledged that the "federal clean air laws require use of either ethanol or MTBE, as an oxygen-enhancing agent to help gasoline burn cleaner, in a third of the United States gasoline supply" and "there are strong environmental and economic reasons for refiners to go ahead and make that move" (to ethanol).

BB. Reclaimed Cell Phones–Cement Plant–Concrete Products Complex

As a consequence of our "high tech," we are faced with the disposal of used and outdated electronic equipment such as wireless cell phones. These types of materials build up in the environment at a fast rate because of their rapid outdating, as contrasted to computer or VCR-type electronics. They usually cannot be refurbished, sold, and/or reused because of their relatively low production cost that renders them disposable.

If these small cellular phones are wasted into refuse landfills, they will contaminate the ground and groundwater with the heavy toxic metals contained in them. Once again, the challenge to the industrial waste engineer is to recover and reuse the basic ingredients in an economical and practical manner. The basic ingredients are plastics and heavy metals. The suggested EBIC is shown in Figure 18.35.

In this complex, the reclaimed cellular phones are heated in an oil-fired furnace to 275°F, at which point the plastics are melted and separated from the residual metal parts retained on a fine screen.

A cement plant, located within the industrial complex, uses the usual sand, shale, and limestone as raw materials, fed to a kiln (heated by oil), and ground to cement. A portion of the cement is sold on the open market, but most is used to feed the adjacent concrete products plant. The latter also receives recovered cement dust as a supplemental material. The heat from the cement stack gas is circulated through a separate oil heater equipped with hot water tubes.

The concrete products plant is divided into three separated operations. All three import normal cement, stone, and cement dust and heater steam condensate as raw materials. One accepts liquid plastic from the furnace as an added raw material, the second accepts recovered furnace metals as an added raw material, and the third operates normally without other external recovered additives.

The first produces plastic–concrete products for uses such as park benches and so on. The second produces metal–concrete products such as ocean reef materials and so on. The third produces normal concrete products such as pipe and other building materials.

No wastes—liquid, solid, or airborne—leave this complex and four products are made and sold externally to lower production costs.

These wastes have been loosely described as “e-wastes” and have been termed as “the most perplexing refuse issue facing the nation” (“Technology’s toxic trash” 2002). “Last year, the state [California] banned televisions and computer screens from landfills, joining only Massachusetts in designating those items as hazardous waste, but diverting e-waste from landfills is only a small step toward solving a burgeoning problem. There’s no clear plan—not in California, not anywhere—about what should be done with the abandoned TVs and computers. The discarded computers and TVs are often shipped to developing countries, where the toxic waste leaks into waterways or contaminates landfills.” As far as recycling of these wastes is concerned “industry experts say there aren’t nearly enough recycling companies to dismantle all the computers and TVs Californians discard, because until recently, there wasn’t much demand for the service. Plus, it’s expensive because the materials often must be shipped out of state, where companies are doing the recycling.”

In an attempt to cover the costs and problems of recycling, the State of California is considering two bills. “One would require manufacturers to pay a fee of up to $30 for every TV or computer they sell, which would be used to subsidize a recycling program. A second proposal requires manufacturers to label all electronics that contain CRTs as

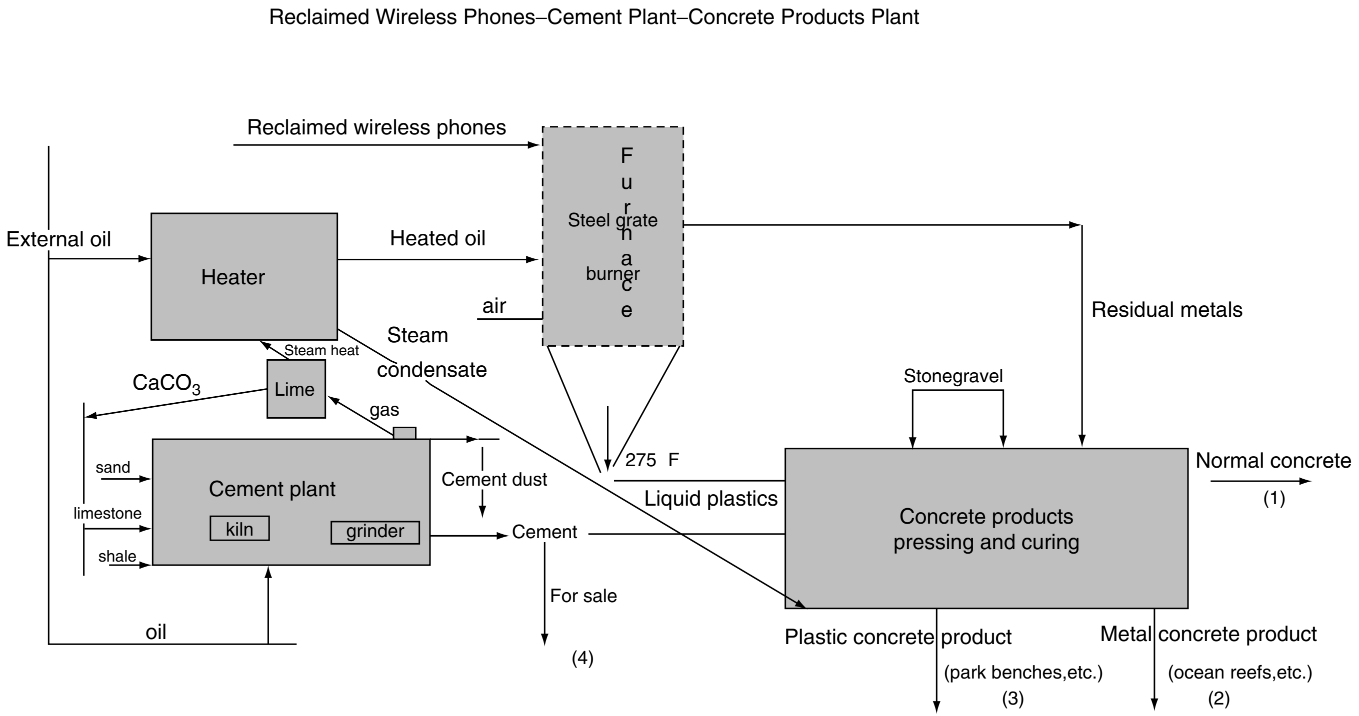


FIGURE 18.35. Reclaimed wireless phones–cement plant–concrete products plant.

hazardous materials, and to include information about how the materials can be recycled when they're obsolete." It's obvious that recycling presents many problems with these wastes, as is the case with other wastes such as glass bottles or aluminum cans. These problems accentuate the potential for using the EBIC method to avoid such situations and costs.

CC. Sugarcane–Fuel Briquet Industrial Complex

The growing and processing of sugarcane results in two major wastes that have an adverse impact on the surrounding environment: bagasse and cachaza (see Chapter 17, Section C, for a detailed description). The sugarcane stalks are chopped into small pieces by rotary knives and the cane juice is extracted from these pieces by crushing them through roller mills. The solid residual material (fibrous) is known as *bagasse* (Nemerow 1995). After the cane juice is extracted from the stalks, the juice is treated with lime in the boiler room. The resulting precipitate is vacuum-filtered to separate the insoluble sugar—the wasted filter cake is termed *cachaza*. Then the clarified juice is further processed by thickeners, with little or no wastage, to produce sugar crystals for sale.

Most of the bagasse is usually burned in the field or in the mill's boilers. This results in local air pollution either directly from the fields or indirectly from the boiler flue gas. The cachaza also represents a solid waste that must be disposed of in some typically costly manner.

If these two troublesome solid wastes can be collected and processed into a useful product, an environmental solution will be attained. The keys here are in the processing, which must be simple and economical, as well as in the usefulness of the product. Such processing is suggested in Figure 18.36.

The bagasse and cachaza are collected mechanically from the cane cutters and filter presses, respectively, and blended together in kettle mixers. The blending and mixing should be facilitated by the moisture content inherent in the filter cake (cachaza). The homogeneous mixture is transported on belt conveyers to the fuel briquette plant. Here, the mixture is pressed and cut into briquettes for ease of air-drying, packaging, and sale for fuel. The utility of the briquettes depends on the moisture content and Btu value of the fuel.

The economics of the processing and the environmental benefits will also be quantified in order to facilitate acceptance of the complexing. If quantification proves positive, this industrial complex will become a reality and the environment will benefit as well.

DD. Hog Production–Animal Feed–Energy Production Environmental Complex

Pig growing and slaughtering compromise a major food industry. Unfortunately, the wastes associated with this production are voluminous and objectionable. They must be disposed of safely and economically even when occurring in rural environments.

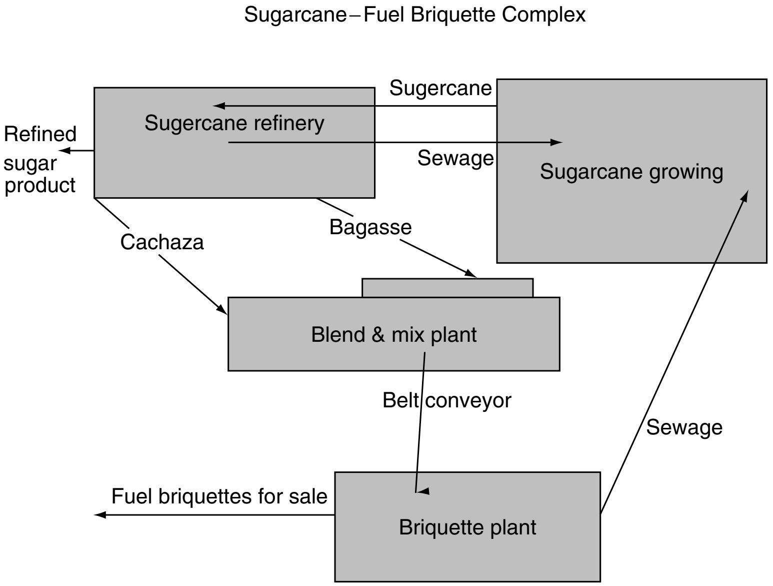


FIGURE 18.36. Sugarcane–fuel briquette complex.

Piglets are fed, fattened, and grown in pens. These pens are generally elevated above a concrete sluiceway that carries away the urine and detritus from the pigs. The grown hogs are periodically removed, slaughtered, and replaced with new piglets.

Generally, the urine and feces wastes are washed into large adjacent lagoons. Here, the solids settle to the bottom; some wastewater seeps into the underlying ground and eventually the groundwater, and some liquid is evaporated from the lagoon surface and/or sprayed on nearby agricultural land or growing fields.

Problems of environmental pollution occur when dikes of the lagoons break, surface wastes overflow the lagoons, or nearby well waters are contaminated with the pig lagoon wastewaters.

All of these problems can be avoided and societal production costs can be reduced by using an industrial complex system such as that shown in Figure 18.37.

Here, the pig wastewaters and feces are sluiced into an anaerobic digester. The waste material is decomposed anaerobically into methane gas and digested sludge. The gas is either fed to and burned in the plant's heating system or generates steam to drive a turbine and electrical system to produce power for sale to local plants. The "ripe" digested sludge is transported to the nearby corn or bean field for fertilization; these crops are subsequently given to the growing piglets.

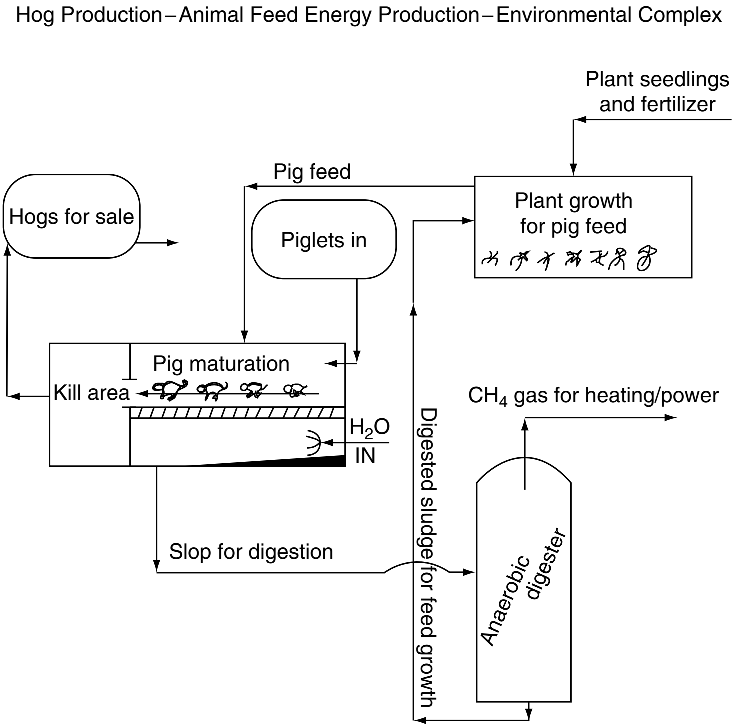


FIGURE 18.37. Hog production–animal feed energy production–environmental complex.

No wastes leave the complex and electrical power and agricultural feed production all enhanced, if not actually increased.

EE. Seawater Desalination Plant–Boric Acid (Borax) Plant Complex

Because of the continuing shortage of freshwater for drinking, the advent of obtaining drinking water from seawater has been of increasing importance. While producing drinking water, salts are extracted from the seawater supply, resulting in a saline waste. This salty waste is usually discharged back to the ocean from where it originated. Often the saline wastewater may interfere, alter, or otherwise harm the near-shore ocean environment.

Because the saline wastewater contains a rich supply of minerals such as borates, it can be used as a raw material for a borax manufacturing plant located in the same complex as the desalination plant. In fact, Chui (2005) reports that "mining companies pump dense brine from the lake [Searles Lake] and use it to produce boric acid, borax, and other products."

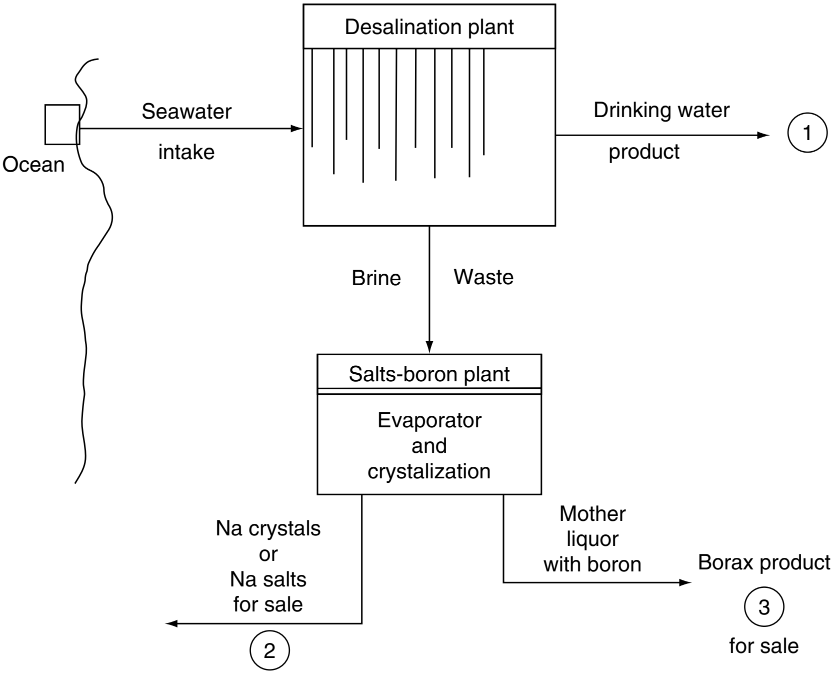


FIGURE 18.38. Seawater desalination plant–Borax plant complex.

Such a complex would eliminate any potential source of saline wastewater and its potential effect on the nearby ocean habitat. An example of such a complex is shown in Figure 18.38.

In this complex, seawater is converted to freshwater by membrane filtration and a brine waste is discharged. Instead of returning it to the sea, it is sent to an evaporation and crystallization plant where sodium salts are removed as crystals and borax recovered from the "mother liquor," and later sold to chemical distributors for sale to industry or the public. No brine is wasted to the environment and three separate product types are obtained.

FF. Cow Feedlot–Power Plant–Fertilizer Complex

As mentioned earlier in this chapter, feces, odors, and organic matter contamination are the important adverse environmental impacts of feedlot production. Animal feedlot wastes contain valuable (but polluting) organic matter. Krueger (2005) reported that each cow on a 500-cow dairy farm produces about 80 lb of waste manure each day. This is being converted into 100 kW of electrical energy by anaerobic digestion of the manure into methane fed to a generator. Because 1 kW of electricity is required (on the average) for a household, this is enough energy to service about 100 homes. Other farm animal wastes such as chicken and pig could also be used in this complex. Hog production wastes can be handled in almost the same manner as shown in Section DD.

Krueger (2005) also verified the expected result that the digested manure is devoid of its objectionable odor but still contains both residual organic matter and minerals. The organics and minerals are valuable constituents for a commercial-grade fertilizer—similar to that of Milorganite produced similarly using Milwaukee, Wisconsin, using digested sewage sludge.

Therefore, we can group all three industries in a single complex, as shown in Figure 18.39, and eliminate all adverse environmental impacts.

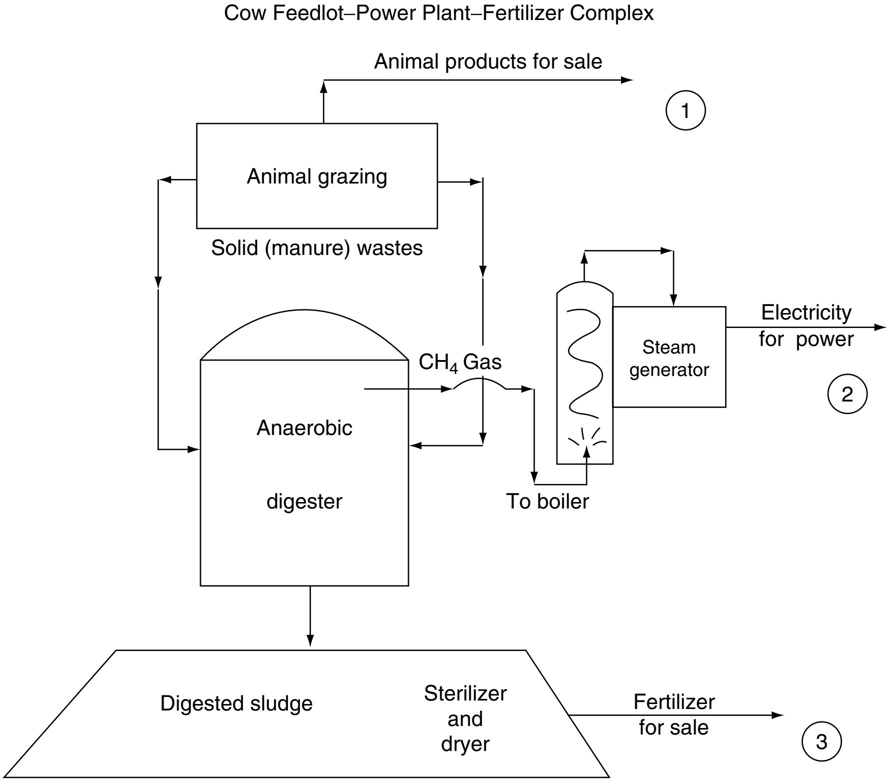


FIGURE 18.39. Cow feed lot–power plant–fertilizer complex.

In this complex, animals such as cows, chickens, and pigs, graze normally in a large land area. But, instead of "smelling up" the surroundings with dung, the manures are fed into an anaerobic digester to produce a steady stream of methane gas. The methane is burned in a small boiler yielding steam that feeds a turbine driving a generator to produce electricity for sale to local homeowners or power plant grid systems. An alternative would be to use the methane gas directly to drive the turbine-driven generator. The waste-digested sludge from the digester is dried and sterilized and then bagged and sold commercially for use as a fertilizer.

Three industrial plants produce three useful products and generate no wastes to the outside environment.

GG. Reused Plastic Waste–Consumer Products Complex

Plastic products after useful service to society are usually wasted—one way or another—into the environment. The usual way is to release them into the trash, which generally finds its way into our "sanitary" landfills. Here, they either remain for the life of the fill or disintegrate, yielding toxic organics and sometimes metals, depending on the nature of the plastic and the operating condition of the fill. The result is both a woeful waste of resources and a danger to the environment and those who may come in contact with that portion of it.

The main deterrent to remedying the situation has been the difficulty in collecting the used plastics and relatively low value that it brings to the recoverer.

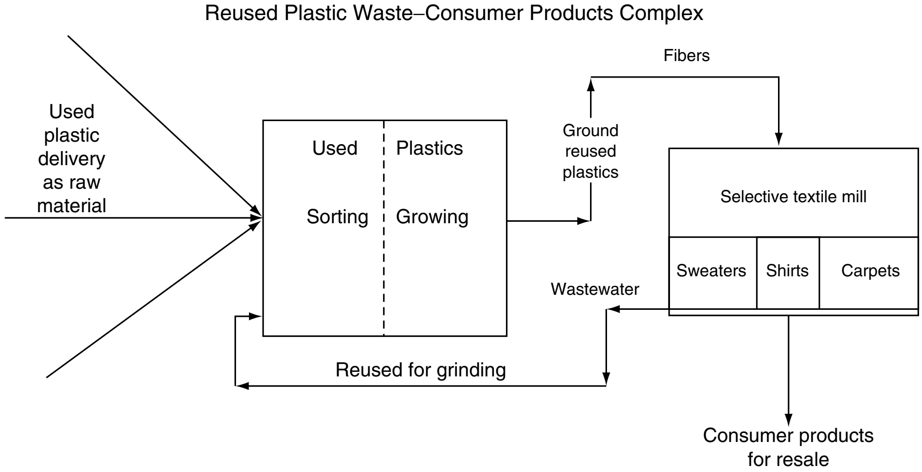


FIGURE 18.40. Reused plastic waste–consumer products complex.

I propose an ideal and logical solution to this conflict between the environment and the reuser. Create an industrial complex in which the used plastic is reused for an economic gain!

In Mexico, the bottling and soda industries have joined forces to collect and recycle the ubiquitous bottles made from polyethylene terephthalate, a thin plastic known as *PET* ("Mexico's PET project" 2004). They formed a company known as *ECOCE,* which will collect the used plastics and transport them to a recycling plant that grinds the plastics into fibers to produce carpets, shirts, sweaters, and other consumer products. One such potential complex is shown in Figure 18.40.

In this complex, used plastics are brought into the complex and sorted and ground at one plant and then the recovered fibers are selectively remade into either sweaters, shirts, or carpets in an ancillary plant. The key to the success of such a complex obviously lies in the ability of the managers to obtain a sufficiently high value for the consumer end-products to justify the expenditure of recovering and reusing the waste plastics. Woven into the economics is the value to a cleaner environment. In such a complex, plastic soda bottles will no longer pollute the environment and useful products will be the result.

HH. Lumber–Textile–Corn Growing–Alcohol Producing Industrial Complex

A potential complex combining Sections P and S of this chapter uses three sources of starch (lumber sawdust, textile de-sizing, and corn) to produce alcohol for an automotive energy alternative to part or all of the gasoline. The three plants all produce useful products and objectionable industrial wastes. The *lumber mill* usually leaves both sawdust, and wood chips, and scraps as solid wastes from the production of finished lumber for commercial and residential customers. These wastes are normally hauled to landfills or burned at a cost to the land or air environments. The *textile mill* must remove the starch sizing from woven goods before dyeing and finishing its consumer goods products. The de-sizing waste is either sent to a municipal treatment plant or biodegraded in its own waste-treatment plant. Both are costly for the textile mill or, if untreated, harmful to the water environment into which it is discharged. Cooking and dyeing wastes must be treated in a biological treatment basin. An *agricultural industry* growing corn is the major plant (among the three) contributing a source of starch for the ethanol plant. But, it also results in the wastage of corn husks, which must be composted and returned to the farmland as a mulch to retain water and fertilizer.

Sawdust and wood scraps, de-sizing wastes, and corn are all fed to the cooker, along with hydrolyzing enzymes for conversion to sugar (Figure 18.41). "Sugar" from the cooker after cooling is led to the fermenter along with a yeast culture to convert it to alcohol. The fermenter evolves a carbon dioxide gas and a liquid ethyl alcohol. The gas is compressed and sold as a product to the beverage industry.

The liquid ethyl alcohol, along with the fermenter mash, are discharged to a distilling vessel, which evolves pure ethyl alcohol at or near the top and residual grain

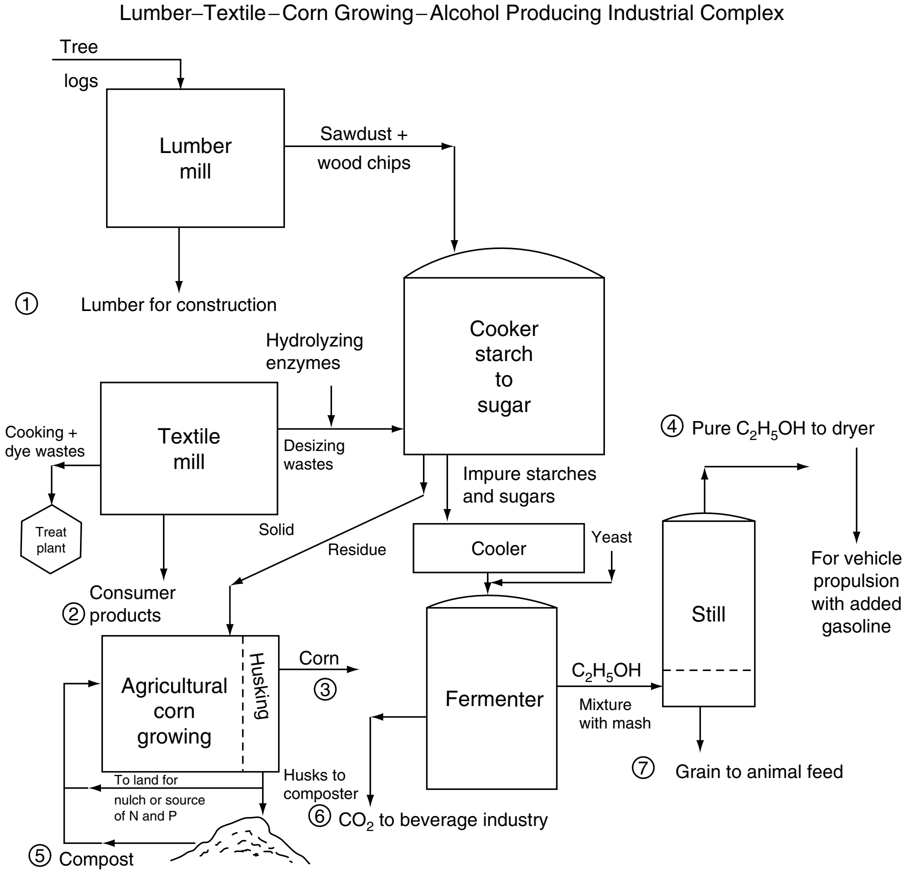


FIGURE 18.41. Lumber–textile–corngrowing–alcohol producing industrial complex.

mash at the bottom. The pure C_2H_5OH (ethyl alcohol) is dried and sold to the transportation industry as a fuel to power vehicles.

It may be difficult to "arrange" for all three raw materials (starch sources) to locate in the same complex with the starch converter. In that case, it may be necessary to omit one or both of the textile and/or lumber mills from the complex. However, from environmental and economic standpoints, it would be preferable to locate all four industrial operations in a single complex.

Products from this four-industry complex are (1) lumber, (2) consumer products, (3) corn, and (4) ethyl alcohol, as well as reusable byproducts (5) compost, (6) carbon dioxide, and (7) distillery grain mash.

Little or no waste from these four industries reach the environment untreated or unused.

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